Fisheries Management interventions to increase employment.

The committee discussed whether there were options to mitigate the loss of employment from ITQs in Australian fisheries (reduction in employment is generally an intended outcome of ITQs in Australia to maximise private rental yields to ITQ shareholders).

Papers are attached and a summary of case studies given below. All involve ensuring ecosystem and targets stocks are sustainable. But in addition, they involve foregoing economic rent to increase employment and other economic and social objectives. Consequently, these would all be inconsistent with the current interpretation of the objective of the Commonwealth Fisheries Management Act 1991, which minimises employment as it is treated as a cost. Therefore, if the committee proposed targeting higher employment, the fundamental change needed is to adjust the objectives of the Act.

Also note that none of these involve expensive government buy-outs of ITQ shares. There is often an assumption that any change to increase employment or other community benefits must involve quota buy-backs. This has been avoided in other countries.

1. Greenland Shrimp

Greenland was one of the early adopters of ITQs with this applied to their factory trawler shrimp fleet in 1990 (which has low employment benefit as processing occurs on the vessels, usually with foreign labour) and in 1997 for their coastal fleet that has higher employment benefit because it lands catch to coastal ports.

Greenland applied royalties to these fisheries and at a higher rate to sectors with less employment benefit. They changed the infinite duration of their ITQs to 5 years duration. They're intending to shift quota to the vessels that land catch into Greenland because this creates higher employment. As Greenland collects public income from fishery rents (unlike Australia) this decision involves a complex and divisive trade-off: more employment but less direct government income from the offshore shrimp fleet.

Greenland also introduced regulation of quota trades to shift production towards parts of the fishery that provide more local employment. "*a special arrangement prevails for coastal vessels that cannot sell and lease out quotas to offshore production trawlers, although they are allowed to buy and lease in. The scheme also exempts large production trawlers from fishing inside three nautical miles outside the baseline and exempt coastal vessels from paying the special shrimp tax, which in 2012–2014 is €14 million, 9% of the off-shore trawlers turnover. The aim of the special arrangement is to maintain employment both in the coastal fleet and at the on-shore factories they supply.... The reason for the continued existence of coastal shrimp fishing is the special arrangement, founded in employment considerations.*"

Nielson et al. 2018. Structural Adjustment and Regulation of Nordic Fisheries until 2025. Nordic Council of Ministers 2018.

2. Danish North Sea demersal fishery

Denmark's North Sea demersal fishery ITQs are famous for their profound effect on small Danish harbour villages. As per Greenland shrimp, they are now choosing to reverse their previous strategy of minimising employment by regulating trading of ITQs shares towards less efficient / higher employment operations. Specifically this is to reinvigorate smaller catch operations so that the fleet will have a larger number of vessels, which in turn revitalises coastal villages.

"*Special arrangements have been in force since 2007 for the small-scale coastal fisheries, revised in 2016 and again in 2017...the revised 2016-scheme distinguishes between an open and a closed coastal segment. Vessels in the open segment have been voluntarily chosen to go into it and are thus bound in the scheme for three years. Then they can exit the arrangement and sell the quota to the highest bidder. Vessels entering the closed segment can never leave the segment and can only trade quota with other vessels in the same segment. However, they receive an extra quota premium compared to vessels in the open segment. Only vessels below 15 m can enter the closed segment. The reason for the revision of the coastal scheme in 2016 is that ongoing assessment revealed that the initial scheme did not protect the small-scale fishery against selling quotas to larger vessels after leaving the arrangement*."

Nielson et al. 2018. Structural Adjustment and Regulation of Nordic Fisheries until 2025. Nordic Council of Ministers 2018.

3. Iceland

Iceland was another early adopter of ITQs with most of their fisheries covered by this system in 1990. As per Australia there was later criticism of the outcomes of ITQs and reforms were introduced including:

- a "quota ceiling" on the percentage of the fishery that individual firms can control (this has been done occasionally in Australian ITQs)
- prevented further contraction in the employment-intensive hook and line fishing sector by regulating that quota could only be traded one-way between that sector and large scale general trawl and net operators.
- introducing royalties so that the public received a direct benefit from the national fishery resources, with this income then available to support employment in other parts of the economy. The royalties only applied to economic rents so had no effect on industry viability.
- Allocating new quota shares (same TAC) and giving these new shares to regional communities rather than private firms. The catch must be landed in these communities so the economic benefit includes processing jobs plus fishing employment plus the economic rent.
- Allowing new entrants by introducing new vessel categories for new entrants and allocating an increasing share of the TAC to this new sector which is providing new jobs.
- Regulating quota trades to shift more catch towards operations that do shorter trips and create more employment.

Nielson et al. 2018. Structural Adjustment and Regulation of Nordic Fisheries until 2025. Nordic Council of Ministers 2018.

4. Norwegian Groundfish Fishery

This ITQ fishery introduced a hierarchy of quota allocation to give greater priority and investment confidence into smaller scale, higher- employment parts of the fishery. So for example, if catch needed to be reduced because of a downturn in productivity, this has little effect on coastal vessels and greater effect on offshore trawlers. They have recognised that this involves a tradeoff with some the sacrificing of some economic yield in favour of employment.

Nielson et al. 2018. Structural Adjustment and Regulation of Nordic Fisheries until 2025. Nordic Council of Ministers 2018.

5. Faeroe Islands

ITQs were introduced in the mid 1990s but then replaced after two years with a system of transferrable effort. Individual fishers were allocated limited days of fishing rather than tonnage of catch. This prevented the fishery from splitting into investor shareholders – leasee fishers.

Nielson et al. 2018. Structural Adjustment and Regulation of Nordic Fisheries until 2025. Nordic Council of Ministers 2018.

Summary of special arrangements to increase employment (although decrease economic yield) in Nordic fisheries

Country	Management	Special arrangements
Iceland	Individual Fishing Quotas	Small vessels (<15 m) using hook-and-line have a separate TAC. Quotas can only be sold to other vessels within the scheme, not to larger vessels. Some small vessels with limited activity have access to fishing on a regional TAC in four areas with Olympic fishery.
Greenland	Individual Fishing Quotas	Small vessels (<120 GT) have their own separate TAC and can only sell quotas to other small vessels, not to large vessels. Only small vessels can fish close to shore. Large vessels pay a special shrimp tax, small vessels are exempt.
Denmark	Individual Fishing Quotas	Small vessels (<17 m) can voluntarily enroll in the open arrangement and have by that allocated extra quotas of cod, sole and plaice. The vessels can only trade quotas with other vessels in the scheme. After three years, the vessels are free to leave. Small vessels (<15 m) can voluntary enroll in the closed arrangement and continuously receive an extra quota premium compared to vessels in the open segment, but can never leave.
Sweden	Individual Fishing Quotas	Small vessels (<12 m) using passive gears and small trawlers <12–15 m) have access to fishing on a TAC with Olympic fishery.
Finland	Individual Fishing Quotas	Small-scale coastal trap net fishing vessels have its own separate TAC. New fishers in the arrangement can apply for non-transferable quotas up to a 5-year period.
Norway	Individual Fishing Quotas	All Norwegian vessels are part of a group with a TAC and have individual quotas. Quotas can with some limitations be exchanged within the group, but cannot be sold to vessels outside the group.
Faroe Islands	Individual Fishing Quotas and Individual Fishing Days	Small demersal vessels fishing around the Faroe Islands are managed by Individual transferable fishing days, whereas the large demersal vessels fishing in the Barents Sea are regulated by transferable IFQs. It is not possible to exchange fishing rights between the two segments

6. Alaska Community Quota

Alaska has 45 community regions that are allocated quota in fisheries. This is an example of the use of regulations to create employment benefits in regions by requiring landing and processing to occur in certain locations.

Each year, the Community quota entity (CQE) may transfer (lease) its IFQ to one or more permanent residents of the eligible community on whose behalf the QS is held, and who must be onboard when the IFQ is fished and landed. Caps limit the amount of QS that can be held on behalf of each community and collectively for all communities.

https://www.npfmc.org/community-quota-entity-program/

7. Indonesia

Indonesia introduced ITQs in many fisheries as per Australia but then later introduced a sophisticated system of royalty collection in ITQ fisheries to create government income while also protecting employment in coastal communities.

So for species like tuna, there is no royalty collected from small, labour-intensive operations, mid level royalties from the larger off-shore domestic fleet, and higher royalties from foreign operated offshore vessels. This process uses a financial instrument to push catch towards higher employment parts of the fleet.

Table B: -Licence fees, bilateral agreement or joint venture requirements and nationality criteria-

STATE	**Licence fees, royalties and others local currency**	**Requirements concerning bilateral framework agreements or joint venture participation**	**Nationality criteria for fishing vessels**
INDONESIA	**LEGISLATION** Fees for joint venture vessels range from US$500 to US$1 000 per vessel, plus royalties on exported fish: -shrimp = 2% of FOB price -tuna= 1.5% of FOB price -skipjack = 1.5% of FOB price -pearl = 1.5% of FOB price -other species = 1 % of FOB price (Decree No. 424 of 1977, art. 1) Registration (fishing permit) fee = US$ 3 per GRT Fee for changes to permit = US$ 100 Royalties on catches: -longliners = US$ 86 per cubic meter (M3) -pole and line vessels = US$ 102 per cubic meter -purse seiners = US$ 107 per cubic meter -fishnetters = US$ 207 per cubic meter -gillnetters and others = US$ 55 per cubic meter (Decree No. 477 of 1985, art. 2) Royalties on catches by fish net = US$ 145 per cubic meter. (Decree No. 477 of 1988)	**LEGISLATION** Guidelines for joint ventures specify: -undertakings not to compete with small-scale or traditional artisanal fisheries; -investor to be bona fide company; -investment to lead to foreign exchange earnings; -share ratio for Indonesian partner to start at 20%, rising to at least 40% within 5 years and to 51% within 10 years. **AGREEMENTS** Joint venture formed between Philippine commercial deep sea fishing company and an Indonesian fish trader for commercial deep sea fishing operations in Arafura and Rarda Seas in East Indonesia among other activities. (Source: GLOBEFISH Databank, July 1995)	

Source: FAO http://www.fao.org/3/V9982E/v9982e20.htm

8. Maine Lobster

Not a fishery has introduced ITQs and then other regulations to protect employment….but still informative because of the range of measures taken to protect employment. Most of these could also be introduced into Australian ITQs. The Maine fishery relies on trap limits to control the catch and this limit can be adjusted through time (this last detail was missing in Australian fisheries that struggled to control catch with gear limits).

The transfer of licences is prevented so that if a fisher retires, the licence is deactivated. This stops the licence becoming a tradeable asset that creates a financial barrier to new entrants.

Allocating new licences each year to enable new entrants to the fishery. The number of traps allowed per licence is adjusted depending on the number of licenced fishers. This creates a dynamic, market-based fleet. The government is active in limiting catch and ensuring stocks are sustainable, but anyone in the community can participate in the fishery.

This type of management is possible in Australian ITQs by relaxing (increasing) the aggregate value of the allocated quota, and simultaneously making the input controls like gear limits and season lengths more binding. So that sustainability is no longer managed by ITQ shares but by input controls.

Anna M. Henry & Teresa R. Johnson (2015) Understanding Social Resilience in the Maine Lobster Industry, Marine and Coastal Fisheries, 7:1, 33-43, DOI: 10.1080/19425120.2014.984086

9. Canadian Halibut

A similar situation to Maine lobster in that ITQs were considered and rejected because of concerns about loss of economic benefit to the community. This is still a useful example because it illustrates the way that input controls could be strengthened in Australian ITQs. Once these were effective in regulating catch, the ITQ shares become redundant and can be relaxed (eg double the ITQ TAC).

In Canadian halibut, different fishing periods across the year were created and fishers had to nominate which ones they wanted to fish. This simple process limited the catch, maintained supply to consumers, and maintained employment.

Pinkerton et al. 2018. Atlantic and Pacific halibut co-management initiatives by Canadian fishermen's organizations. Fish and Fisheries. 19:984–995.

10. Solomon Islands reef fish, skipjack tuna and sea cucumber.

These fisheries are managed with different controls depending on whether the product is captured for local sale and consumption versus as an export fishery. Catch is quarantined for the parts of the fishery that are important for local employment with the remaining catch available for export markets. Target species management decisions prioritise keeping stocks sufficiently abundant that local fish supplies are maintained. The allocation of the export catch involves royalty leasing so that rents are returned to the community rather than given to private shareholders. This is formally called a "food security viability constraint" and is the same process as applied in many countries for energy security with quarantining of a portion of domestic production oil and gas for local supply.

Doyen et al, 2017. Ecoviability for ecosystem-based fisheries management. Fish And Fisheries November 2017, Volume 18 Issue 6 Pages 1056-1072

11. Bay of Biscay, France. Multispecies Fishery

Quota trading and catch limits are regulated to ensure viability of different part of the fleet (vessel size and specialisation). This is for objectives of employment in the fishing sector, processing sector and retail (restaurant sector).

Doyen et al, 2017. Ecoviability for ecosystem-based fisheries management. Fish And Fisheries November 2017, Volume 18 Issue 6 Pages 1056-1072

Nordic Council of Ministers

STRUCTURAL ADJUSTMENT AND REGULATION OF NORDIC FISHERIES UNTIL 2025

Structural Adjustment and Regulation of Nordic Fisheries until 2025

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Contents

Preface

Fisheries policies are broadly debated in the Nordic countries with a focus on the balance between biological concern of fish stocks, economic return to society, profitability and interests of the coastal communities.

Fishery was in the first half of the twentieth century considered as subsistence trade for the poor. This has changed dramatically due to high investments giving improved efficiency of the fleets and today fishing is considered an industry in the Nordic countries. Many coastal communities remain, however, economically dependent on fisheries in terms of employment, income etc. While this transition was followed by the introduction of Total Allowable Catches to solve increasing pressure on fish stocks, more focus is today on how to regulate the fish resources in the most economically efficient way, in order to get high economic returns to society. This has led to the introduction of Market Based Fisheries Management in many countries and in other countries, where Market Based Fisheries Management is not implemented, debate whether introducing it.

The debates on Nordic fishery policies and in particular on Market Based Fisheries Management have been going on for many years, emphasizing that Market Based Fisheries Management is a powerful, but also a controversial tool. The supporters claim that Market Based Fisheries Management increase economic returns, while opposers states that employment falls, that a handful large companies end up overtaking the whole fishery, use cheap foreign labour and destroy the coherence of small local coastal communities. Therefore, a deeper understanding of the functioning of Market Based Fisheries Management is warranted. Indeed, a need for demystifying Market Based Fisheries Management prevails.

Some examples shed light on this point as follows:

- In Greenland, a Bill of a New Fishery Law, suggesting both the introduction of a notice period for termination of ITQs in the shrimp fishery and reallocation of quotas from large to small vessels, was the most mentioned Law in the Greenlandic national media in 2017;
- In Denmark, a report from the State Auditors from 2017 criticized the administration of the ITQ system for not delivering on the political intention on preventing concentration of quotas on a few owners and not administrating the rules on concentration properly. A public debate on quota concentration followed and lasted for months. Whether right or wrong, it became one of the reasons why the fishery policy administration organizationally was moved from the Ministry of Environment and Food to the Ministry of Foreign Affairs;

- In Sweden, evaluations have shown that the ITQ system in pelagic fisheries has served its purpose and changed the fleet structure. However, the system has not been introduced to other fisheries even though the Swedish Parliament in 2014 delegated the decision on the possible introduction of ITQs in other fisheries to the Government;
- In Norway, a Parliamentary Committee in 2014 recommended introduction of a full ITQ system. Another Parliamentary Committee concluded in 2016 that it would be beneficial to rationalize and simplify the Norwegian quota system, pursuing the objectives of an industry exercised and owned by active fishermen and that also include a variation in the fleet with regard to vessel size and regional affiliates;
- In the Faroe Islands, the 2018 revision of the fisheries policy have been debated for many years and led to the introduction of a new Individual Quota regulation with quotas sold at auctions coming into force in the demersal fishery in 2019;
- Iceland was the first Nordic country to introduce ITQs. The system is well established and the debate appears less heated. However, some opposition against the system remains and in 2009 extra quota for fishermen using jigging reel was added to the coastal quotas of rural communities;
- In Finland, the poor economic performance was an important reason for introducing ITQ's in the large-scale pelagic fishery in 2017.

This report forecasts the development in seven Nordic fisheries until 2025 assuming unchanged fisheries policies. The forecast is compared to developments under hypothetical policy changes. The report contributes to the debate by clarifying the economic effects of different policy priorities ex ante. The results are presented as a basis for discussions at the Conference "Fisheries and Society – challenges to 2025". The target group is Nordic civil servants and policy makers, fishermen and their organisations, researchers, non-governmental organizations and other stakeholders with an interest in fisheries.

This report is part of the project *Structural development and regulation of Nordic fisheries approaching 2025.* The project is funded by the the Fisheries Cooperation of the Nordic Council of Ministers, from which funding is gratefully acknowledged. The results and views presented in the report, however, remain solely the responsibility of the authors.

The report consists of seven country case studies and a cross-country assessment. The Greenlandic and Danish cases are written by Ayoe Hoff, Max Nielsen and Rasmus Nielsen, University of Copenhagen. The Icelandic case is written by Daði Már Kristófersson, University of Iceland and Hordur Sævaldsson, University Akureyri. The Finnish case is written by Jarno Virtanen and Jari Setálá, Natural Resources Institute, Finland, the Swedish case by Staffan Waldo and Cecilia Hammarlund, Swedish University of Agricultural Sciences/Lund University and the Norwegian case by Kristin Roll, University of South-Eastern Norway, and Frank Asche, University of Florida, USA. Finally, the Faroese case is written by Heri á Rógvi and Hans Ellefsen, Ministry of

Fisheries of the Faroe Islands. The forecasting for all country chapters are based on extensive bio-economic modelling, which was done by Ayoe Hoff in close collaboration with the person responsible for each country chapter. Hans Staby Frost, University of Copenhagen, has contributed with valuable discussions regarding the model setup. The chapter on the economics of fishery policy is written by Peder Andersen. Charlotte Bukdahl Jacobsen has edited the report. The project was coordinated by Max Nielsen, who has also written the remaining chapters.

We hope that this report will contribute to the ongoing debate on both the future fisheries policies in the Nordics countries and on the effects of Market Based Fisheries Management.

Carl-Cristian Schmidt
Chair Nordic Marin Think Tank and organizer of the Conference
Fisheries and society – challenges to 2025 11–12 October 2018
Copenhagen September 2018

Summary

Fishery policies are broadly debated in the Nordic countries, focusing on balancing biological concern of fish stocks, economic return to society and coastal communities' interests. Market Based Fisheries Management is used in several Nordic countries today and is the core of these debates. While it by many is considered a powerful tool that works towards ensuring improved economy of fisheries, it is also considered a controversial tool.

In this report *Structural Adjustment and Regulation of Nordic Fisheries until 2025* we: (i) document the effects of Marked Based Management in selected Nordic fisheries historically, (ii) analyse and forecast the structural development of the selected Nordic Market Based Managed fisheries until 2025 under the current fisheries regulation, (iii) analyse and forecast the structural development of these fisheries under alternative hypothetical regulations serving other political purposes, and (iv) provide Nordic lessons on Market Based Fisheries Management as a basis for the political debate on the future of Nordic Fisheries. The results will be presented at the Conference "*Fisheries and society – challenges to 2025*," to be held in Stockholm 11–12 October 2018.

In *chapter 2*, standard fisheries economics and management theory is presented. It is explained how open access in fisheries leads to a "race for fish" ending with overfishing, small fish stocks, too many fishing vessels and low earnings. It is further explained how different fisheries management instruments can solve this "tragedy of the commons", emphasizing the efficiency of instrument focusing at Market Based Fisheries Management. This scheme is founded on allocation of property rights that can be traded on a market. The choice will, off course, depend on the objectives of the fishery policies.

Chapter 3 introduces the dynamic bio-economic Fishrent model, which is applied to forecast socio-economic return and profit from the base period 2012–2014 until 2025. The following scenarios are analysed: (i) Current management with a 4% limit on yearly adjustment in number of vessels, (ii) Free quota trade between all vessels with a 4% limit on yearly adjustment in number of vessels, (iii) Current management with no limit on fleet adjustment, and (iv) Current management with a 4% limit on yearly adjustment in number of vessels and a 10% extra fishing tax on turnover. The socio-economic return measures "The net-surplus that, at a given time, remains for the remuneration of capital and labour above the rate that is achieved in other businesses including extraordinary taxes paid".

Seven country cases of Market Based Managed fisheries from each of the Nordic countries are studied and results presented separately in chapter 4–10.

Chapter 4 presents the case of the Greenlandic single species shrimp fishery. The fishery consists of large off-shore vessels processing on board and coastal vessels supplying factories. The off-shore fishery has been regulated with Individual

Transferable Quotas (ITQs) since 1991 and the coastal fishery since 2000. Coastal vessels are not allowed to transfer quotas to off-shore vessels.

The annual socio-economic return provided from the 30 vessels is EUR 82 Million (average of 2012–2014), corresponding to 44% of the turnover. Fishery employment is 291 fulltime persons. The socio-economic return relative to turnover is the highest observed in this study and follows from a two-third fleet reduction since 2002. The high socio-economic return is due to the long presence of ITQs, high efficiency of off-shore vessels and 5–6 years of price increases.

It is predicted that socio-economic return, compared with today, can increase with up to 60% in 2025 with the current regulation, following continued structural adjustment and forecasted shrimp stock increases. This is the highest predicted in this study. The fleet will be reduced to 20 vessels, accompanied by decreasing employment, met by increasing factory employment. Free quota trade can raise the socio-economic return even more. Shrimp taxes on top of income and corporation taxes are important to fund public spending, forming 9% of the landing value in 2012–2014. It is predicted that an extra 10% tax on turnover will not reduce profit in 2025, since continued structural adjustment increase profit more.

Chapter 5 analyses the Icelandic pelagic and Stern trawler fishery. Demersal fresh fish trawlers, demersal freezer trawlers, pelagic fresh fish vessel and pelagic freezer vessels are studied. Focus is on the large vessels with most Stern trawlers being over 42 meter and most pelagic vessels being 60–80 meter. Iceland has the longest Nordic history of ITQs and one of the longest worldwide, starting in the mid-1980s.

The annual socio-economic return of the 79 vessels is EUR 255 Million, corresponding to 42% of turnover (2012–2014). Fulltime employment is 2,394 persons. As in the Greenlandic case, the socio-economic return is high, mainly due to the long presence of ITQs and the following continued structural adjustment, and due to the fact that the large vessels take advantage of economies of scale.

The socio-economic return with unchanged management is predicted decrease to EUR 203 Million in 2025, corresponding to 26% of turnover. The fleet is reduced to 57 vessels and employment to 1,764 fulltime persons. The reduction follows from the forecasted fish stock reductions and from a choke problem, which significantly reduces fishing on some species unrealistic much and induces underestimation of the socio-economic return. Free quota trade raises the socio-economic return to 51% of turnover, while full adjustment allows for an increase to 54% of turnover. Under full adjustment the fleet is reduced to 33 vessels and employment to 1,066 fulltime persons. Hence, the structural adjustment seems to continue. Given that the fishery has already been regulated with ITQs for many years, the predicted reduction in the socio-economic return is surprising, but reasons include that reduction in fish stocks and choking effects induces underestimation of the socio-economic return. But the reason may also be that vessels have high capital costs with expected future earnings capitalized in the quota values, affecting profit negatively when stocks dwindle.

Fishing taxes on top of income and corporation taxes are important to fund public expenditures in Iceland, forming 6% of the turnover in 2012–2014. It is predicted that an extra 10% tax on turnover reduces profit in 2025. The reason may well be that expected future earning has been capitalized in quota values, thereby taxing the current quota owners that have already paid a part of their expected profit to former quota owners.

In *chapter 6*, the case of the Danish demersal fishery in the North Sea is presented. Six groups of vessels of different length up to 40 meter using net, trawl and seine are included. These small and medium sized vessels have been managed with ITQs since 2007.

The annual socio-economic return of the 147 vessels is EUR 19 Million, corresponding to 19% of the turnover (2012–2014). Fulltime employment is 359 persons. The socio-economic return is of medium size in this study following a large fleet reduction since 2007.

The socio-economic return is predicted to grow to EUR 28 Million in 2025, to 31% of the turnover, under the current management regime. The fleet size will decrease to 117 vessels and employment to 272 fulltime persons. Full adjustment will increase the socio-economic return to 39% of the turnover, further reducing the fleet to 90 vessels and employment to 192 fulltime persons. Hence, the strong structural adjustment that started after 2007 is predicted to continue. It is further predicted that an extra 10% fishing tax on turnover will not lead to reduced profit in 2025 compared to 2012–2014. Profit increases, induced by the continued structural adjustment, more than counterbalanced this effect.

In *chapter 7*, the case of Finnish pelagic fisheries with vessels above and below 24 meter is analysed. The fishery has been managed with ITQs since 2017.

The annual socio-economic return from the 63 vessels was zero in 2012–2014 with employment being 110 fulltime persons. The zero return follows from the absence of input regulation with only Total Allowable Catches being in force until 2017.

The annual socio-economic return in 2025 is predicted to EUR 2 Million with unchanged management, which is 10% of the turnover. This is expected to rise to 38% under full adjustment. The fleet reduction is correspondingly reduced to respectively 42 and 31 vessels, while employment falls to 73 and 37 fulltime persons. Hence, socio-economic return and profit is predicted to increase substantially, but it might take some years since the ITQ system has just been initiated. A possible 10% tax on turnover added to the current management is not predicted to change profit compared to 2012–2014. The reason is that structural adjustment presses profits up and counterbalance the effect.

Chapter 8 provides the Swedish case of pelagic fisheries with vessels in the group of 18–24 meter and larger than 24 meter. The fishery has been regulated under an ITQ scheme since 2009. Coastal herring fishery is not included in this study, since it is managed separately.

The annual socio-economic return of the 30 vessels is EUR 12 Million, corresponding to 23% of the turnover. Employment is 167 fulltime persons. The socio-economic return is medium sized in this study and follows from a fleet reduction of 55% in 2009-2013.

The annual socio-economic return is with unchanged management predicted increase to EUR 22 Million in 2025 following fish stock increases. This corresponds to 35% of the turnover and increases to 40% with full adjustment. The fleet is reduced respectively to 25 and 22 vessels, while employment falls to 141 and 120 fulltime persons. Hence, even though ITQs have already improved the socio-economic return and profit, the structural adjustment seems to continue. A 10% tax on turnover added to the in other respects unchanged management is not predicted to reduce profit compared to 2012–2014, since met by increased profit resulting from structural adjustment

In *chapter 9,* the Norwegian demersal fishery north of 62° is analysed. Five vessel length groups on up to 28 meters using conventional gear and a trawler group are considered. Individual Quotas have prevailed since 1996. These are transferable within but not between vessel groups, with transferability further restricted regionally and with 20% of quotas sold kept back and reallocated to all vessels in the group. Overall quotas are allocated between vessel groups by holding smaller vessels using conventional gears less prone to quota fluctuations than trawlers.

The annual socio-economic return of the 1,192 vessels is EUR 233 Million, 26% of the turnover (2012–2014). Fulltime employment is 5,489 persons. The socio-economic return is of medium size in this study and is achieved after a fleet reduction to half since 1996. Hence, despite the fishery is performed with on average relative small vessels, the socio-economic return is on a medium level, indicating that the current management ensures some structural adjustment.

The socio-economic return is predicted to be reduced to EUR 198 Million in 2025, following forecasted fish stock reductions and choking problems. The choking problem reduces fishing on some species unrealistic much, leading to some degree of underestimation. The socio-economic return relative to turnover is, however, predicted to increase to 36% of the turnover. The fleet is reduced to 792 vessels and employment to 3,637. Free quota trade raises socio-economic return a little, while full adjustment allows for an increase to 49% of the turnover in 2025. Thus, adjustment sluggishness shift gains further into the future.

The last country case of demersal fishery at the Faroe Islands is presented in *chapter 10* focusing on large trawlers and longliners. The fishery has been regulated with transferable days at sea since 1996, but it has been decided to change regulation to Individual Quotas from 2019.

The annual socio-economic return provided from the 45 vessels is EUR -7 Million, a deficit on 9% of the turnover. The deficit indicates that the Faroe society is better off economically by stopping the demersal fishery and use the capital and labour in other sectors. The deficit indicates that the current effort regulation have not been able to limit fishing significantly.

With the 2019 management shift and otherwise unchanged regulation, the socio-economic return is predicted to increase to EUR 16 Million in 2025, corresponding to 25% of the turnover. But the adjustment takes time and with full adjustment it can increase to 43%. The fleet is reduced to 34 vessels, with full adjustment to 22. Free quota trade is predicted to result in socio-economic return on 30% of the turnover. A tax on 10% of turnover, which can also be public revenue of selling quotas at auctions, can be introduced together with the new 2019 management, with the profit still predicted to increase from the 2012–2014 level.

In *chapter 11*, the annual socio-economic return in 2012–2014 is compared across countries. It is largest in Greenland (44% of the turnover) and Iceland (42%), following both from the long presence of ITQs and from the fact that these fisheries are performed with large vessels exploiting economics of scale.

The predicted socio-economic return in 2025 is also compared across countries. Again, with continued current management it is largest in Greenland (60% of the turnover) and Iceland (49%), but it increases in all countries. The largest increase is predicted at the Faroe Islands (from –14% to +25% of turnover) and in Finland (from -7% to +10%). These predicted large increases follows from improved management, with Finland introducing ITQs in 2017 and with the Faroe Islands having decided to introduce Individual Quotas from 2019. In all the seven country cases, fleet reductions are predicted.

Founded on the country cases, several lessons are learned. These lessons are important in the debate on future fisheries policy in the Nordic countries. The debate centers on prioritizing the socio-economic return of fisheries to wealth creation, on employment in fishing communities that is often spread around the coast in sparsely populated areas, and on fishing taxes as a funding source for public spending. The different priorities also serve as a framework for the policy setting. The lessons learned from Market Based Fisheries Management in the Nordic countries by this study are:

1. ITQs is a powerful instrument to increase earnings and remove overcapacity, but simultaneously fleet size and employment in fisheries is reduced;
2. All prevailing Nordic Market Based Fisheries Management systems have special arrangements for some vessel groups;
3. The Market Based Management systems in the Nordic fisheries all have some variation of concentration rule in force;
4. It is not a universal rule that Market Based Fisheries Management always removes the small vessels;
5. Fishing taxes may play a core role for wealth creation in the fishery dependent Nordic countries;
6. Expensive quotas makes it difficult to remove or drastically change an ITQ system;
7. Continued Market Based Fisheries Management is forecasted to increase socio-economic return and profit towards 2025 substantially;
8. Free quota trade induces extra earning compared to current regulation in 2025;
9. An extra fishing tax on 10% of the landing value can in most of the country cases be collected without reducing profits in the long run.

1. Introduction

1.1 Background

Fish stocks have by many been considered as inexhaustible for centuries. Half a century ago, however, the technological development gradually improved the efficiency of the fishing fleets, improving the economy of the fishermen that earlier had just been considered a subsistence activity. The improved income provided incentives for new fishermen to enter the fisheries sector. The result, in the Nordic countries and elsewhere, was an overexploitation of fish stock and in some instances stock collapses, because there were too many fishermen exploiting the resource. That changed the understanding of fish stocks from being inexhaustible to being a renewal and potential an exhaustible resource.

In the years around 1980, the 200 nautical mile Exclusive Economic Zone was introduced and provided the foundation for national fisheries management in the Nordic countries. Total Allowable Catches were implemented and licenses prevented the fleets from growing. While the focus was on biology and rebuilding of fish stocks, to many fishermen and vessels (overcapacity) typically remained within the fishing sector, often enhanced by subsidies for modernization and renewal of vessels with higher fishing capacity. On the other hand, considerable effort was put in force to reduce the overcapacity through decommissioning schemes (subsidies for stop fishing). To avoid the situation where too many fishermen were competing for too few fish, Market Based Fisheries Management (MBFM) has been introduced in several Nordic fisheries.

MBFM is founded on property rights to fish allocated to fishermen and often that the property right to fish can be traded on a market. MBFM includes ITQs, but also other regulation instruments that rely on a market, such as tradable effort regulation and quotas sold at auctions. MBFM reduces the fleet by letting the most efficient fishermen buy quotas from other fishermen. Through that, the aim to reduce the overcapacity problem and increase efficiency and earnings of the remaining vessels could be met. However, MBFM may also lead to fewer fishing vessels, and thereby to reduced employment in fisheries. While profits of the Nordic fleets were earlier very low and often negative, and the Governments had expenses for subsidies, several fisheries now generate profits and contribute to general wealth in the Nordic societies,.

The fishery policy agenda is thus turning. From the earlier directed focus on avoiding overexploitation and overcapacity, to a more positive focus today on how to allocate the economic wealth fisheries create.

1.2 Purposes

The purposes of this report are: (i) to document the effects of Marked Based Management in selected Nordic fisheries historically, (ii) to analyse and forecast the structural development of the selected Nordic Market Based Managed fisheries until 2025 under the current fisheries regulation, (iii) to analyse and forecast the structural development of these fisheries under alternative hypothetical regulations serving other political purposes, and (iv) to provide Nordic lessons on MBFM as a basis for the political debate on the future of Nordic Fisheries.

One fishery subject to Marked Based Management is selected from each Nordic country and different types of fisheries are selected to represent the diversity of the Nordic fishing fleets. For Greenland, Iceland, Denmark, Finland and Sweden ITQ regulated fisheries are selected. For Greenland, the shrimp fishery, for Iceland the pelagic and Stern trawler fishery, for Denmark the demersal fishery in the North Sea, and for Finland and Sweden the large scale pelagic fishery. For Norway, the groundfish fishery north of 62° is selected. This fishery is regulated with Individual Quotas, where vessels with certain restrictions can trade quota with other vessels in the same vessel group, but not with vessels in other groups. For the Faroe Islands, the demersal fishery is selected, in which the current effort regulation will be replaced by an individual Quota system in 2019.It is a possibility of sale of demersal quotas at auction in the system, but it is not likely yet, since the quotas still are historically low.

The effects of MBFM are documented in the seven national case studies. The case studies identify the development in number of active vessels, fleet structure, profits, contribution to GDP, etc. over the period Marked Based Management has been in force. It is shown that Marked Based Management has a strong effect on the fisheries in terms of increasing the economic return to society and reducing the fleet size and employment. It is, however, further clear that the development is also driven by other factors. For example, a reduced fleet size can be due to new regulation, but also to technological development. Although it is often difficult to split the effects of the different drivers, this report provides important documentation on the functioning and effects of MBFM.

The structural development of the selected fisheries is forecasted until 2025, measured as number of vessels, employment, contribution to GDP and profits. The forecasts are made under a number of assumptions using a bio-economic model where fishermen maximize profit and where the society maximizes the contribution of economic return from fisheries to national wealth. Hence, the forecasts are based on the assumption that fishermen act in their own best economic interest and that fisheries regulators act in the economic interest of the society. A model named Fishrent is applied for the forecasts, see chapter 3 and the appendix.

Effect on the fish stocks are forecasted by estimating a function where recruitment of fish increases with biomass until the Maximum Sustainable Yield (MSY), after which it falls. This function is identified in a way such that the stock will not increase to above the maximum stock size observed over the last twenty years. Total Allowable Catch is determined through a policy aiming at MSY, while individual fisheries will set their catches at a level that is as close as possible to MSY, while at the same time ensuring maximum economic outcome from the fishery.

The economics of fisheries is analysed both from a fisherman perspective and from the perspective of society. The analyses depart from the financial accounts of companies. The private economic analysis of fishermen focuses on profits, while the socio-economic analysis focuses on *socio-economic return*. Socio-economic return measures "The net-surplus that, at a given time, remains for the remuneration of capital and labour above the rate that is achieved in other businesses including extraordinary taxes pai". The definition appears from Nielsen *et al.* (2012) with taxes added. The socio-economic return is calculated as turnover minus fuel costs minus variable costs minus fixed costs minus opportunity costs of labour minus opportunity cost of capital plus extraordinary taxes paid. In economic terms the socio-economic return is the sum of the *resource rent* and the *producer surplus*. Hence, while profit measures the net return a company have from their fishery, socio-economic return measures the net return a society have on the existence of a fishery, more than if labour and capital had been used in other sectors.

Economic forecasts are made for a representative vessel in each vessel group under several assumptions including fixed fish prices, fixed input prices, and that fishing technology remain unchanged in the future.

The purposes of the fishery policies differ substantially and includes, on top of maximization of profit and socio-economic return, also regional political priorities on settlement and local employment, as well as special arrangement e.g. for small vessels. This report doesn't prioritize these purposes. It rather forecasts what will happen until 2025 if these different policy priorities are implemented in practical policy.

The forecasts are subject to considerable uncertainty, implying that interpretation of the results must be made cautiously. However, the forecasts to 2025 also make it possible to discuss the direction of the fisheries policy early and at a time where it remains possible to change it. Furthermore, where the forecasts of each policy option are subject to uncertainty, comparing the forecasts of the different policy options provide less uncertain information, since the uncertainties are similar for all policy options.

1.3 Why knowledge on future structural adjustment and management is important

Regulation of the fishing sector is crucial to avoid the "tragedy of the commons", i.e. that everyone takes what he can get, because if he doesn't take it, then his neighbours will. Furthermore, regulation determines the structural and economic development of fishing fleets. Hence, MBFM and in particular ITQs have gradually become the foundation for the Nordic fishery policies, because MBFM has proven capable of balancing the fishing fleet to the available fish resources in a sustainable manner. That is the reason why this report focus on the importance of Marked Based Management for the Nordic fisheries until 2025.

MBFM typically contributes to reducing a number of problems, mainly with overcapacity, induces increased efficiency and leads to increased earnings over time. With the improved economy, it becomes possible for the societies to prioritize new political initiatives in fisheries. For example, in the form of creating or maintaining special arrangements for certain vessels groups or regions, as is already the case in many Nordic countries and in particular in Norway, in the form of holding back a minor share of the quota for allocation to e.g. new establishment of young fishermen, in the form of funding public expenses by income from fishing taxes as is the case in the West Nordic countries, and in the form of the option of strengthening environmental regulation that affects fisheries, as it is done in the Baltic Sea area.

To get MBFM to be an effective tool, a long time horizon is needed to secure a willingness to invest the necessary means into the fishing sector. As such, MBFM reduces the degrees of freedom for politicians for many years ahead. When the system is introduced, it is to a large extent the "point of no return", unless the Governments buy back quotas at a market price that might be high (due to the fact that future earnings are capitalized in the quota values), unless bankruptcies in a large part of the fishing industry are acceptable or unless positive shocks such as price increases or unexpected quota increases saves the economy. Or that fishing quotas are only given for a fixed time period or other measures for return introduced. Such measures are off course affecting the value of the quota.

This report provides forecasts of the expected structural development in selected fisheries and draws the lessons learned from introducing MBFM. It forms the foundation for a political debate on where the current regulation brings Nordic fisheries until 2025. Thereby, political considerations on the direction and purposes of the fisheries policy become possible at an early stage, where it remains possible to act and mitigate possible negative and unwanted effects. Political priorities, such as increased wealth creation of fisheries, increased profit, increased employment, special arrangement for certain vessel groups and fishing taxes, are analysed.

The hypotheses in the report, based on standard fisheries economic theory, are: (i) that MBFM of Nordic fisheries have been, or will be, a powerful tool to eliminate earlier overcapacity which have led to increased profits and increased contributions to GDP, but also to reduced employment in fisheries and coastal communities, (ii) that this development continues in the future, but in countries that have had MBFM for many years at a reduced pace, and (iii) that focus in the future Nordic fishery policies with MBFM moves to take advantage of the improved wealth creation of fisheries to new political priorities, such as special arrangement for certain vessel groups, fishing taxes and to improve the marine environment.

1.4 Content of this report

This report contains ten chapters after this introduction. In chapter 2, the economics of fisheries policy is focusing on the economic and regulatory framework conditions for fishermen from a theoretical angle. The point of departure is existent knowledge on natural resource and fisheries economics.

Chapter 3 presents the forecast scenarios, founded in alternative political priorities. Furthermore, the forecast model is described including the assumptions and limitations of the model.

Chapter 4–10 are case studies analysing a single fishery, one from each of the seven Nordic countries. Each of these chapters presents a separate country case study that can be read without reading the full report. The fisheries being regulated by ITQs are presented first. First the analysis of the Greenlandic single species shrimp fishery in chapter 4, then the Icelandic pelagic and Stern trawler fishery in chapter 5, the Danish demersal fishery in the North Sea in chapter 6 and the large scale pelagic fisheries in Finland and Sweden in chapter 7 and 8. Chapter 9 presents the Norwegian groundfish fishery north of 62° regulated by Individual Quotas subject to restricted quota trade, while chapter 10 analyse the Faroese demersal fishery from 2019 managed with Individual Quotas.

Each of the chapters 4–10 goes through one case study and present earlier studies, fisheries regulation, data, forecast results and policy considerations. The historical effects of Market Based Management in each country case is analysed, forecast results are presented and compared across current regulation and hypothetical alternative regulation.

Chapter 11 presents the Nordic lessons on MBFM in the Nordic countries appearing from the cross-country comparison of the seven country cases provided. Finally, the report contains one appendix that present the formal basis for the applied bio-economic forecast model.

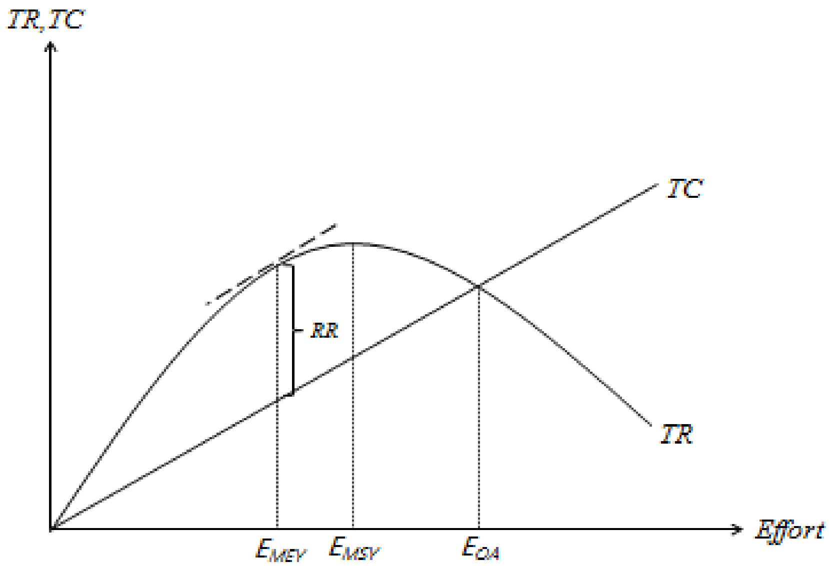
2. Fisheries economics and management theory

The use of the living marine resources plays an important role for the Nordic Countries, economically and socially, but in some countries significantly more than in others and often related to regional policy goals. The importance of marine resources is linked primarily to the fish resources, although the recreational use is of increasingly importance. At the same time, the governance of fish resources has changed quite dramatically over the last forty years going from an almost open access regime to well defined property right regimes. Since 1983, the European Fishery Policy has played an important role for the Nordic countries, members or non-members. The European Fishery Policy has also played an important role for understanding conflicts about fishing rights, market access and the priority between efficiency, employment in the fishery sector and more general in local regions.

Basic fisheries economics and management theory give a solid background for understanding major principles and dilemmas in various fisheries management systems and specific regulation initiatives. The role of and the importance of MBFM, founded on property rights, and the right economic incentives have become very clear, as the property right issue is important for understanding mankind's short-term and long-term management and mismanagement of the living resources in the oceans.

Historically, an important feature of mankind's exploration of renewable resources like fish stocks has been the lack of property rights to the fish stock. The implication has been the so-called "race for fish" and the "tragedy of the commons" phenomena. If nobody has the property right to the fish or everybody has the right to go fishing, "race for fish" will occur. The implication is economically overfishing and in many cases biologically overfished stocks as well, meaning small stocks and low long term catches. The tragedy is the fact that the economic surplus of the fishery, resource rent and producer surplus, will be low or completely disappear (the dissipation of rent), see Figure 1. The Figure is a simple presentation of classical fishery economics where open access is compared to economic optimal management (maximum long-term resource rent of a fishery).

Figure 1: The standard bio-economic model



The x-axis represents the fishing effort, which could be the amount of days at sea, meanwhile the y-axis represent both the total revenue (TR) and the total costs with cost of capital and labour in their best alternative use (TC). The open access equilibrium is where the TR and TC curve intersect, which results in the effect, E_{OA}, here the resource rent equals zero. E_{MSY} represents the effort at the MSY. The optimal fishing effort is where TC is moved up until it tangent TR. Here the fishing effort is E_{MEY}, which equals the Maximum Economic Yield. At this level of effort the resource rent is maximized and equals RR.

Figure 1 show the long- term relationship between fishing effort (e.g. number of fishing days by the whole fleet) and total revenue (catch times the price of fish). The biological dynamics behind the model is the fact that you can catch the growth of the stock and keep the stock at a certain level. If you catch more, the stock will go down and vice versa. If the stock is very low, the growth is small due to a small spawning stock biomass. If the stock is very large, the growth is also small but this is due to lack of food relatively to the large spawning stock biomass. The shape of the curve is, of course, species specific and determined by the environmental conditions. The importance of this part is that fisheries policy will determine the long-term harvest in the specific fishery. The dynamics of a fish stock also implies that it take time to rebuilt a stock and the less to catch during the rebuilt phase the faster the stock is rebuilt to the target stock level. When replacing costs of capital and labour in alternative use with actual costs, the analysis in Figure 1 also holds for profit instead of resource rent.

The economic part of the story is linked to fishing cost. In Figure 1, the cost structure is simple. We assume that the cost per fishing day is constant. Therefore, the cost curve is a straight line. A more realistic assumption will not change the fundamentals in the model. However, if the cost curve is not a straight line if some vessels are more efficient than others are, infra marginal vessels will gain producers surplus. The sum of resource rent and producer surplus is the socio-economic return to society. Under open access fishing activities, fishing effort E, will increase if the marginal vessel have a profit, i.e. as long there is a net profit of fishing. Therefore, under open access, fishing activities will be equal to EOA. If fishing effort could be reduced and cost reduced at the same time, society would gain resource rent (pure economic surplus from the fish resource). In Figure 1, the maximum resource rent would occur if fishing effort were reduced to the optimal level of fishing effort EMEY. This is where the difference between total revenue and total cost is the largest possible.

The lesson learned by using the simple model is that fishery management is needed if the objective is to create resource rent. Furthermore, fishing activities, measured by e.g. fishing days, will be smaller in the optimal managed fishery than in the open access fishery, and long-term catches might be smaller (as shown in the Figure) under open access fishery compared to optimal fishery. This implies that number of fishermen is smaller under optimal management compared to an open access fishery. However, the employment in the processing industry may be higher as catches might increase. The net employment impact depends on the specific fishery. If fishing is relatively cheap (low cost or high efficiency), biological overexploited stocks are most likely and as a consequence catches will be low, employment in the processing industry is small and there will be no resource rent and no or low producer surplus for the society from the fishing sector. Consequently, if fishing effort is not restricted and fish resources are mismanaged private and public consumption will be influenced negatively. If there is no or a minor focus on resource rent and the objective is to have a fishing fleet with many vessels and a high number of crew members management should focus on inefficient vessels which need a high number of crew members to operate.

The model presented in Figure 1 compares the start and final situations following a management change. But it does not consider the adjustment path and speed. For that, a dynamic model is needed that identify the Maximum Economic Yield by maximizing the discounted net present value of all future earnings. Thereby, the economic optimal adjustment path is identified taking into account when it from an economic point of view is best to catch fish and when it is best to leave the fish in the sea to spawn thereby making larger future catches possible. While a dynamic model provides detailed knowledge on the adjustment path, the policy conclusions of the simple bio-economic model in Figure 1 still holds.

There are many ways to control fishing effort but it is important for rent creation that the management are cost effective. The most used and classical methods such as closed areas, days in harbour, Total Allowable Catches , mesh size, fleet and horse power restrictions, and alike will reduce the pressure on the stocks as fishing effort will be less efficient. At the same time, it also means that cost of fishing a certain amount of fish goes up. Therefore, the resource rent will dissipate. In complicated fisheries (multispecies fisheries, different fishing areas, different fishing methods, and various types of fleets the right economics incentives have to be combined with other regulations to balance different goals and avoid conflict. It is important to notice that the use of only biological oriented management will not take into account fishermen's behaviour. Therefore, only if biological measures are combined with the right economic incentives, waste of resource rent due to high fishing cost can be avoided. If the objective of fishery management include biodiversity and environmental goals various non-economic incentives are relevant to include combined with economic instruments.

In order to create resource rent and to avoid biologically and economic overfishing, focus on the right economic incentives is important. Taxes on catch or revenue are in theory resource rent creating but in practice not very often used. ITQs works in theory as well in practice very well if rent creating is an objective of fishery management. ITQs work like taxes as they reduce the incentives to expand fishing effort. In the tax case, the revenue goes directly to the state (owner of the resource). If ITQs are used, the state can sell the quotas and the system is like a tax system. If the state allocates the quota to existing fishermen (grandfathering methods), the owners of the quotas gain the resource rent.

An ITQ system is a market based system and has proved to be an efficient management system to create resource rent. The reason for power of the ITQ systems' capacity to create resource rent is simple. An ITQ system gives the right economic incentives to solve the tragedy of the commons problem by moving the regulatory framework from open access to a Market Based Fisheries Management system. The core in the MBFM system is property right. In the ITQ system the property right is the right to fish a given amount of fish (or share of the total quota), to buy more fish or to sell part of the quota or the whole quota. Over time, the ITQ market will allocate fishing rights to those fishermen who have the highest efficiency.

There are many versions of a MBFM system. In Table 1, an overview of the different types of MBFM systems is adopted from Eliasen *et al.* (2009) that use the synonymous Right Based Fisheries Management for Market Based Fisheries Management.

Table 1: OECD typology of Right Based fisheries management systems

Right Based Management type	Key features
Territorial Use Rights	Allocation of a certain area of the ocean to a single user, usually a group, who then undertakes fishing by allocating rights to users within the group.
Community Based Catch Quotas	Catch quotas are attributed to a "fishing community" with decisions on allocation on rights within the community taken on a cooperative basis.
Vessel Catch Limits	Restrict the amount of catch that each vessel can land for a given period of time (week, month, or year) or per trip.
Individual Non-Transferable Quotas	Provide a right to catch a given quantity of fish from a particular stock, or more usually, a percentage of the Total Allowable Catch.
Individual Transferable Quotas	Provide a right to catch a given quantity of fish from a particular stock, or more usually, a percentage of a Total Allowable Catch which is then transferable (sale, leasing, loan).
Limited Non-Transferable Licenses	These licenses can be attached to a vessel, to the owner, or to both ad have to be limited in number and applied to a specific stock or fishery to be considered as market-like.
Limited Transferable Licenses	By making limited licenses transferable, fishermen are provided with an increased incentive to adjust capacity and effort over the long to short term in response to natural and economic conditions.
Individual Non-Transferable Effort Quotas	Rights are attached to the quantity of effort unit that a fisher can employ for a given period of time.
Individual Transferable Effort Quotas	Transferability makes a short and long term adjustment easier and allows for a better use of fishing capacities.

Source: Eliasen *et al.* (2009).

The efficiency of the various systems of Right Based Fisheries Management depends on the time horizon of the right, the trading flexibility, and the how easy it is to substitute between different fishing input. If the time horizon is short, the incentives to long term planning are not in place. If quota trading is not allowed or trading is very restricted, the quotas will not end up at the most efficient vessels and the result is loss of resource rent as well as of producer surplus. Finally, if fishing rights are not connected to catch quotas but only right to fish (a license) or the right to some input like fishing days, to use specific vessels size or alike, fishing effort can increase by substitution. An example would be if fishermen buy more efficient technical equipment and catch more per fishing day. As all inputs cannot be restricted or controlled, effort regulation will not be an economically efficient Right Based Fisheries Management system.

The right mix of regulatory measures and type of Right Based Fisheries Management system are closely related to the objectives of the fishery policy. What is the political tradeoff between resource rent now and in the future, the tradeoff between employment on the vessels and in the fishing industry more generally, and the tradeoff between small vessels and larger vessels? Furthermore, in some cases there might be a tradeoff between fishing activities and environmental goals. Finally, if a fishery has overcapacity the question is how fast the capacity should be reduced, as the transition towards a more rent creating fishery is costly as fleet capacity has to be removed and fish stocks need to be rebuilt. To find the optimal adjustment path that maximizes the discounted net present value of all future earnings of e.g. a small fish stock and a large fishing fleet to larger fish stock and a smaller fishing fleet is a true dilemma as such an adjustment always have losers and winners. Similar true dilemma exists if a fishery is a mixed fishery with different fleets, target species and conflicting interests among fleets exists and adjustment can take place without transaction costs. Only in very simple fisheries these trade-offs do not occur. And even in these cases we can face management challenges related to monitoring and enforcement cost. To quantify these tradeoffs, empirical models and analyses are needed and the choice of the optimal mix of regulatory measures strongly depends on the objectives of the fishery policy. The following chapters provide country cases of Nordic Market Based Managed Fisheries.

3. Scenarios and forecast model

3.1 Scenarios for future fishery policies

The analysis is based on the four scenarios in Table 2 and compared to the initial situation in 2015. The initial 2015 situation is estimated, since fishery account statistics including fishing cost data were not known at the time of modelling. The reason is that it typically takes up to two years before account statistics becomes publicly available, since company accounts first have to be recorded and on the basis of these statistics must then be collected. The 2015 initial situation is therefore identified on the basis of the base period, which is the average of 2012–2014, corrected for known changes in the fishing patterns in 2015.

Table 2: Definition of scenarios for future fisheries policies

Scenarios	Definition
2015 initial situation	For 2015, fleet data, catches and prices are known at the time of modelling, while costs are not known. Therefore, 2015 is calculated in the forecast model and adjusted in relation to known adjustments.
1. 2025 with current management	Current regulation continues unchanged and a 4% limit is imposed on yearly adjustment in number of vessels in each segment. Current regulation of the selected vessel groups is in Greenland, Iceland, Denmark, Finland and Sweden ITQs with certain restrictions in most cases. In Norway it is Individual limited Transferable Quotas and at the Faroe Islands it is Individual Quotas from 2019.
2. 2025 with ITQ management and free quota trade[1]	Free trade in permanent quotas between all vessel groups and a 4% limit on yearly adjustment in number of vessels in each segment. This scenario corresponds to scenario 1, except for free quota trade.
3. 2025 with current management and full adjustment	Current management with no limit on yearly fleet adjustment. This scenario corresponds to scenario 1, except for that there is no limits imposed on annual fleet adjustment.
4. 2025 with current management and a 10% landing tax	Current management with a 4% limit and a 10% tax on the landing value. This scenario corresponds to scenario 1, except for the 10% tax on landings. For the countries that already have fishing taxes, Greenland and Iceland, the 10% landing tax is an extra tax on top of the ones that already are in force.

The first scenario is the continuation of the currents fisheries regulation in each of the seven country cases. Regulation of all selected vessel groups is founded on elements of MBFM. For the included vessel groups in Greenland, Iceland, Denmark, Finland and Sweden, the continuation of ITQ systems, given certain restrictions in most countries, is analysed. For Norway it is Individual Quotas with limited transferability, while for the Faroe Islands, it is Individual Quotas, initiated in 2019. This scenario is founded on a limitation in the yearly adjustment in the fleet on 4%, implying that only 4% of the fleet can either enter or exits the fishery each year. The reason for the limitation is that this speed of adjustment following fishery reforms is observed in most fisheries.

Scenario 2–4 departs from scenario 1 by changing different factors one by one, keeping everything else the same as in scenario 1. In scenario 2, free exchange of quotas between all vessel groups are allowed in each country case, corresponding to lifting all restrictions on quota trade between the vessel groups. In scenario 3, the limitation on yearly adjustment of the fleet on 4% is removed, while everything else is the same as in scenario 1. This scenario measures what happens if fishermen act purely in their own economic interest and maximize earning without any delay. In scenario 4, the current regulation is also kept unchanged, but combined with a 10% tax on the landing value. For the countries where fishing taxes are already in force (Greenland and Iceland), it is an extra tax on 10% of the landing value.

There are numerous alternative ways for defining the scenarios of possible future political priorities. Considerations on economic earnings, (profit and socio-economic return), employment in coastal communities, special arrangements for part of the fleets and funding of public spending by fishing taxes, appears today as the most relevant considering the ongoing discussion in the Nordic countries.

3.2 Vessel groups

The forecasts are made for a representative average vessel in selected vessel group. The vessel groups are selected both to represent the diversity of Nordic fisheries and to ensure that data are available. The forecasted structural development depends on restrictions on permanent quota trade. The vessel groups analysed in this report are shown in Table 3 together with the prevailing restrictions on quota trade.

Table 3: Vessel groups and restrictions on quota trade

Country	Vessel groups included	Restrictions on quota trade
Greenland	*Shrimp fishery* 1. Off-shore production trawlers 2. Coastal trawlers (<120 GT)	Off-shore vessels are allowed to sell to coastal vessels, the opposite quota trade is not allowed.
Iceland	*Pelagic and Stern trawler fishery* 1. Demersal fresh fish trawlers 2. Demersal freezer trawlers 3. Pelagic fresh fish vessels 4. Pelagic frozen fish vessels	All vessels are allowed to trade quota with each other, except for vessels < 15 meter that are not allowed to sell permanent quota to larger vessels.
Denmark	*Demersal North Sea fishery* 1. Netters < 15 meter 2. Netters 15–25 meter 3. Trawlers < 15 meter 4. Trawlers 15–24 meter 5. Trawlers 24–40 meter 6. Danish seines 15–24 meter	All vessels are allowed to trade permanent quotas with each other, except for small vessels that have voluntarily enrolled in one of the two special coastal arrangements; one for vessels < 17 meter from which the vessels cannot sell permanent quota for a period of three years and another for vessels < 15 meter from which vessels cannot sell permanent quota at all.
Finland	*Large-scale pelagic fishery* 1. Trawlers < 24 meter 2. Trawlers > 24 meter	Vessels within the two groups are allowed to trade permanent quota with each other.
Sweden	*Large-scale pelagic fishery* 1. Vessels 18–24 meter 2. Vessels > 24 meter	Vessels within the two groups are allowed to trade permanent quota with each other.
Norway	*Demersal fishery north of 62°* 1. Conventional vessels < 11 meter 2. Conventional vessels < 11–15 meter 3. Conventional vessels < 15–21 meter 4. Conventional vessels > 21 meter 5. Conventional ocean vessels < 28 meter 6. Trawlers	Vessels are allowed to trade quota with some restrictions within each vessel group, but quota trade between vessels groups is not allowed.
Faroe Islands	*Demersal fishery* 1. Large demersal trawlers > 400 HP 2. Long-liners > 110 GRT	In the Individual non-Transferable Quota system the two vessel groups are not allowed to exchange quotas.

Demersal vessel groups are selected in Norway, Denmark and at the Faroe Islands, while pelagic vessels are included from Finland and Sweden. From Iceland, both demersal and pelagic vessels are analysed, while for Greenland focus is on the single species shrimp fishery.

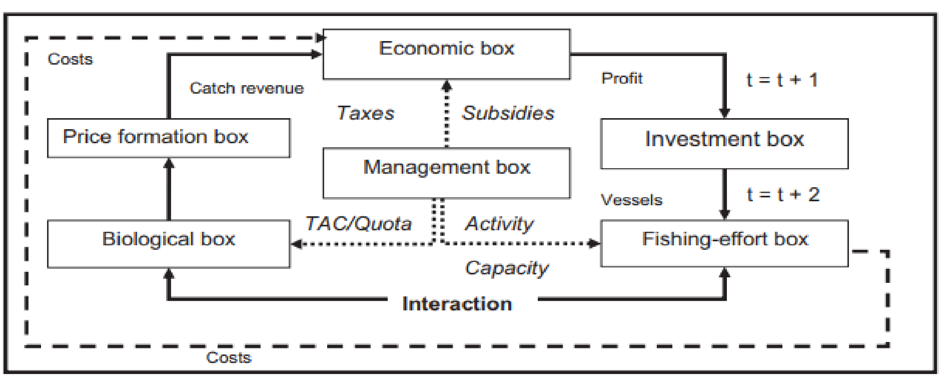
Restrictions on permanent quota trade are absent in the case presented for Finland and Sweden, while quota restrictions follow the vessel groups in the Norwegian and Greenlandic case. For Iceland and Denmark, special arrangements giving some advantages to small coastal vessels are not attached to a single vessel group, but are possible to achieve for vessels that cross more groups. In Denmark one of the coastal fishery arrangements is for vessel below 17 meter, i.e. with some vessels being in the group up to 15 meter and others in the group on 15–25 meter. Given this and that the arrangement is voluntary, implying that only a part of the vessel in the modelled group can trade quotas between them, the forecast of the Danish fishery is obsessed with uncertainty. However, with the focus on large vessels over 40 meters in Iceland and with the majority of the Danish vessels in coastal arrangements being in vessel groups below

15 meters, the problem is of minor importance. At the Faroe Islands, Individual Quotas are introduced in 2019.

The forecasts are made on a year by year basis for the period 2016–2025 with 2025 chosen as the year that is given emphasis in the analyses. The applied dynamic bio-economic model of fisheries, the Fishrent model, is used for the forecasts. The model forecast the future structural development in the selected fisheries, all other things being equal, by maximizing the discounted net present value of economic earnings for the period 2016–2025, by changing the number of vessels and number of days at sea. First, socio-economic return is maximized to provide a picture of the optimal use of the fish resources from a society point of view. Afterwards, profit is maximized to identify the optimal economic behaviour of the private fishing companies. These forecasts are made for all four scenarios. For a detailed formal presentation of the model see the appendix and for a theoretical foundation of the model, see chapter 2.

The Fishrent model consists of a number of interconnected modules/boxes, which are the *biological box*, the *price formation box*, the *investment box*, the *fishing effort box*, the *management box* and the *economic box*. The model is structured on feedback between the economy and capacity of the fishery, and the biology of the exploited fish stocks. This means that year-to-year changes observed for total fish stock biomass are fed back into the model and hereby influence fishing opportunities, economy and fleet size, while on the other hand year-to-year changes in fleet size, given fleet economy, will feed back into the model and affect stock development. The structure of the model is sketched in Figure 2.

Figure 2: Structure of the FishRent model



Source: Frost *et al.* (2013).

In the *management box* in Figure 2 it is assumed that the fishing activities are regulated with Total Allowable Catches and ITQs with different degrees of transferability in each country case, except for at the Faroe Islands. In the Faroese case, Individual Quotas sold at auction are applied from 2019. Catches for a given year are restricted by the Total Allowable Catches, assuming that the vessel groups included in the model together fishes a constant share of it. This implies that the catch from vessel groups, which are not included in this analysis, but fish the same stocks, develops the same catch patterns as the included vessel groups. The assumption is introduced to account for the total catch of the stocks. The assumption seems reliable for fish stocks regulated by Total Allowable Catches with a relative stable allocation, as the ones included in this analysis.

Catches are determined by the size of the fish stocks and fishing effort (*fishing effort box*) and are restricted by the quota limits, set in accordance with the Total Allowable Catches (from the *management* box). Fishing effort is defined as fleet size (capacity measured as number of vessels) times days at sea per vessel. In the multi-species fisheries, it is assumed that each vessel group's relative time spent on their target stocks is constant. This assumption is introduced since costs are only available on an annual basis, whilst the cost of targeting the individual stocks remains unknown. The implication is that it is not possible, for example, to switch effort away from a target stock that declines more than other stocks, as well as it is not possible to switch to completely new target stocks.

The fleet size is determined in the *investment box* and depends on previous year's profitability (*economic box*). Increasing profits lead to investments while decreasing profits leads to disinvestment. The catches in a given year will influence stock changes (the *biological box*) and as such future catch possibilities. Market prices are set in the *price formation* box and are assumed constant at the 2015 level. Socio-economic return and profit are determined in the *economic* box, and depend on landings, prices and costs/opportunity cost. These, again, are determined by fishing effort. Fuel use is determined by fishing effort, while fuel prices are assumed constant. Labour costs are determined by turnover, since shares are used as a basis for remuneration of the crew in the Nordic fisheries. Other variable costs are also determined by turnover. Fixed costs and capital costs are determined by number of vessels at constant cost per vessel.

Opportunity costs of labour are determined by fishing effort at a constant annual wage, as opposed to actual costs of labour that are determined by turnover. The reason is that wages in alternative jobs are determined on the labour market for alternative jobs and not within fisheries. Opportunity costs of capital are set to 6% of the physical assets, which is assumed a reasonable rate of return in fisheries. Opportunity cost of capital is taken of the physical assets. Since assets of owning fishing rights from a societal point of view is only a matter of allocation between seller and buyer of quotas, investment in purchase of quotas do not need to give return from a societal point of view.

Costs of purchase of permanent quotas are included in the operating costs of the vessels. Quota purchase costs are not known, but instead calculated approximatively as the average of the willingness to pay by the vessels that buy the quota and the willingness to accept by the vessels that sells the quotas. Both willingness to pay and willingness to accept are based on vessel profitability the previous year. Hence, the model is founded on, that vessels in the most efficient groups purchase quotas permanently from other vessel groups and, thereby, reduce the size of the other vessel groups.

Within the *biological box*, the forecast of catches is founded on the estimation of a function where recruitment of fish increases with the size of the fish stocks until the MSY, after which it falls. This function is identified in a way such that the stock will not come above the maximum observed over the last twenty years (1995–2014). Total Allowable Catch is determined through a policy aiming at MSY (the management box), while individual fisheries will set their catches at a level that is as close as possible to

MSY (the effort box), while at the same time ensuring maximum economic outcome from the fishery.

The forecasts in this report are founded on data from the base period, which is the annual average of 2012–2014 where all data are available. From the base period, data for the initial year 2015 are calculated by taking into account that data on fleet, catches and prices are known. The calculation is made by scaling all other data after the development in the known data. From 2016 and onwards, forecasts are fully made in the model by maximizing socio-economic return and profit under the restrictions sketched above.

The causalities and relations in the model are summarized in Table 4.

Table 4: Summary of causalities and relations in the FishRent model

Item	Description
Biology/management:	
Biomasses (size of fish stocks)	Biomasses are determined by being the same as the year before with recruitment of fish added and mortality of fish (fishing and natural mortality) removed.
Recruitment of fish	Recruitment of fish depends on the biomasses as given in a second degree polynomial with an optimum at the MSY.
Total Allowable Catches	The Total Allowable Catches are set given a MSY target.
Economy:	
Turnover	Catches are determined by fishing effort and the size of the fish stocks (biomasses) in a Cobb-Douglas production function. Fish prices are assumed constant at the average 2012–2014 level.
Fuel costs	Fuel consumption is determined by fishing effort and fuel prices are assumed constant at the average 2012–2014 level.
Labour costs	Labour costs are determined as a fixed share of turnover and based on the average 2012–2014 level.
Other variable costs	Other variable costs are determined as a fixed share of turnover and based on the average 2012–2014 level.
Capital costs	Total capital costs are determined by number of vessels with capital costs per vessels being constant at the average 2012–2014 level.
Fixed costs	Total fixed costs are determined by number of vessels with fixed costs per vessels being constant at the average 2012–2014 level.
Opportunity cost of labour	The use of labour in alternative sectors is determined by fishing effort with annual wages in alternative sectors being assumed constant in each country case at an assessed realistic annual level.
Opportunity cost of capital	6% of physical assets (i.e. assets excluding values of fishing rights)
Investments	Investments in vessels are determined by the profit last year with increased profit leading to investments in more vessels and decreased profit inducing exit of vessels.
Other:	
Fishing effort	Fishing effort is determined by number of vessels and days at sea per vessel.
Discount factor	3.5%.
Fishing technology	Unchanged at the 2012–2014 level.
Maximum days at sea/vessel/year	Set in each case study to reflect the maximum days a vessel realistically, this has been set to at the maximum observed days sea per vessel per year over 2012–2014 for each vessel group. The maximum days at sea per year increase with size of the vessels with the largest vessels potentially being able to fish almost year round.
Maximum catch/vessels/year	Set to reflect the maximum catch a vessel realistically is able to catch per year. The maximum catch per vessel per year depends on size of the vessel and type of fishery (pelagic and demersal).
Trade in permanent quotas	The quantity of permanent quotas sold is determined by the relative expected future profits of vessel groups. Vessel groups with high expected future profits buy permanent quotas from vessels with less expected future profits. The annual price of quotas traded permanently is calculated as discounted future profits allocated over the infinitive earning period. The price of the quotas is set as the average of the sellers' willingness to accept and the buyers' willingness to pay, which again are determined by their profit.

Source: See Appendix.

The causal structure of the model is that the activity of the fishing fleet (number of vessels and days at sea) in a year determines catches and costs and, through that, socio-economic return and profit. The fishing activity also affects fish stocks and the larger the fishing effort, the less the fish stock. Hence, a large fishing effort leaves less fish in the sea for future fishing, corresponding to that savings on a Bank Account is used and the balance is reduced, while a small fishing effort leaves more fish in the sea to be caught in the future. Furthermore, many fish in the sea in the form of a large fish stock induce a high recruitment of fish, which lead to further growth of the stock in the long run. At sufficient high fishing efforts, fish stocks fall to a level where sustainable long run catches will fall. The activity of fishing, determined by the Total Allowable Catches, is set by the fishery regulator at the largest possible catch that can be sustained in the long run. That is, at the MSY.

Founded on this structure, the number of vessels and days at sea in each vessel group that gives the maximum net present value of all discounted future socio-economic returns and profits are identified. The maximization made under a number of restrictions reflect that fishermen fish to earn money, and plan their fishery to earn as many money as possible, whilst the restrictions are included to reflect that in reality fishermen do not always fully do that. For example, the decision to stop fishing is often based not only on economic considerations, but also depend on age, family and future expectation of income. Hence, the forecasts are both founded on economic rational behaviour of fishermen reflected in the maximization and on corrections of realized behaviour deviating from this reflected in for example the annual 4% limit on fleet adjustment.

While forecasts can provide good input to the debate on future fishery policies, they also critically depend on the methodology applied and the assumptions on which the model forecast is built upon.

First, with forecasts made for representative vessels in each group, the results measure the effect of changing the activity and number of vessels in each vessel group, while it does not take into account that vessels within each vessel group can trade quotas with each other, implying that the most efficient vessels can buy quotas permanently from less efficient vessels. Socio-economic return and profit are underestimated due to that.

Second, the assumption of multi-species fisheries that each vessel group's relative time spent on the various stocks is constant makes switch of effort to other species impossible in the forecast model. When such switches are not possible, the "choke" species problem appear. The "choke" species problem indicates that if the Total Allowable Catch on one stock decrease, fishing on all stocks must be reduced correspondingly. The model does in such a situation forecast a substantially reduced activity of the vessel group, whilst in reality the vessels could have continued to fish on the remaining stocks. The implication is that socio-economic return and profit are underestimated.

Third, technology is assumed unchanged in the future, implying that to the extent technology improves over time, which is normally seen, socio-economic return and profit is underestimated.

Finally, the use of a twenty years period as the basis for the biological forecasts implies that if the stock is larger in the base period 2012–2014 than over the last twenty years, catches will fall until 2025. On the other hand, if the stock is smaller in the base period 2012–2014 than over the last twenty years, catches will grow. That induces uncertainty in the forecasts in all scenarios. The relative forecasts between scenarios, however, are not uncertain, since the uncertainties are the same in all scenarios.

4. Greenlandic shrimp fishery

4.1 Introduction

ITQs have been in force in shrimp fishery for offshore trawlers with onboard processing from 1990 and for coastal trawlers from 1997. The management have ensured reduction of earlier overcapacity and increased earnings without compromising sustainability. It has also reduced fleet size and employment. The system remains in play today.

The legal framework for taxing direct export of shell shrimp from offshore trawlers was introduced in 1990. While the tax revenue was high the first year, it was reduced to a low level over the following two decades. The tax rate, however, grow with the size of shrimp prices, in order for the Government to collect the surplus when they are high. And with price increases 2010–2015 and continue high prices afterwards, shrimp tax revenue has become a very important income source of the Government in 2017.

The policy consideration balance between a coastal fleet that supply factories and secures employment in both sectors and a highly efficient offshore trawler fleet contributing substantially to GDP and ensure funding of public spending through taxes. With one of the longest histories of ITQ management and the highest resource rent tax in fisheries worldwide, the Greenlandic shrimp fishery present an interesting model of fisheries management relevant to consider in many countries.

The Parliamentary Bill on a New Fishery Law has been intensively debated in the media the last year. It suggests reallocation of quotas permanently from offshore to coastal shrimp trawlers and the introduction of a notice period of five years for termination of ITQs, instead of the current infinitively running system.

The proposers argue that recruitment of young people to shrimp fishing is ensured and that employment increase in coastal shrimp fishing and at factories. This is considered important with few alternative jobs.

Opponents find that the contribution of the efficient offshore shrimp trawlers to GDP and tax revenue is reduced, that termination of ITQs induces a compensation liability for the Government to the offshore trawlers and that employment consideration is expensive in fisheries and better provided by developing other industries. Furthermore, the New Fishery Law negatively affects the ability of the fisheries to contribute to fund independence of Greenland. The reason is that quotas are moved from efficient offshore trawlers exporting shell shrimp, to less efficient coastal trawlers supplying factories producing peeled shrimp at an aggregated substantial lower contribution to GDP.

The purpose of this chapter is to contribute to the debate on the future fishery policy by forecasting economy and employment quantitatively until 2025 under the current management, and compares with hypothetical policy changes of free quota trade and higher shrimp taxes. This case study analyses the economy of the whole domestic shrimp value chain, e.e. fishery and processing. The reason is that offshore vessels process on board implying that fleet segments can only be compared when including also land based processing. Experience on how ITQs and taxes play together is provided. The Bill of the New Fishery Law is not directly assessed, although the forecast provide indications on the size of the effects.

The case study is performed by Max Nielsen, Ayoe Hoff and Rasmus Nielsen, Institute of Food and Resource Economics, University of Copenhagen, Denmark.[1]

In the following, the current and historical management of Greenlandic fisheries is described, while section 3 provides a literature review of economic studies assessing fishery policy reforms in Greenland over the last decade. Section 4 present data and section 5 the results of the scenarios. Section 6 concludes the chapter with policy considerations.

4.2 Management

Fishing around Greenlandic dates back centuries, with fishermen from several European countries targeting mainly cod. European fishing continued up to modern time, with cod catches peaking over the 1980ies. Today, a few European vessels remain active at East Greenland. Commercial fishing by Greenlanders diversified from cod fishing to also include shrimp in particular over the 1980ies. Shrimp fishing began in the middle of the 1970 when the offshore fishing developed. Shrimp replaced cod almost fully in the 1990ies and many Greenlandic shrimp trawlers were added to the fleet, including the publicly owned vessels operated by Royal Greenland Trading Department, today Royal Greenland Ltd.

Today, shrimp fishing and processing is by far the most important economic activity, although Greenland halibut fishing have also developed to a large business. With climate change, a larger diversity of species is now present and caught at East Greenland, including mackerel and herring.

With the 200 nautical mile Exclusive Economic Zone coming into force in 1982 with the Convention of Law of the Sea (United Nations 1982), Greenlandic ownership of fish stocks formed the foundation for stock management with Total Allowable Catches. It also made it possible to prioritize domestic vessels and exclude foreign vessels. Greenland remained, however, member of the European Union, implying that the Common Fisheries Policy made it possible for EU vessels to continue fishing until the EU exit in 1985. The EU exit was followed by an agreement that in return for free access for Greenlandic fish product to the EU market and financial compensation, allowed some European vessels to continue fishing, although the disappearance of cod over the 1990ies limited their activity. Today, a limited number of European vessels prevail at East Greenland.

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[1] Lector Emeritus Hans Frost has contributed with valuable comments and discussions.

In the 1980s, total allowable catches were introduced. Subsidies were also given to new vessels and together with private overinvestment, overcapacity in the shrimp fishery were induced. The commercial disappearance of cod in the early 1990ies made shrimp the most important species and led to vessels switching for the shrimp fishing, further worsening the overcapacity problem.

For offshore production trawlers, the solution in 1990 was ITQs. Since increased profit was anticipated, the legal basis for shrimp taxes was introduced at the same time for these vessels on the direct export in order for the Home Rule Government to achieve a share of the increased earning. For coastal shrimp trawlers, the solution at that time were a transferable license system (Directorate of Fisheries, Hunting and Agriculture 1995), where vessel capacity were graduated after catch capacity based on size of vessel, engine, historical catches, etc. A licensed vessel had free fishery and could sell its license to other vessels.

While the ITQ management for offshore vessels reduced overcapacity and increased earning, the license system appeared not to have the intended effect, due to increased utilization of the single vessels and technological progress. The system was replaced by ITQs in 1997. ITQs have prevailed for shrimp since then and in 2012 the system was also introduced in the inshore Greenland halibut fishery for vessels over 6 meter.

Today, the Fishery Act (Greenland Parliament 1996) with revisions, together with Government Directives including for licenses, quotas and technical conservation measures, forms the legal framework. The Government fixes annually Total Allowable Catches following biological advice. Each vessel permanently owns a fixed share of the Total Allowable Catch that identifies the annual quota. Both permanent quota shares and annual quotas are freely tradable, except for that coastal vessels less than 120 GT are not allowed to sell to offshore vessels. This limitation ensures the balance between the two vessel groups. The Fishery Act also specifies that offshore vessels are allowed to fish three nautical miles outside the baseline, where coastal vessels have to fish inside that area.

A landing obligation on 100% exists for coastal vessels and on 25% for offshore production trawlers, to ensure raw material for factories. Offshore production trawlers further have an on board production permit on the remaining 75%. A few vessels had until 2015 a coastal license together with a 30% production permit.

Concentration rules prevail to avoid that few companies control the quota market. Ownership with decisive power[2] of a company or individual is limited to 33.3% of the total allowable catches allocated to offshore vessels and to 15% of the Total Allowable Catch allocated to coastal vessels. In these shares, company ownership of another company with decisive power count.

The Act on Shrimp Taxes (Greenland Parliament 1990), which changed to the Act on Resource Taxes on Greenlandic Fishery (Greenland Parliament 2017), has been the legal foundation for the shrimp tax. Until 2017, the tax solely applied for shell shrimp

[2] Decisive power exist when one company own more than half of another company.

processed on board offshore vessels and exported directly. The rationale is that since direct export doesn't contribute with jobs at factories, it must contribute to the society in another way, with tax revenue. The tax rate is progressive with the tax rate increasing when prices increase.

4.3 Literature review

The importance of the fishing industry for Greenland continuously induce political debate and recurring launches of analyses on the balance between the fishery policy purposes of contributing to the socio-economy and to national employment.

One literature direction of people emphasize the socio-economic contribution of the fishery sector to the national economy and GDP, given that fishery and fish processing is the most important sector economically. This direction favours the current ITQ management as an instrument to create societal welfare. Some finds that the current management with safe guards for coastal vessels to avoid that these are brought out by larger vessels, ensures a reasonable balance between the employment intensive coastal fleet, that also secure employment at factories, and the highly efficient offshore trawler contributing to GDP. Others find that the transfer of quotas from coastal vessels to more efficient offshore trawlers under increasing returns to scale induce substantial growth in the sectors socio-economic contribution. And some of these see that growth have a role to play in providing the economic foundation for Greenlandic independence.

Another literature direction focuses on fishery and fish processing as the largest sector nationally in terms of employment and considers maintenance of jobs as necessary for maintaining small fishing communities. Fishery reforms that at the expense of a larger GDP contribution reduce employment, induces a social risk when few alternative jobs are available. And such reform might aggravate the already prevailing social problems. This direction might be against ITQs since it reduce employment. But it might also favour it if quotas are reallocated from offshore to coastal vessels.

A third literature direction sees the extension of the efficient offshore trawler fleet as a way to achieve the maximum GDP contribution and thereby the largest possible welfare in the Greenlandic society. However, since profits goes to the private fishing companies, taxes are needed for the society to obtain a fair share. This direction is in favour of ITQs in combination with fishing taxes.

Over the last decade, more studies have been conducted for the shrimp fishery. The Greenland Home Rule (2009) initiated a Fishery Commission with industry members that were required to work within the policy purpose of maximizing earning of the sector for the Greenlandic society. The work was initiated at a time with the belief that new industries such as mining and hydropower would soon ensure full employment, implying that job maintenance in fishing was not of highest priority.

Their analysis showed that if offshore production shrimp trawlers replaced all coastal vessels and all factories, the sector contribution to GDP could increase EUR 10.3 Million (11%), while employment would be reduced by 900 persons (65%). On this basis the Commission recommended lifting the landing duty and the ban of quota sale from coastal vessels to offshore vessels. ITQs were further seen as the best instrument to ensure efficiency in Greenlandic fisheries and were recommended for more fisheries than shrimp, including halibut inshore. While ITQs were introduced for the inshore halibut fishery in 2012, the landing duty and the ban of quota trade for shrimp remains.

Schütt *et al*. (2014) show in their bio-economic analysis for the Nordic Council of Ministers that simultaneous lifting the landing duty and the ban of shrimp quota sale, with unchanged production permits for offshore vessels, would increase the socio-economic return from EUR 34 Million to EUR 90 Million per year, corresponding to an increase of 37% of the landing value. Employment at vessels would be reduced from 572 to 332 (58%), all coastal shrimp trawlers would disappear and employment at factories would be reduced to about half.

The larger socio-economic gain revealed in Schütt *et al*. (2014) compared to the Fishery Commission is due to price increases, biological gain from effort reduction and to the fact that socio-economic return include over-normal salary.

Nielsen *et al*. (2016) identify profit of one kilo of shrimp (live weight) in the whole value chain from catch in Greenland, over processing, export and consumption in Denmark for coastal caught and peeled shrimp and shell shrimp caught by an offshore vessels. In 2013, profit in the whole value was EUR 0.61 for peeled shrimp and EUR 1.08 for shell shrimp. It is concluded that profit per kilo shrimp can be increased substantially if offshore trawlers replace coastal trawlers. The amount is conservatively estimated to at least EUR 25.2 Million per year. Hence, the study confirms the gain found in earlier studies of lifting the landing duty and the ban of quota sale between vessel groups.

The study also finds that shrimp from Greenland compete at the world market with both Canadian shrimp and warm-water shrimp farmed in low wage countries such as Ecuador, Indonesia and Bangladesh (Ankemah-Yeboah et la 2017, Nielsen *et al.* 2018). Competition at the world shrimp market is assessed stronger for peeled shrimp than for shell shrimp, owing to peeled shrimp being labour intensive and to the prevailing higher tariffs. Higher profit and less competition are therefore assessed to make shell shrimp a safer choice for Greenland than peeled shrimp.

The studies demonstrate that a socio-economic contribution exists, which is the necessary for being able to collect any tax revenue. Against this background, the Ministry of Finance (2017) initiated a working group with members from the industry, banks and the ministry that identified the resource rent in Greenlandic fisheries and came up with models for resource rent taxation schemes. The group was required to work within the policy understanding that fish resources are the property of the society. The group found that all fishermen should contribute to society for access to fishing, but also found that the tax should be on level where fishing remains profitable. It was recommended that a possible taxation scheme consists of a general tax to cover public expenses to the fishery and a tax on extraordinary high earnings, with the tax rate increasing with at high prices.

The New Fishery Law was presented and discussed in the Greenlandic Parliament in 2017. It is suggested that the current shrimp quota allocation on 43–57% between coastal and offshore shrimp vessels is changed to fifty-fifty, that a 5-years notice period for terminating the indefinitely running individual transferable shrimp quotas is introduced, and that minority ownership of companies have to count in the concentration rules (Government of Greenland 2017).

The Government of Greenland (2017) assesses that the Law increases fishery employment and with increased landings also employment in processing. It is further assessed that the socio-economic consequences are efficiency losses from less efficient coastal vessels taking over for offshore vessels and from reduced investments following uncertainty on future management. If the Government is liable to companies that loose quotas, a substantial one-time expense might also result. The loss in GDP contribution were in the long run identified to be up to EUR 24 Million annually, while the loss in public income is up to EUR 17.3 Million.

4.4 Data

Fishing and fish processing is the largest industry in Greenland. Fish products account for 87% of the goods export value (2015, Statistics Greenland 2018a), with shrimp, Greenland halibut and cod being most important. The sector is the largest industry in terms of contribution to GDP, with the direct contribution from fishery, processing and wholesale of fish products being 13% (Copenhagen Economics 2013). With 3,548 registered employed, a fulltime employment on 1,867 persons and a large number of persons having some income from fishery, the sector is also the largest in employment terms (Nielsen *et al.* 2017). And employment in fishery further plays a central role in maintaining many small coastal communities.

Shrimp is the core economically. The shrimp sector account for 54% of the goods export value in 2015 (Nielsen *et al*. 2017), earn high profits, is the single product with the largest contribution to GDP (Nielsen *et al.* 2017) and deliver EUR 20.0 Million in shrimp tax revenue in 2015, on top of income and company taxes. Shrimp is also important in providing jobs that are well-paid compared to in other parts of the fishery sector, with 573 fulltime employed totally in fishing and processing (in 2012–2014, see Table 5).

Shrimp are caught from the West Greenlandic stock in Davis Strait and Baffin Bay, while catches from the stock at East Greenland forms less than 1% (2012–2014). Coastal vessels fish solely at West Greenland, while some off-shore vessels have a minor additional catch at East Greenland and earlier a small catch in a few years at Flemish Cap. All vessels use trawl. The products from the shrimp industry can be divided into mainly two categories of products; one is boiled frozen shrimp with shell produced on-board the off-shore production trawlers. These are exported directly from the trawlers without being landed to a land-based production facility in Greenland. The second category is produced from the shrimps landed in Greenland and produced as cooked and peeled shrimps at the land-based factories.

Physical data are known from the vessel and license register (Greenland Fishing License Control 2018) and the landing statistics (Statistics Greenland 2018a), while economic data and data for fulltime employment originates from the account statistics

(Statistics Greenland 2018b). Physical and economic data for the shrimp industry is shown as annual averages over 2012–2014 in Table 5 for the coastal fleet, the off-shore production trawler fleet and for the land-based shrimp factories.

Table 5: Physical and economic data, annual average 2012–2014

	Coastal trawlers	Offshore trawlers	Land-based factories	Total
Physical data				
Fulltime employment/segment	203	88	282	573
Number of vessels	21	9	.	30
Number of factories	.	.	4	4
DAS/vessel	168	294	.	.
Posted quota rights assets/vessel (EUR 1000)	156	312	.	.
1st important species	Shrimp (~100%)	Shrimp (~100%)	.	.
Total account data (EUR Million)[1]				
Turnover	34	153	121	309
Fuel Costs[2]	7	26	10	43
Crew costs	12	39	16	67
Variable costs[2]	5	25	80	110
Fixed costs[2]	5	18	10	33
Capital costs	5	6	3	14
Opportunity labour cost[3]	8	11	11	31
Opportunity capital cost[4]	5	9	3	16
Shrimp tax revenue	0	14	0	14
Profit	1	38	2	41
Socio-economic return[5]	4	78	5	86

Note: 1. The account data for the coastal fleet is identified by upscaling from the available data from 16 vessels to the 21 active vessels. That data thus cover 86% of the vessels. For the production trawlers accounts are available from 5 of 9 vessels and cover 56%. The reason for the lower coverage of offshore production trawlers is that separate account for the activity of these vessels within Royal Greenland and Polar Seafood Greenland has not been available. Account data for land-based factories are identified by upscaling from two factories on the basis of supply of raw materials to these. The analysis rest on the assumption that upscaling is representative. With fishing in each fleet segments and processing at each factories taking place in the same way, this is assessed to be the case.

2. The total costs of fuel costs, variable costs and fixed costs are known, but the allocation between the three components is an estimate.

3. Total opportunity cost of labour is identified on the basis of an annual average salary of a fishermen/factory worker in another sector on EUR 40,000 multiplied by the number of full time employed.

4. Total opportunity cost of capital is calculated as 6% of the physical assets of the companies.

5. The socio-economic return = turnover – fuel costs – variable costs – fixed costs – opportunity costs of labour – opportunity cost of capital – extraordinary taxes paid.

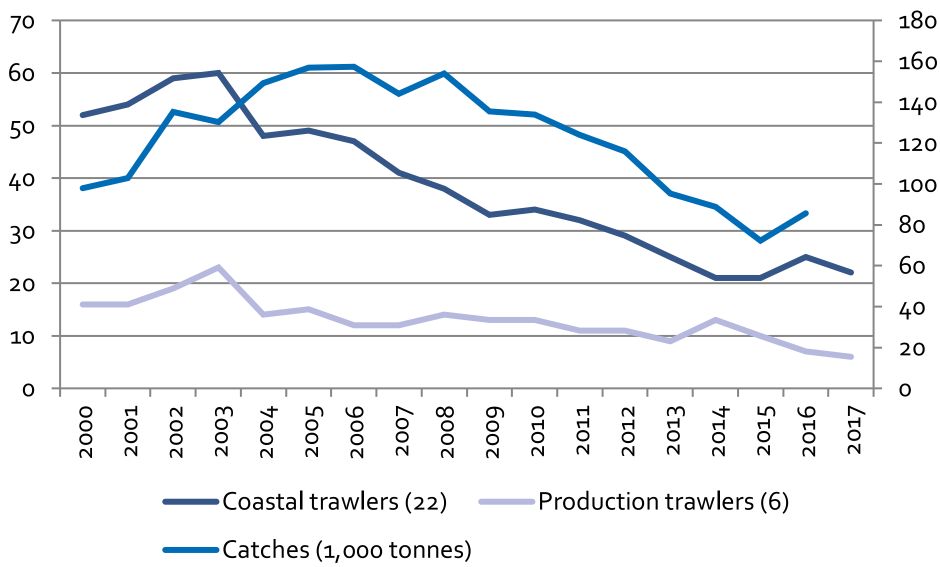
Source: Statistics Greenland (2018b), Account Data, Statistics Greenland (2018c), Landing Statistics and Greenland Fishing License Control (2018), The License Register.

1 coastal vessels and 9 off-shore production trawlers are active in 2012–2014 as an annual average. 2 vessels with a license for coastal fishing and with an onboard production permit on 30% of the catch are moved to the off-shore production fleet. In the period, 25 coastal vessels without onboard production were licensed, but only the 21 active vessels are included in this analysis. 4 factories prevail, two owned by Royal Greenland Ltd. and the two others by Polar Seafood Greenland Ltd. The factories are located in Nuuk, Sisimiut, Ilulissat and Aasiaat. Hence, the shrimp industry is

concentrated in the largest cities in Greenland. Total fulltime employment was 573, half of these at factories. Coastal vessels employed 203 and off-shore production trawlers 88. The average asset of a coastal vessel was EUR 1.5 Million and 21.7 for an off-shore production trawler. That reveals a capital intensive off-shore trawler fleet producing shell shrimp founded on economies of scale and/or economies of scope in the production, and a coastal trawler fleet supplying factories, together being labour intensive in peeled shrimp. The annual days at sea per vessels is estimated, based on Schütt *et al*. (2014). The numbers indicate that the off-shore vessels are at sea a substantially larger number of days a year than the smaller coastal vessels.

The development in number of vessels in the two fleet segments is shown in Figure 3 together with total catches from the West Greenland shrimp stock.

Figure 3: Number of Greenlandic vessels with license for shrimp fishery in West Greenland and total catches, 2000–2017



Note: Number of vessels includes all Greenlandic vessels with a license for shrimp fishing at West Greenland. Foreign vessels including Danish are not included. Vessels with a license at East Greenland are only included if it also hold a license at West Greenland. Research fishery licenses and licenses given to dinghies in 2008 are excluded. Production trawlers includes offshore trawlers with a license for offshore fishery and a production permit on 75% and trawlers with a license for coastal fishery with a production permit on 30% (where the last disappeared in 2015). Catches includes both Greenlandic and foreign fishing at the West Greenland stock.

Source: Greenland Fishing License Control (2018), License Register, Nuuk, Greenland, NAFO/ICES Pandalus Assessment Group (2017).

The number of licensed vessels dropped from 78 in 2002 to 28 in 2017, corresponding to a reduction on two-third. In 1993 the number of coastal vessels holding a license for shrimp fishery was 131, of which 119 were active (Directorate of Fisheries, Hunting and Agriculture 1994). That corresponds to a 82% decrease in number of active vessels from 1993–2017. The number of offshore vessels was also substantially higher at that time. Hence, a large reduction of the shrimp fleet is observed since the introduction of ITQs starting with offshore vessels in 1990 and continuing with coastal vessels in 1997. In 2002–2017, the fleet reduction in the two vessel groups is largely the same.

Total catches at the West Greenland shrimp stock are fully taken by Greenlandic vessels, except for a minor Canadian catch in the Baffin Bay in some years and a minor catch by one Danish vessel. The catch is increasing until 2000, at a stable high level in 2005–2008 and decreasing afterwards, although the catch increases again in 2016.

The continued fleet reduction over the period in both fleet segments might be explained by the diminishing resource base until 2015. However, the continued technological development and productivity growth are also gradually making the two fleets more efficient. The fleet adjustment is also made easy by the presence of ITQs, where it is possible for some vessels to buy other vessels out.

The account data in Table 5 are available for 86% of active coastal vessels, 56% of off-shore vessels and from half the factories. Based on this, total numbers for each fleet segment and for the shrimp factories are found by upscaling. Turnover is after payment of the EUR 14 Million by the off-shore vessels. Opportunity cost of labour is identified as the annual salary a fulltime fishermen/shrimp factory worker can achieve if they stop in the fishing industry and have a job in another sector. It is approximated to the annual salary of an unskilled industrial worker at land at EUR 40,000. Opportunity cost of capital is identified as 6% of the assets excluding the value if fishing rights.

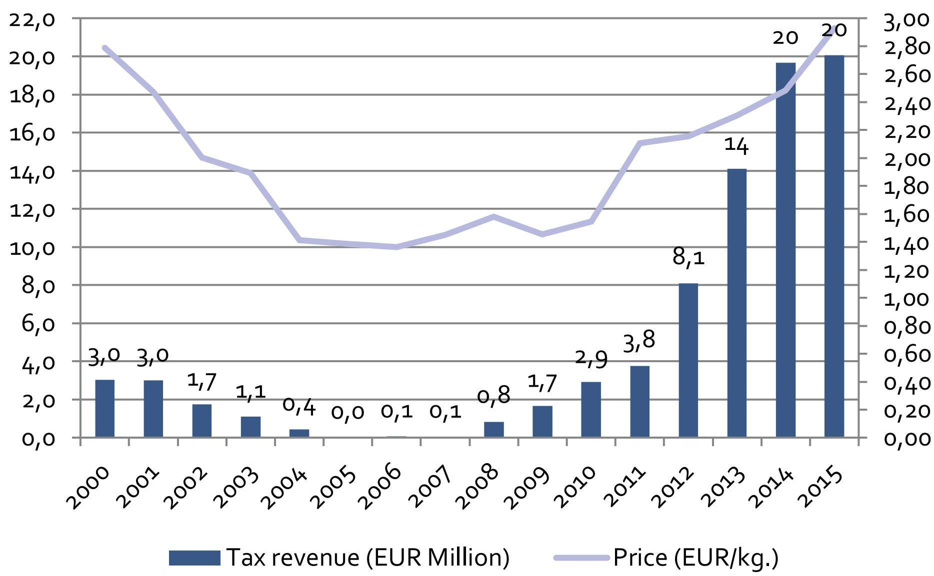
Profits are with EUR 38 Million, corresponding to 25% of the landing value, high for the off-shore production trawlers. For both coastal vessels and factories profits are largely zero. Hence, the profit numbers confirms the finding of former studies that the profit of the shell shrimp value chain is substantially higher than for the peeled shrimp value chain.

Socio-economic return measures "The net-surplus that, at a given time, remains for the remuneration of capital and labour above the rate that is achieved in other businesses including extraordinary taxes paid." The definition appears from Nielsen *et al.* (2012) with taxes added. The socio-economic return is calculated as turnover minus fuel costs minus variable costs minus fixed costs minus opportunity costs of labour minus opportunity cost of capital minus extraordinary taxes paid. In economic terms the socio-economic return is the sum of the resource rent and the producer surplus. While profit measures the net return a company have from their fishery, socio-economic return measures the net return a society have on the existence of a fishery, more than if labour and capital had been used in other sectors.

The socio-economic return is for the off-shore trawler with EUR 78 Million, 51% of the landing value, higher than profit. The reason is that actual cost of labour exceed the opportunity cost, i.e. that the crew on off-shore vessels have a higher salary than could have achieved in other sectors, and that off-shore vessels pay a shrimp tax of EUR 14 Million. For coastal vessels and factories, the socio-economic return is also higher than profit, but it remains close to zero. As for profit, the socio-economic return in the shell shrimp value chain is well above in the peeled shrimp value chain.

The shrimp tax was introduced in 1991 together with ITQs for off-shore vessels. The first year, EUR 17 Million was collected in tax revenue. However, pressure from the industry lead to a substantial reduction in the tax starting the following year and continuing (Ministry of Finance (2017). In Figure 4, the development in tax revenue in 2000–2015 is shown. Since the tax rate increase with shrimp prices, the development in prices is also presented.

Figure 4: Revenue collected by the Government of Greenland as taxes on shell shrimp and shell shrimp prices, 2000–2015

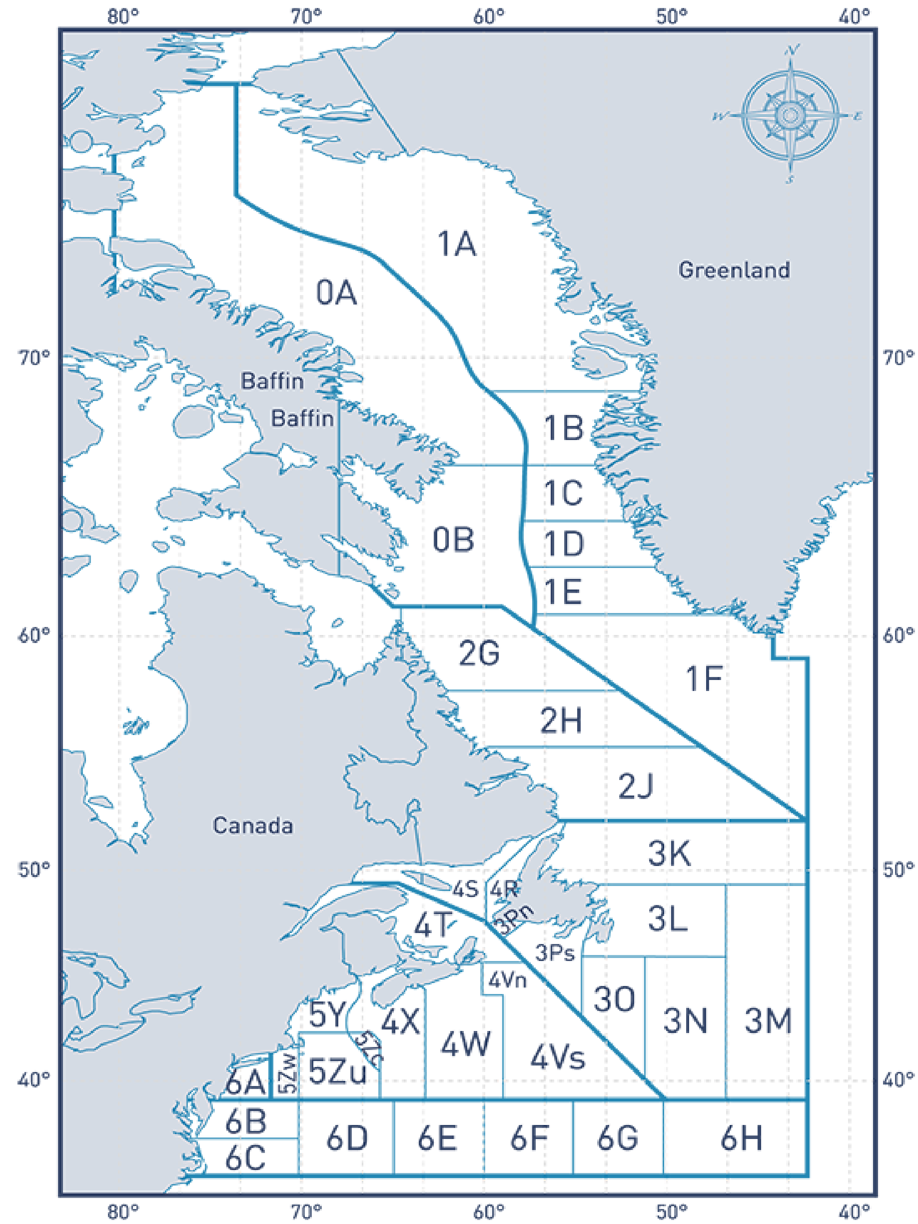


Source: Tax data are from Greenland Home Rule (2009) and Ministry of Finance (2017), while price data are from Statistics Greenland (2018a).

In 2012–2014, the shrimp tax revenue was on average EUR 14 Million, corresponding to 9.1% of the catch value for the offshore production trawlers. The shrimp tax also increase in 2015 and 2016. The shrimp tax revenue has become an important source of income for the Government of Greenland. The tax revenue follows the price development for shell shrimp. When prices are low, no taxes are collected, while tax revenue increase together with the price increases over the period 2010–2015. Prices on shrimp are formed on a world market in competition with cold-water shrimp from Canada and farmed warm-water shrimp from e.g. Ecuador and Asia. Both reduced catches from Greenland and Canada, and reduced growth of warm-water shrimp farming contribute to explain the price increase and, thereby, the increase in tax revenue.

The West Greenland shrimp stock is considered as one single population covering the whole West Greenland area (NAFO Subarea 0/1), as shown at the map in Figure 5.

Figure 5: Map of fishing areas at West Greenland



Source: NAFO (2018).

The Greenland fishery exploits the stock in Subarea 1 (Division 1A–1F), where the Canadian fishery since 1981 has been limited to Division 0A. The Total Allowable Catch is set by the Government of Greenland founded in biological advices from NAFO made by the NAFO/ICES Pandalus Assessment Group (2017). The Total Allowable Catch includes an amount unilaterally allocated for Canadian fishing. Key indicators for the status of the main West Greenlandic shrimp stock are presented in Table 6.

Table 6: Status of stock, fishing and management of the West Greenland shrimp stock, 2015

	Spawning stock biomass[1]		Total Allowable Catch[2]	Fishing mortality[3]
	Current	MSY		
Northern shrimp (tonnes)	248,100	178,500	93,400	The probability that Z exceed ZMSY is 15.5%.

Note: 1. Spawning stock biomass is the fishable biomass (>17 mm) for the whole West Greenlandic shrimp stock.
2. The Total Allowable Catch is for the whole West Greenlandic shrimp stock.
3. Z measures the shrimp mortality caused both by fishing and cod predation. The risk of the total mortality exceeding the mortality corresponding to the MSY, ZMSY, is estimated to be 15.5%.

Source: NAFO/ICES Pandalus Assessment Group (2017).

The current spawning stock biomass is about 40% above the spawning stock biomass corresponding to the MSY. The shrimp mortality from fishing and cod predation face a minor risk of exceeding the mortality corresponding to the MSY on 15.5%. Thus, the current spawning stock biomass is at a sustainable size, while shrimp mortality faces a minor risk of not being sustainable. The West Greenlandic shrimp fishery certified for being sustainable by the Marine Stewardship Council.

Founded in the situation in 2012–2014, projections on the expected development in 2016–2025 are presented in the next section.

4.5 Results

The development in the shrimp fishery is forecasted until 2025 using the method described in chapter 3 in four scenarios and compared with the initial situation in 2015. The four scenarios for the Greenlandic shrimp fishery are:

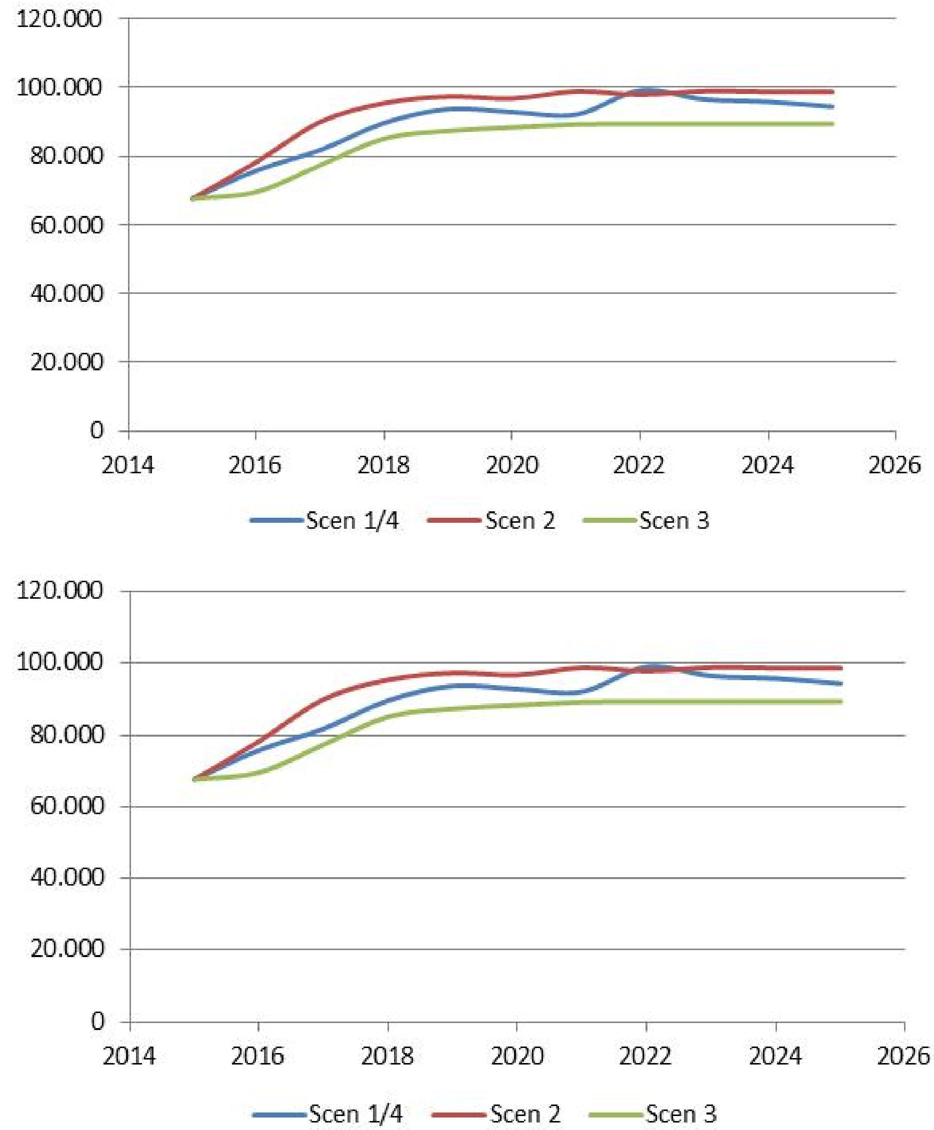
1. Current management in Greenland: ITQs with coastal trawlers not allowed to sells to offshore trawlers and a 4% limit on yearly adjustment in number of vessels in each segment;
2. Free ITQ trade between all shrimp trawlers and a 4% limit on yearly adjustment in number of vessels in each segment;
3. Current Greenlandic management with no limit on yearly fleet adjustment;
4. Current Greenlandic management with a 4% limit and 10% extra taxes on the landing value.[3]

[3] While the shrimp tax revenue in the base period formed 9.1% of the landing value, scenario 4 impose an extra tax on 10% of the landing value excluding the initial tax revenue. Hence, scenario 4 assesses the effect of an 18.3% tax on the initial landing value, corresponding to twice the level in the base period.

Two forecasts are made for each scenario, i.e. (i) the total socio-economic return is maximized over time with the results being presented in Table 7 and (ii) total profit of the fleet is maximized with the results in Table 8. The net present value of all future earnings is maximized through variation in number of vessels and days at sea per vessel. The forecast results are shown in the Tables for 2025 comparted to the initial situation in 2015. While socio-economic return measures the extraordinary economic contribution of fisheries to the socio-economy, profit is the surplus for the private fishing companies. As opposed to the other country cases, the economic forecasts for the Greenlandic shrimp industry include both fishing and processing.

The biological foundation of the shrimp fishery in the initial situation is shown in Table 6. Future recruitment of shrimp is forecasted by estimating a function where recruitment of shrimp increases in spawning stock biomass until the MSY, after which it falls. This function is identified in a way such that the stock will not come above the maximum observed in the period 1995–2014. Catches are then determined at the MSY level by fleet size and total days at sea, thereby assuming a MSY quota setting policy. The forecasted catches are shown for maximizing socio-economic return (top chart) and for maximizing profit (bottom chart) in Figure 6.

Figure 6: Predicted catches that induce the maximum socio-economic return and profit, 2012–2015, tonnes



The reason for the increase in catches from the initial year is that the stocks were lower in the base period 2012–2014 than over the period 1995–2014 on which the biological forecast is founded. The predicted catches increase over time until 2025 both when maximizing socio-economic return and profit, as well as for all scenarios. The uncertainty of the future recruitment of shrimp also induce uncertainty on the economic forecasts. The relative forecasts between scenarios are, however, not affected by the uncertainty.

The forecasts are made under the following assumptions: i) Prices on shrimp and all inputs to production, such as fuel, salary and interest rate, are assumed constant, ii)

Maximum days at sea per vessels is 270 for coastal vessels and 312 for offshore vessels, iii) Days at sea in the initial year 2015 scaled down to ensure that the known 2015 quota is not exceeded, iv) Maximum catch per vessel per year is restricted to be below a maximum of 2 times the catch per vessel in 2015 and v) the profit maximisation is performed with the expected value of future purchased permanent quota shares included as a cost, identified as the average of quota buyers and sellers willing to pay/accept.

Table 7 shows the forecasts where socio-economic return is maximized in the four scenarios. The Table displays the socio-economic return for the two fleet segments, land-based factories and total, together with the total number of vessels and the total fulltime employment. The total socio-economic return in the initial year 2015 on EUR 69 Million is smaller than in the base period 2012–2014. The same accounts for profit. The reason for the difference is the reduced West Greenlandic shrimp quota in 2015.

Table 7: Forecast of socio-economic return, fleet and employment adjustment in 2025 by maximizing socio-economic return

	Coastal Trawlers	Offshore Trawlers	Land-based Factories	Total
Socio-Economic return (mill EUR)				
2015 initial situation	8	59	1	69
2025 scenarios:				
1. Current management	17	108	3	127
2. ITQ management free quota trade	5	129	2	135
3. Current management full adjustment	15	112	3	129
4. Current management 10% landing	17	108	3	127
Number of vessels/processing (tons)				
2015 initial situation	21	9	35,616 tons[1]	30
2025 scenarios:				
1. Current management	14	7	36%[1]	20
2. ITQ management free quota trade	14	10	3%[1]	24
3. Current management full adjustment	10	7	18%[1]	17
4. Current management 10% landing	14	7	36%[1]	20
Employment (full-time)				
2015 initial situation	203	88	282	573
2025 scenarios:				
1. Current management	135	66	384	585
2. ITQ management free quota trade	135	97	292	524
3. Current management full adjustment	98	69	333	500
4. Current management 10% landing	135	66	384	585

Note: 1. For processing, the total quantity of shrimp peeled at the land-based factories are shown for the 2015 initial situation, while increases in relation to this production in the initial 2015 situation is shown for scenarios 1–4.

The socio-economic return on EUR 69 Million in 2015, reveal a fishery that has been economically well-managed for many years. For off-shore vessels the initial socio-economic return is with EUR 59 Million and 39% of the landing value remarkable. The socio-economic return in 2025 is projected to grow to EUR 127 Million with unchanged management that keeps the current separate management of coastal trawlers and off-shore trawlers. This increase is both due the presumed shrimp stock increase and a continued fleet reduction with the coastal fleet being reduced from 21 to 14 vessels and the off-shore fleet from 9 to 7 vessels. Production on land-based factories increases with 36% in scenario 1, due to the presumed growth in landings. But the socio-economic contribution of factories is in all scenarios close to zero. Employment will remain largely unchanged (rise from 573 to 585), following reductions in fishery and increased employment at factories on shore.

In scenario 2 with free trade of quotas, the socio-economic return is EUR 135 Million, 8 Million higher than in scenario 1. The coastal fleet is reduced to the same degree as in the no-nothing scenario, while the off-shore fleet due to quota purchase from coastal vessels and the presumed increased catches, increase from 9 to 10, instead of fall to 7 vessels in scenario 1. Factories remain almost unaffected, with reduced supply from coastal vessels counterbalanced by landings from off-shore vessels, despite these only land 25% of their catch. Fulltime employment is reduced to 524, 10%, with employment in the coastal fleet falling from 203 to 135, meet by a rise from 88 to 97 on off-shore vessels.

In scenario 3 with full adjustment the socio-economic return in 2025 comes to EUR 129 Million, almost the same as in scenario 1. Hence, the adjustment largely happens before 2025.

Profits from the fleets and factories in the initial year 2015 compared with the forecasted year 2025 is shown in Table 8. Profit is after subtraction of estimated costs of future purchase of quotas (permanent and leases). While socio-economic return measure the surplus for the society as a whole, profit measure the surplus for the companies, after taking costs of quota purchase into account. Profit determines production decisions of companies, implying that the profit scenarios are more realistic than the scenarios for socio-economic return. The reason is that companies take decisions in their own interest, not in the interest of the society.

Table 8: Forecast of profit, fleet and employment adjustment in 2025 by maximizing profit

	Coastal Trawlers	Offshore Trawlers	Land-based factories	Total
Profit (mill EUR)				
2015 initial situation	2	29	0	31
2025 scenarios:				
1. Current management	7	61	1	70
2. ITQ management free quota trade	4	67	1	72
3. Current management full adjustment	6	64	1	71
4. Current management 10% landing tax	6	51	1	58
Number of vessels				
2015 initial situation	21	9	35,616 tons[1]	30
2025 scenarios:				
1. Current management	14	7	31%[1]	20
2. ITQ management free quota trade	14	9	17%[1]	22
3. Current management full adjustment	8	7	9%[1]	15
4. Current management 10% landing tax	14	7	31%[1]	20
Employment (full-time)				
2015 initial situation	203	88	282	573
2025 scenarios:				
1. Current management	135	66	369	570
2. ITQ management free quota trade	135	85	332	552
3. Current management full adjustment	82	70	308	460
4. Current management 10% landing tax	135	66	369	570

Note: 1. For processing, the total quantity of shrimp peeled at the land-based factories are shown for the 2015 initial situation, while increases in relation to this production in the initial 2015 situation is shown for scenarios 1–4.

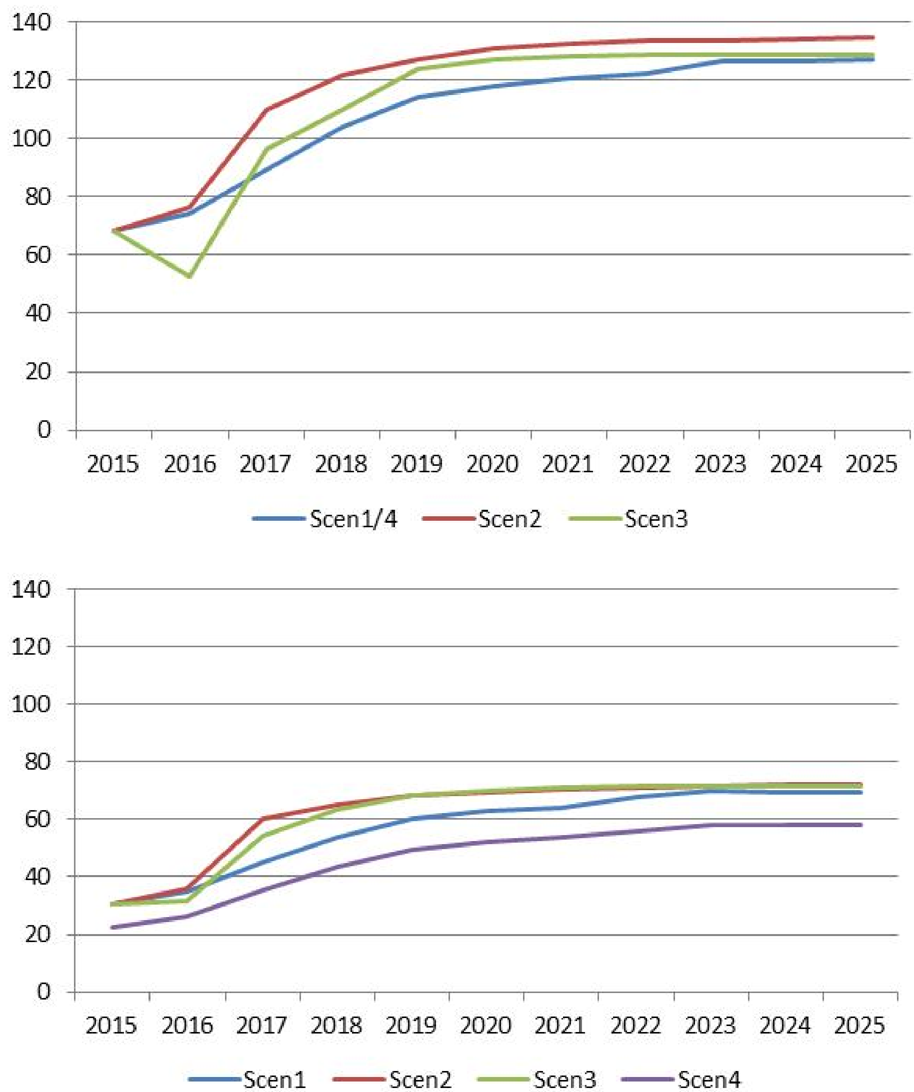
Profits in 2025 are lower than socio-economic return, due to high salary in shrimp fishing and the shrimp tax. Just as for socio-economic return, profit in scenario 1 increase substantially, while fleet and employment is reduced. In scenario 2 with free trade of quotas, the same profit effects are seen as for socio-economic return, although profit change lees than socio-economic return. The offshore fleet includes 9 vessels for profit instead of 10 for socio-economic return, with the same effect on employment on these vessels. Factory activity and employment is reduced, as opposed to being unchanged for profit, since offshore vessels have to pay for quotas and, therefore, buy lesser quotas from coastal vessels.

Profit under full adjustment develops in the same direction as for socio-economic return, although the coastal fleet and employment at coastal vessels is reduced more and employment at factories is lower, which follow from higher costs of labour and quota purchase costs.

When introducing an extra tax on 10% in scenario 4, profit is reduced from EUR 70 Million to EUR 58 Million, i.e. with EUR 12 Million. Both the fleets and employment remains unaffected in relation to scenario 1. Since the forecasts of profit and socio-economic return further leads to exactly the same fleet size, the extra tax can be imposed without any effect on societal wealth.

The results above are analysed for one year, 2025, but the effect comes gradually over time. Figure 7 displays the development over the forecasted decade, respectively for socio-economic return and profit.

Figure 7: Forecast of socio-economic return (top) and profit (bottom) 2015–2025, EUR Million



The trends shown are similar to the final 2025 results. Free quota trade gives the largest socio-economic return over the full period. The current management is lowest for socio-economic return from 2017 and onward, while the full adjustment scenario is lowest until 2017 and in between afterwards. Hence, the speed of adjustment is slowest in scenario 1. The same situation accounts for profit, except for that the tax scenario gives the smallest profit over the whole period, since the companies have to pay the tax. The adjustment appears similar for each scenario for socio-economic return and profit.

Where socio-economic return is a societal measure, profit is the company measure that determines the decisions by companies. Hence, with fleets developing very similar when forecasting socio-economic return and profit, the more realistic results appearing from profit maximization largely leads to the best possible situation for society in each scenario. Thus, the ITQs ensure that the contribution from the shrimp fishery to the Greenlandic economy is as large as possible under the circumstances.

4.6 Policy considerations

The Greenlandic shrimp fishery has been managed with ITQs since 1991. The fishery is well-managed ensuring biological sustainability and the management is mature in having allowed the industry to consolidate and increase efficiency. The number of vessels and employment has been substantially reduced over many years and fewer and larger companies remain. The forecasts support that this development is not over, even without changes in policy settings.

The fishery supply land-based factories. Coastal trawlers land all their catches to peeling factories, while offshore trawlers process 75% onboard and supply the remaining 25% to land-based factories. Coastal trawlers and factories are labour intensive, offshore trawlers are capital intensive.

The debate of the future policy for the Greenlandic shrimp fishery goes in three different lines of arguments, on top of keeping the management unchanged. Some argue that the Greenlandic society need more jobs, which can be achieved by letting labour-intensive coastal trawlers and factories takes over from offshore vessels. The new Fisheries Law that was intensively discussed in the Parliament and in the media in 2017 is a step in that direction. Others argue that the shrimp fishery have the ability to increase the contribution to GDP, thereby increasing, but far from providing the full the economic foundation for Greenlandic independence, needing replacement of the annual Danish Grant on at least EUR 500 Million. That argument claims that only the most efficient vessels, offshore vessels, stay active. That is, offshore trawlers must be allowed to buy quotas from coastal trawlers, which furthermore also reduce land-based processing. Finally, a group also argue that the shrimp tax in recent years have grown to a level where Government spending depends on them. That group sees the presence of an efficient fleet as a necessary precondition to be able to increase the shrimp tax, thereby making more public spending possible.

Employment in the shrimp industry can be prioritized politically by reallocating quotas to coastal trawlers from off-shore trawlers. The Bill on the New Fishery Law is a step in that direction, reallocating 7% of quotas. That gives 15 and 12 more employed at coastal trawlers and factories in 2025, while employment falls with 6 persons at off-shore trawlers in the full adjustment scenario. The socio-economic return is reduced by EUR 5 Million.

The Law further provides the legal basis for a policy turn-around, by making it possible to terminate ITQs after a five years notice period. If the Law is adopted, it becomes possible to take the full step and increase employment in shrimp fishery substantially. With all quotas hypothetically given to coastal trawlers, total employment in the industry increase from 585 to 1,210 in scenario 1. Socio-economic return, however, falls from EUR 127 Million to EUR 62 Million, corresponding to EUR 100,000 per extra person employed in the shrimp industry. That makes the Greenlandic society poorer. Moreover, the shrimp tax revenue fall and the Government might be liable to compensate losers of quota. The possible compensation liability remains uncertain and the question may be taken to Court. While the Law introduces a future policy option of notified termination of management, it doesn't suggest use of it for now.

Quota concentration also forms part of the debate. It is argued by some that the rules allow for too large quota ownership by individuals and companies, implying that ownership must be spread. Spreading is assessed to lead to more and smaller vessels, as well as larger employment, while the socio-economic return fall.

Enhancing employment in the shrimp industry does not lead to increased employment in the whole society in the long run, since labourers do not work in a sector where they contribute as much as possible to the national economy. By them working in other sectors where they are more beneficial would make the Greenlandic society wealthier, which also induce full employment in the long run. Hence, where employment in the shrimp sector may increase, employment in other sectors falls in the long run.

The GDP contribution of the shrimp industry can be letting only the most efficient vessels fish. Hence, the off-shore vessels must take quota over from the coastal vessels. In this situation, the ban of quota sale from coastal vessels to off-shore offshore vessels must be lifted and off-shore vessels must be allowed to fish within the 3 nautical mile zone. The free quota trade scenario identifies the socio-economic return to EUR 8 Million larger than in scenario 1, with employment being reduced by 61 persons. That corresponds to EUR 130,000 per person annually.

In a hypothetical long run example where only off-shore vessels are fishing, the socio-economic return can be increased to EUR 156 Million, EUR 29 Million above the level in scenario 1 in 2025. Employment falls to 315 persons, 270 persons under the employment in scenario 1 in 2025. Hence, large gains in wealth can be achieved for the Greenlandic society by implementing a policy of letting the most efficient off-shore trawlers fish at the expense of coastal trawlers. Some further argue that such a policy can play an important role in funding Greenlandic independence.

In scenario 4, company profits are taxed and used to fund public welfare. It is found that increasing the shrimp tax with 10% of the landing value, doesn't affect fleet structure and employment. Profit fall, but Government income rise.

Taxes can be increased more, but only to the level where companies face deficits. Otherwise, they leave fishing and the socio-economic return fall. Under such circumstances, the maximum extra tax revenue that can be collected in 2025 is the full fleet profit of EUR 71 Million under the free quota trade scenario, corresponding to an extra tax rate on 35% of the landing value in 2025. At higher taxes, fleet structure and employment will be affected in the long run, with less surplus prevailing for investments, over time making the fleet older and less efficient.

Since expected future earnings are capitalized in quota values, taxes must be set to avoid deficits of new quota owners. Otherwise, the socio-economic return fall. Taxing without societal losses therefore slowly becomes too late over time, making tax increases an option mainly when profits increase. For example following price and quota increases or policy changes.

With the shrimp stock sustainable exploited, the political tradeoffs is balancing (i) contribution to GDP, (ii) shrimp employment, and (iii) contribution to Government income. All three cannot be achieved at the same time and shifting circumstances and political priorities makes balancing ever-relevant. Revealed by the core role of (ii) and (iii) in the debate following the Fishery Commission in 2009 at a time where alternative jobs was expected in mining. And revealed by the core role of the (i) in the intensive debate on the Bill of the New Fishery Law in 2017 at a time where alternative jobs are difficult to see.

While forecasts can provide good input to the debate on future fishery policies, they are also founded on uncertain assumptions. First, it is assumed that the shrimp stock increase to the average level over 1994–2014 from the low level in the base period. If this doesn't happen, socio-economic return, profit and employment in the shrimp industry are overestimated. Second, the forecasts are made under constant prices. The predicted increase in Greenlandic catches, however, may all other things equal, induces a downward pressure on prices. While shrimp prices are formed on a world market, where Greenlandic and Canadian shrimp are perfect substitutes, and where these also substitute warm-water farmed shrimp (Nielsen *et al*. 2017), a downward price pressure exist. But it is limited. To the extend prices are overestimated, so are socio-economic return and profit. Third, the forecasts depart from that technology in the base period stays unchanged. With technological development happening continuously, for example currently by the introduction of robotics under deck on fishing vessels, socio-economic return and profit are underestimated, while employment in the shrimp industry is overestimated. Fourth, profit after cost of quota purchase is identified as an approximation for changes in quotas, not changes in permanent quota shares. If quotas increase due to biological improvements, the quota values are overestimated. On the other hand, with quota values identified only for quota changes, trade in quotas that appear as person shifts of non-economic reasons (e.g. pensioning), are not taken into consideration. That underestimates the cost of quota purchase. Underestimation of cost of quota purchase results in too low socio-economic return and too low profit and it affects the speed of adjustment. Vise versa for overestimation.

5. Icelandic pelagic and Stern trawler fishery

5.1 Introduction

The objective of this chapter is to forecast structural development of the Icelandic pelagic and stern trawler fleets until 2025. In total there are four segments as both fleets are split into fresh fish and frozen at sea vessels. Predictions and policy considerations are made with a model utilizing fleets current statistical and economic data and status of their target species.

The Icelandic fishing industry has been a paramount part of the nation's economy for a long time. The importance has though declined considerably in the past years, with growth in service and production sectors, but is still above 40% of nation's total value of goods export. Demersal products are thereof around 70% and pelagic products 30% (Statistics Iceland 2017). Icelandic authorities have been for a prolonged period at the forefront of fisheries management by extending the EEZ and to implement individual quotas and ITQs.

The Exclusive Economic Zone (EEZ) was extended in steps from 12 miles in 1952 to 200 miles in 1976. Management of pelagic species was initiated in 1969 with a Total Allowable Catch of Icelandic herring and in 1975 individual quotas (IQ) were announced and in 1980 for capelin. Demersal ITQ management system was established in the year 1984 and in 1990 a uniform system of ITQs covering almost all fisheries in Iceland was established, with almost full transferability of quotas.

Since 1990 the demersal catch almost halved in terms of quantity and the pelagic catch has also halved from year 2000. The adjustments were mostly left to the industry, with consolidation of quotas and scrapping of vessels and factories. Majority of the quotas are held by vertically integrated companies; managing quotas, fisheries and processing facilities. Specialization in fishing and processing is widespread, fleet segments target either demersal species, pelagic species or shellfish. Vessels size has increased and their number decreased. Majority of pelagic catch is landed by 25 vessels and the fleet of stern trawlers consist of 45 vessels which land 50–55% of all demersal catch.

Positive effects are felt in the industry: With less quotas the focus has turned from catch quantity to value maximization and full utilization of the whole fish. Output has risen with use of fully automated processing equipment with latest computer technology. Profitability and efficiency have increased with fleet and factories adjustments. Fishing fee is in force and its value has increased substantially with higher profitability. But, negative are as well felt: Consolidation of quotas, following sales or mergers, resulted in fewer vessels and factories, thus reducing employment opportunities. The transferability also resulted in quota displacements between geographical regions, negatively affecting some fishing communities.

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This chapter contains five sections after this introduction. In section two the structure and history of the Icelandic ITQ management system is discussed. Section three covers the literature review of research concerning Icelandic fisheries management. In section four underlying data and indicators for the analyses in the Icelandic case studies is addressed. Section five goes through model results on forecasted fleets structural development until 2025. Section six concludes the Icelandic case with future policy considerations.

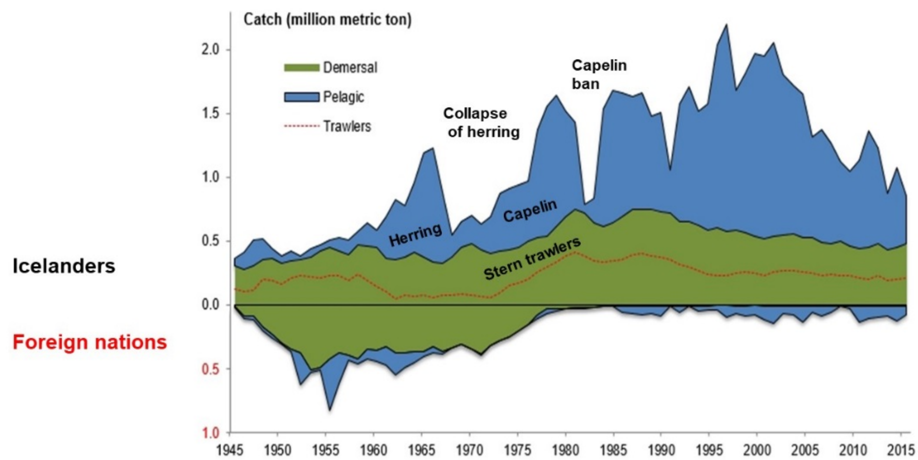
5.2 Fisheries management, catch and the fleet

Fishing around Iceland used to be open access with participation of foreign nations until the 1950s. The Exclusive Economic Zone (EEZ) was extended in three steps between 1952 and 1976. In 1952 it was extended from 3 to 4 miles and as well closing off bays and fjords. The year 1958 saw an extension to 12 miles, increased to 50 miles in 1972. Finally, in May 1976 Icelanders won full jurisdiction over the 200-mile EEZ, thus fully controlling their fishing grounds (Hannesson 2004).

5.2.1 Catch in Icelandic waters

Catches on the pelagic fish herring increased rapidly late 1950s and reached a peak of 690 thousand tons in 1966, two years later the herring stocks collapsed. In the 1970s production increased again with capelin fisheries. It made up roughly half of total catch in Icelandic waters some years, but the stock has been in low past years. Demersal catch increased during and shortly after WWII until 1960 with larger fleet of smaller boats and sidewinder trawlers. Following the collapse of herring stocks in late 1960s the herring fleet turned toward demersal fisheries which increased the demersal catch substantially. The catch of Icelandic vessels augmented again in the 1970s with introduction of stern trawlers and extension of the EEZ. Their number and share of total catch increased sharply the upcoming years, see area under the red line in Figure 8. Simultaneously, foreign trawlers lose their most important fishing grounds, following the 50 and 200-mile extension of the EEZ. Between 1970 and 1975 the annual average demersal fisheries in Icelandic waters were 765,000 tons; of which foreign catches were 300,000 tons. Demersal fisheries of Icelandic vessels peaked in the 1980s, but since the year 1990 the catch has almost halved in terms of quantity.

Figure 8: Catches of the Icelandic fleet since 1945[1]



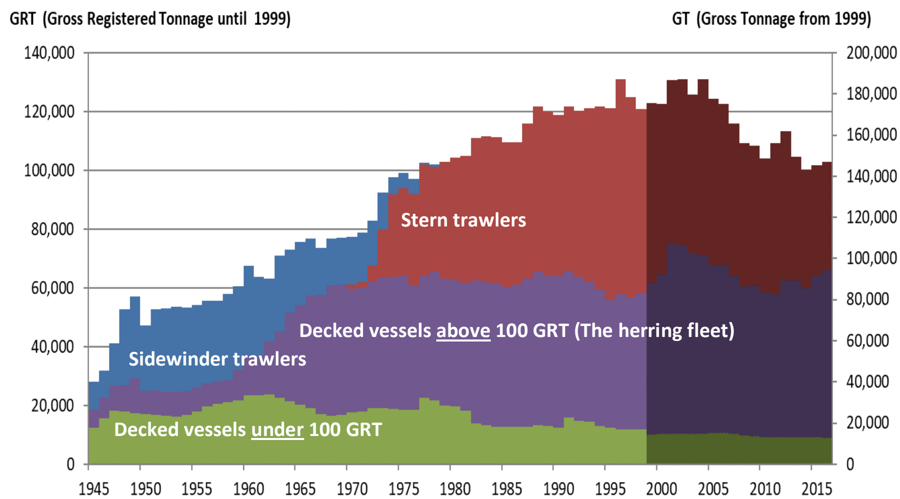
Note: 1. The area under the red dotted line represents trawlers part of the demersal catch. Sidewinder trawlers until the introduction of stern trawlers in the 1970s.

Source: Statistics Iceland (2017b), Jónsson and Magnússon (1997).

5.2.2 The fishing fleet

Excess capacity and overcapitalization characterised the 1970s and early 1980s. The fishing effort of the fleet increased constantly from late 1960s until the year 1977 concurrent with expanding vessel and engine sizes (Runolfsson and Arnason 2001). The previous herring fleet was in lack of projects outside the winter capelin season. This fleet of more than 200 vessels, build or renovated in the 1960s, turned to demersal fisheries with various fishing gears. As well, the stern trawlers replaced the old side winding trawlers build in the late 1940s, see Figure 9. The first stern trawlers began operations in Icelandic waters in 1970, five years later there were 58 fishing in the EEZ. When the nation gained control over Iceland's 200 mile EEZ in 1976, serious concerns were raised that demersal stocks were being overfished, especially the valuable Atlantic cod (*Gadus morhua*) (Palsson and Helgason 1995).

Figure 9: Development in the size of the Icelandic fishing fleet since 1945, GRT to 1998 and GT from 1999



Source: Jónsson and Magnússon (1997), Statistics Iceland (2017c).

5.2.3 Pelagic management

The collapse of the Atlantic herring in 1968 acted as an alarm signal to the nation (Arnason 2005). Management of pelagic species was initiated in 1969 with a Total Allowable Catch of Icelandic herring and in 1975 individual quotas (IQ) were announced, in the wake of a three-year harvesting moratorium. In 1980 quotas for capelin were introduced, after warnings from fisheries biologists at the Icelandic Marine Research Institute which raised concerns of possible overfishing (Matthiasson 2003). In 1986 transferability of annual quotas was introduced and in 1988 consolidation of quotas was allowed among capelin going vessels. Initial allocations in Icelandic herring and capelin fisheries were divided between vessels participating in the fisheries the prior year and with an active fishing licence in those species; that is, not based on previous catch history. Today when fishing of new species commences (pelagic, demersal or crustacean) it often starts with some form of open access, with or without Total Allowable Catches, individual quota allocation then relies on each vessel catch performance the previous three fishing periods. (Ministry of Industries and Innovation 2014).

5.2.4 Demersal management

Various forms of fisheries restrictions have been applied in demersal fisheries. From 1977 to 1983 effort limitations were in force, principle of this system was to reduce fishing effort. In 1983, when the cod stock was in decline, the effort limitations were abolished as fishing effort and fleet capacity had been rising while number of days at sea contracted (Runolfsson and Arnason 2001). Then Iceland's Althing (national parliament) voted on and accepted a demersal management system with ITQs, according to which each vessel's allocation was based on catch performance between 1981 and 1983. The initial demersal quotas were allotted in 1984, with quotas being partly transferable by authority of the Ministry of Fisheries. Between 1985 and 1987 an effort option was active which offered vessel operators an opportunity to boost their share of the initial allocation. This system remained in force until 1990, although vessel allocations could not be increased after 1988. The effort system made it difficult to limit total available catches in some species (Runolfsson and Arnason 2001, Arnason 1993).

Vessel renewals or enlargements were integrated into the 1984 demersal ITQ management. All vessels fishing in Icelandic waters in 1983 received fishing licences, indicating gross registered tonnage (GRT). New licences were not issued unless a vessel of similar size in GRT was decommissioned. However, vessels added to the fleet prior to 1 January 1986 could be enlarged, under certain conditions, until 1997. If a vessel was to be renovated, by import or newbuilding, the renovation GRT was restricted to vessel size registered 1 January 1985. All newbuilding/import of vessels, therefore, needed additional GRT from a vessel within the current fishing fleet; that is, GRT had to be bought. Restrictions controlling total fleet capacity were abolished in 1999; then renovation/newbuilding of vessels could be carried out without additional cost (Runolfsson and Arnason 2001, Lög um stjórn fiskveiða nr. 38/1990, Runolfsson 1999). Since then the fleet has been gradually modernized with the import of both newly built and used vessels.

5.2.5 1990 Uniform fisheries management

The uniform system of ITQs established in 1990 covered almost all fisheries in Iceland. It combined fundamental laws and management regarding fisheries into a comprehensive Fisheries Management Act (No. 38/1990), which entered into force in 1991. Since then legislation relating to demersal, pelagic and crustacean species is combined into a single Act, allowing the majority of ITQs to be almost freely transferable; a move which has motivated the consolidation of fishing rights. Smaller boats below 10 GRT were outside the demersal ITQ system between 1984 and 1990; during this period their number rose sharply (Runolfsson 1999). Boats below 10 GRT were outside the ITQ system from 1984, but were included in 1990 (Ministry of Industries and Innovation 2014). Smaller boats less than 6 GRT were left out and only permitted to catch with hooks and lines. The majority of these boats were integrated into the ITQ system in two steps; in 2001 and 2004.

5.2.6 Current management system

The structure of the Icelandic ITQ system is still like the initial uniform system implemented in 1990. The fisheries act was reformed in 2006, resulting in the current Fisheries Management Act No. 116/2006. According to the Fisheries Management Act, the total allowable catch is issued annually by management of the Ministry of Fisheries, having obtained recommendations from the Marine Research Institute. The Total Allowable Catch is valid for one fishing year, a twelve-month period commencing 1st

September annually. All species subject to the system are issued a Total Allowable Catch. Finally, the annual vessel catch quota (harvesting right) is issued by the Directorate of Fisheries, based on a vessel's share of the current Total Allowable Catch (permanent quota share). The annual and permanent quotas for each species are divisible and transferable among vessels with fishing licences (Ministry of Industries and Innovation 2014).

All entities participating in commercial fishing in Icelandic EEZ need fishing permit. The permits are split into two types; a general catch quota and a hook-and-line catch quota. Each vessel may only hold one type of fishing permit each fishing year. In general hook-and-line catch quotas may only be used for longline and hand-line fishing, two months of the year they can use gillnets for lumpfish fishing (Ministry of Industries and Innovation 2014). The catch from vessels with hook-and-line catch quotas is made up of demersal species. The recent fishing years, vessels with general catch quotas have been allocated about 90% of the quotas, calculated in cod-equivalent kilos.[4]Vessels with hook-and-line catch quotas are allocated the remaining 10%, but this fleet has more than 17% of the total issued quota of Atlantic cod (Directorate of Fisheries 2017a).

The vessels with current hook-and-line catch quota were outside of the 1984 demersal ITQ management, this fleet mainly targets demersal species. In 1990 the size of these vessels where 6 GRT, in 2002 the size was increased to 15 GRT and in 2014 it was extended to 30 GRT and maximum length 15 meters. The hook-and-line catch quotas were issued 1996, 2001 and 2004, since then all segments of the Icelandic fleet have been issued ITQs, later (2009) an open access costal jigging system was installed. Restrictions are valid in quota trade between vessel with general catch quotas and vessels with hook-and-line catch quotas. The hook-and-line vessel can freely transfer quotas within their system and from vessels with general catch quotas. However, to prevent consolidation of fishing rights the hook-and-line quotas cannot be transferred to vessels with general catch quotas.

In 1998 a maximum quota share was introduced which restricts a company's quota allowance, commonly named a "quota ceiling". The ceiling was introduced to reduce the ongoing quotas consolidation and to prevent a handful of firms controlling all fishing in the country. The current maximum quota share is 12% of the total issue quota in cod-equivalents kilos. For individual species the ceiling is normally 20%, but in certain species it reaches 35%.

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[4] A cod-equivalent kilo is a special conversion factor to assess all species at the same value as cod, which always equals one. All species are calculated by Directorate of Fisheries annually. Example: If the cod-equivalent kilo of haddock is 0.71 it means that 1.40 kilo of haddock equal one kilo of cod (1/0.71), or the value haddock is 71% of value of cod. (Ministry of Industries and Innovation 2014, Directorate of Fisheries 2014a).

5.3 Literature review

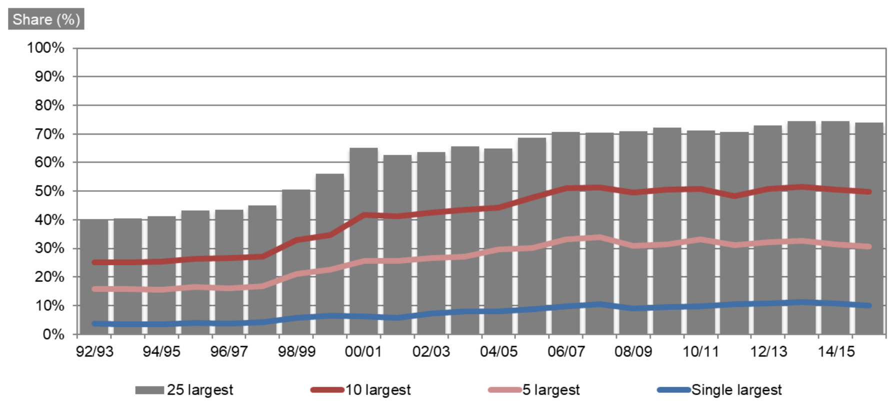
The initial 1980s IQ and later the 1990s ITQ system has been a controversial issue in Iceland. The system has been harshly criticised and different forms of fisheries management have been the subject of intensive political debate. Several matters of opinion have been brought to court and even to the UN Human Rights Committee (Hannesson 2004, Ministry of Industries and Innovation 2010). In 2009 a reconciliation committee was established on behalf of the Ministry of Fisheries to identify matters of dispute and bring forward a proposition regarding a future revision of the 2006 Fisheries Management Act. The committee's report was issued in 2010 (Einarsson 2011). Since then, a major policy review has not yet passed the Althing parliament. Revisions of the fisheries legislation were also carried out by committees in 1991–1993 and 1999–2001 (Ministry of Industries and Innovation 2001, Eythórsson 2000).

The fishing industry has been and still is an extremely important part of the rural economy of Iceland. Since 1984 structural changes have steadily emerged, following the fleet´s efficiency optimization, aiming for reduced harvesting cost and increased profitability (Hannesson 2004, Arnason 2005, Arnason 1993, Runolfsson and Arnason 2001), (Eythórsson 2000, Gissurarson 2000, Arnason 2002, Yagi *et al.* 2012, Christensen, Hegland and Oddsson 2009). Restrictions on quota transferability within the uniform ITQ system were lifted in 1990, encouraging optimization of the industry. Consolidation of quotas, following sales or mergers, resulted in fewer vessels and factories, thus reducing investment and employment opportunities within the industry (Eythórsson 2000, Skaptadottir 2000).

The transferability also resulted in quota displacements between geographical regions, negatively affecting some fishing communities (Eythórsson 2000, Yagi *et al.* 2012, Skaptadottir 2000, Eythórsson 1996, Danielsson 1997). In 1998 a maximum quota share was introduced to restrict a company's quota allowance in terms of total catch share, as well as individual species (Ministry of Industries and Innovation 2014). A few large, vertically integrated companies have strengthened their quota holdings since 1990 (Arnason 2005, Palsson and Helgason 1995, Runolfsson and Arnason 2001), (Eythórsson 2000, Bjorndal, Child and Lem 2014, Directorate of Fisheries 2017a).

The issue of quota concentration into fewer hands has been on the agenda publicly in Icealnd and within the literature since early 1990. Criticism concerning quota consolidation has been along similar lines regarding the demersal and pelagic industry. Concerns were raised that demersal fishermen were becoming tenants leasing the quotas and reducing their income as the number of smaller ITQ holders fell and the larger companies increased their share (Palsson and Helgason 1995, Eythórsson 2000, Eythórsson 1996). Others maintained that although the number of companies and owners had decreased, the number of shareholders and, therefore, owners had risen parallel with the listing of fishing corporations on the Icelandic stock exchange (Runolfsson and Arnason 2001, Gissurarson 2000, Runolfsson 1997). Listing of fishing companies commenced in 1991 and increased sharply until 1997, peaking with 24 companies in 1999. Majority of these companies were deregistered between 2000 and 2008, primarily owing to mergers and as former owners bought them back. Only one company is listed on the stock exchange in 2015 (Baldursson and Gunnlaugsson 2004, Gunnlaugsson 2014).

Figure 10: Allocation of all quotas in cod-equivalent kilos on the largest companies, 1 September each year[1]



Note: 1. This series represents consolidation of demersal stocks quite well, as it contains all demersal quotas in the extended economic zone issued in the beginning of the fishing year.

Source: Directorate of Fisheries (2017a), Runolfsson (2000).

Less restrictions on quota transferability in the 1990s enabled the industry to rationalize. Since year 1990 the demersal catch almost halved in terms of quantity. Icelandic authorities left it to the fishing industry to adjust to reduced quotas. The quota consolidation measured in cod-equivalent kilos* rose sharply between 1997 and 2000 following prolonged period of reduced quotas, see Figure 9 and 10. Small privately-owned companies were bought or merged with other companies. The buyers often vertically integrated companies; managing quotas, fisheries and processing facilities. The larger companies, as well merged to operate their processing facilities year-round with enough raw material. Since 2007, 25 major companies controlled approximately 55% of the total demersal quotas issued each fishing year. During this three-decade period, the industry focus has as well turned from catch quantity to value maximization; aiming on product quality and full utilization of the whole fish.

The structure of the Icelandic pelagic industry has even changed further. Initial capelin quotas were issued to 42 companies in autumn 1980. Most of the companies were privately owned and only a quarter of them linked to enterprises within the pelagic processing industry. Since year 2000 the pelagic catch has almost halved, following less capelin quotas. Quotas concentrations increased continuously from 1997 to 2007, when the privately-owned companies were bought or merged with other companies, see Table 9. There are only 11 pelagic oriented companies left, as well they manage more than 1/3 of all demersal fishing rights (Directorate of Fisheries 2017a). A maximum quota ceiling is valid for capelin and I-herring and currently three companies reach the maximum 20% ceiling (Ministry of Industries and Innovation 2014). This ceiling will certainly affect future mergers and reductions of companies and quotas, thus restricting further consolidation. Moreover, in accordance with Act 98/1998 only Icelandic nationals and/or entities under the control of Icelandic parties can participate in Icelandic fisheries (Ministry of Industries and Innovation 2014).

Table 9: Pelagic companies' consolidation, capelin as the fundamental species

Year	Companies	Capelin	I-herring	A-herring	Blue Whiting	Mackerel
1982	41	100%	-	-	-	-
1992	33	100%	18%	-	-	-
2002	26	100%	88%	97%	99.7%	-
2012	11	99%	99%	100%	100%	82%
2012	8 Major	94%	93%	92%	86%	68%
2012	5 Major	74%	71%	63%	62%	53%
2012	3 Major	55%	53%	40%	51%	34%
2012	Largest	20%	20%	13%	5%	13%

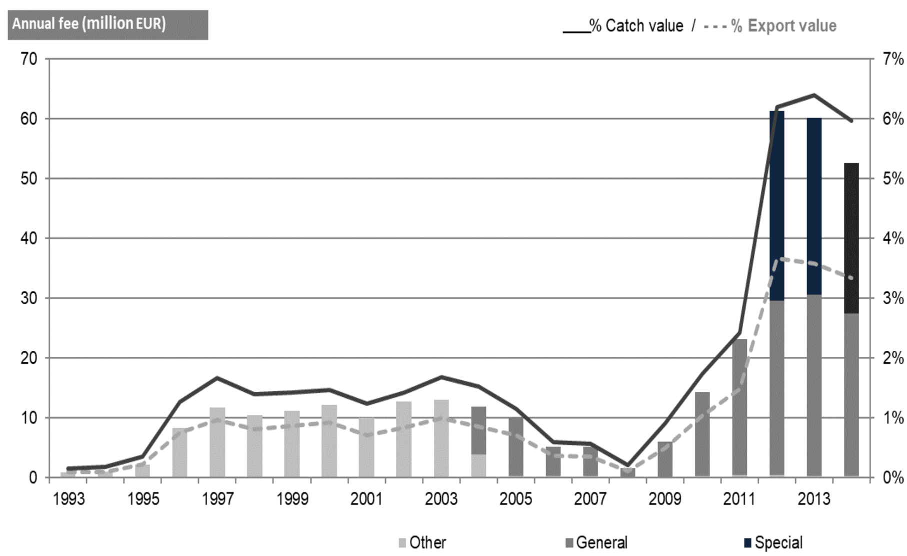
Source: Directorate of Fisheries (2017), Saevaldsson (2014).

Other matters of dispute can be narrowed to three issues in random order:

1. Initial quota allocation and difficult entrance of newcomers: The demersal quotas were allotted in 1984 for free to a restricted number of individuals and companies that owned vessels with active fishing licence. Since then, entrance limitations have applied which has created dissatisfaction (Palsson and Helgason 1995, Eythórsson 2000, Gissurarson 2000). The scarce quotas are expensive (Arnason 2008, Saevaldsson 2007) thus making it very difficult for newcomers to enter the industry unless they are wealthy or have inherited vessels and quotas;
2. Property right and wealth creation by quota trading: In the wake of increased transferability of quotas in 1990 the system created wealth in the form of valuable fishing rights (Hannesson 2004, Eythórsson 1996, Arnason 2008). Holders of quotas gain wealth by selling out their share at a sizable profit. This has created dissatisfaction and given rise to complaints of inequality, uneven distribution of common rights and the privatization of these rights (Palsson and Helgason 1995, Yagi *et al.* 2012, Eythórsson 1996). The opponents of the system cite the first Article of the Fisheries Management Act No. 116/2006, amended in 1988, which states the following: "[T]he exploitable marine stocks of the Icelandic fishing banks are the common property of the Icelandic nation."(Ministry of Industries and Innovation 2014);
3. Fishing fee and property right: The fee was initially set in 2002 but did not become valid until 2004 (Lög um stjórn fiskveiða nr. 38/1990, Matthiasson 2008). It remained below EUR 0.03 per cod equivalent kilo until 2010 when it was increased to EUR/kg 0.04. The fee was raised significantly again in 2012 to EUR/kg 0.06. In 2012 a special fee, based on companies' profit, was levied on top of the normal fee amounting EUR 0.14-0.17 per cod equivalent kilo. In 2013 the special fee was EUR 0.04 for companies in demersal industry and EUR 0.24 for pelagic industry (Directorate of Fisheries 2017b). The size of fees has been a source of friction; the quota holders wanting a minimal fee while others maintain that fees should at least cover the cost of monitoring catches, enforcing management and conducting fisheries research plus a certain amount for the use of common property (Hannesson 2004, Gissurarson 2000, OECD 2011, Matthiasson 2008).The

fishing fee was EUR 52.2 Million in 2014, around 5.9% of fishing vessel ex. catch value and 3.3% of seafood export in goods value (Directorate of Fisheries 2017b). The fishing fee has been an important source of income for the Icelandic government since 2012, constituting of 1.5–1.7% of the total revenue of the treasury, year 2013 and 2014 (Fjársýsla Ríkisins 2017a, Fjársýsla Ríkisins 2017b).

Figure 11: Annual fishing fee and share of catch and export value 1993–2014



Source Runolfsson (2000), Arnason (2008).

To tackle the opposition to the ITQ system various measures have beenw taken. The most important is that some quotas have been allocated to individual communities, following structural changes (Byggdakvoti) (Christensen, Hegland and Oddsson 2009, OECD 2011, Directorate of Fisheries 2017c). In 2003 approximately 0.4% of the total demersal quota was allocated to support rural communities adapting to structural changes. This has grown gradually, reaching around 2.0% in 2015. In addition, the entry of newcomers to the fishing industry has been encouraged since 2009 allowing a certain category of vessels to participate in coastal fisheries using jigging reel only (Strandveidar) (Directorate of Fisheries 2014b). Initially 4,000 tons were allocated to this category, externally to the catch quotas. In 2015 a coastal fishery permit was issued for approximately 8,600 tons in cod equivalents of demersal fish, or around 2.0% of the Icelandic demersal quotas. Finally, quotas have been allocated to longline fisheries, baited onshore with fishing trips lasting no longer than 24 hours (Linuivilnun) (Directorate of Fisheries 2014c). In the past few years, longline fishery permits have been issued for around 5,500 tons in cod-equivalents of demersal fish, or around 1.5% of the Icelandic demersal quotas. The aim of these measures is to bolster employment in outlying coastal communities where much of Icelandic fisheries originated. The above measures were outside the pelagic fishing industry till 2012. Until then no quota had been allocated from pelagic species to outlying coastal communities. This is probably because catching and processing pelagic species is more capital intensive than demersal fisheries. Therefore, it is easier to recommence fishing and processing of demersal species to increase employment in outlying communities participating in structural changes.

5.4 Fleet data

This section describes historical and current statistical + economic data of all four fleet segments of the project, along with introduction of advances in the Icelandic fleet the past years. With less demersal catch in the 1990s and less pelagic quotas from 2000 the industry focus has turned from catch quantity to value maximization and full utilization of the whole fish. Improvements have been made in preservation of the raw material with increased chilling onboard the vessels and in the processing to sustain quality and extend shelf life of fresh and frozen products.

5.4.1 Fleets specialization and increased profit

Specialization in fishing is widespread in Icelandic fisheries, fleet segments target either demersal species, pelagic species or shellfish. Majority of the demersal catch is landed by stern trawlers both fresh and frozen at sea. Stern trawlers are large vessels, normally over 42 meters long, other important groups of vessels are fleet of large long line vessels and the smaller costal fleet. Pelagic fish is normally caught with vessels 60 to 80 meters long, capable of carrying up to 3,000 metric tons per trip in chilled storage rooms. Profitability and efficiency have risen substantially in the industry with fleet and factories adjustments and technology advances. The use of fully automated processing with latest computer technology is widespread. Improvements and innovations in transportation and logistics have as well increased efficiency; with use of temperature controlled containers, better storage boxes and readily available refrigerated warehouses. The availability of air cargo capacity has also greatly increased, supporting a huge rise in the export of chilled fresh fish products.

5.4.2 Icelandic stern trawlers

The first stern trawlers began operation in 1970 when they replaced former fleet of sidewinders trawlers. Five years later there were 58 of them fishing in the EEZ and their fishing effort increased sharply. With the stern trawlers, availability of raw material to demersal processing facilities equalised over the year. Formerly majority of the annual catch was landed by smaller bots during the winter fishing season. Stern trawlers proportion of demersal catch increased sharply to above 50% all total catch. The fleet size was restricted with the 1984 partly transferable quota system. Stern trawlers catch per vessel peaked in the 1980s and reduced almost constantly until late 1990s, when fleets excess capacity was removed. Adjustments were not centralized by authorities, they were mostly left to the companies. The industry has in many ways adapted well. Part of the fleet was converted to freezer trawler in 1980s and 1990s. The uniform ITQ system allowed majority of ITQ to be almost freely transferable, which led to consolidation. Since then number of trawlers and companies have decreased almost constantly. From 2010 the processing of fresh fish in land based facilities has increased at the cost of frozen at sea vessels. Catch per vessel has increased sharply the past years to 5,000 tons in year 2015.

Table 10: Fleet of stern trawler, fresh and frozen at sea, and their precursor sidewinder trawlers

	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015
Stern trawlers										
Fresh fish vessels	3	58	87	102	109	65	51	36	29	26
Frozen at sea vessels				7	29	47	33	29	28	19
Total stern trawlers	*3*	*58*	*87*	*109*	*138*	*112*	*84*	*65*	*57*	*45*
Annual catch	600	172,000	377,000	342,000	371,000	278,000	26,600	275,000	23,600	225,000
% All demersal catch	0.1%	39%	56%	57%	54%	53%	53%	53%	51%	49%
Catch per vessel	*200*	*3,000*	*4,300*	*3,100*	*2,700*	*2,500*	*3,200*	*4,200*	*4,100*	*5,000*

Sidewinder trawlers		
Fresh fish vessels	22	6
Total side winder trawlers	*22*	*6*
Annual catch	80,000	11,000
% All demersal catch	17%	2%
Catch per vessel	*3,700*	*1,700*

Source: Statistics Iceland (2017).

5.4.3 Pelagic going vessels

Until mid-1990s the only pelagic species in Icelandic waters were capelin and Icelandic summer spawning herring. The capelin normally has more than 80% of the annual pelagic catch. Since 1995 three other pelagic species have entered the Icelandic EEZ; blue whiting, Atlanto-Scandian herring and Atlantic mackerel. Initial quotas in capelin were issued in 1980 and simultaneously, vessel size was restricted; i.e. vessels could not be added to the fleet without vessels of equivalent size being decommissioned. Restrictions controlling total fleet capacity were abolished in 1999. Transferability of permanent quotas was allowed among capelin going vessels in 1988. Then consolidation of quotas started and the number of vessels declined as companies merged vessels quotas. In 1990 the pelagic fleet merged to the uniform system of ITQs, with almost full transferability. The years between 1995 and 2005 were record years in terms of pelagic catch. The number of vessels increased until 2000, however, since then fleet size has declined sharply in numbers with less quotas. Pelagic companies have adjusted to these changes; number of vessels and fishmeal factories have been scrapped since 2005. At the same time, positive effects have followed by increased processing directly for human consumption, the industry aiming for value instead of quantity.

Table 11: Fleet of pelagic going vessels , fresh and frozen at sea

	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015
Pelagic vessels										
Fresh fish vessels	63	107	53	52	44	43	47	30	18	20
Frozen at sea vessels							3	10	8	5
Total pelagic vessels	*63*	*107*	*53*	*52*	*44*	*43*	*50*	*40*	*26*	*25*
Average vessel capacity (tons)	280	290	710	760	840	830	1,050	1,400	1,650	1,800
Annual catch	243,000	535,000	827,000	1,043,000	757,000	1,000,000	1,439,000	1,136,000	596,000	845,000
Catch per vessel	*3,900*	*5,000*	*15,600*	*20,100*	*17,200*	*23,300*	*28,800*	*28,400*	*22,900*	*33,800*

Source: Statistics Iceland.

Statistical and economic data of fleet segments utilized in the model are displayed in Table 12 as average of 2012–2014 numbers. The fleet consist of two groups; demersal and pelagic fleet which are then further divided into two sections; fresh and frozen at sea. Demersal fresh fish vessels focus on cod, while vessels with frozen at sea is more equally distributed among other species. It is similar for the pelagic fleet; frozen at sea focuses at Atlantic mackerel, while fresh fish vessels target capelin.

Table 12: Overview of fleets data per vessel, i.e. input to model

Average 2012–2014	Demersal trawlers Fresh fish	Demersal trawlers Frozen onboard	Pelagic vessels Fresh fish	Pelagic vessels Frozen onboard
Physical data				
Full Time Employment (per vessel)	23	48	15	43
Number of vessels	27	25	21	6
No. of Sea Days per vessel	195	232	71	142
Most important species NS (value)	COD (51%)	COD (23%)	CAP (39%)	MAC (38%)
Second important species NS (value)	POK (10%)	POK (12%)	MAC (19%)	CAP (19%)
Third important species NS (value)	HAD (8%)	HAD (6%)	HER-vasu (16%)	HER-noss (18%)
Account data (1000 EUR per vessel)				
Turnover	4,671	9,842	6,132	16,980
Fuel Costs	575	1,384	973	1,808
Crew costs	1,728	3,838	2,085	6,622
Variable costs	1,073	1,809	1,251	3,420
Fixed costs	331	579	532	1,757
Capital costs	226	391	478	823
Opportunity labour cost/employee	48	48	51	55
Opportunity capital cost, 6%	241	414	515	873
Estimated tax revenue	271	571	356	985
Profit	737	1,841	812	2,549
Socio-economic return2	1,937	4,339	2,353	7,503

Note: 1. Tax revenue is estimated as a fixed percentage of taxes paid by the whole Icelandic fishing fleet in 2013–2014, which formed 5.8% of the turnover.
2. The socio-economic return = turnover – fuel costs – variable costs – fixed costs – opportunity costs of labour – opportunity cost of capital – extraordinary taxes paid.

Table 13 shows the status of the fishing stocks included in the analysis.

Table 13: Status of stock, fishing and management in Iceland, 2015

2015	SSB (tonnes)	TAC (tonnes)	F-MSY*
Cod	533,000	216,000	0.20
Haddock	87,450	30,400	0.20
Pollock	135,000	58,000	0.20
Capellin	460,000	580,000	0,32
Herring vasu	346,000	82,200	0.10
Herring noss	5,264,000	328,000	0.35
Blue Whiting	4,292,740	1,260,000	0.20
Mackerel	4,886,564	1,229,000	0.15

Note: SSB is Spawning Stock Biomass, TAC is Total Allowable Catch and F-MSY measure fishing mortality at MSY of the stocks included in the analysis. All F-MSY are currently at sustainable level.

5.5 Results

As described in the introduction of this report 4 forecast scenarios are considered, the results of which in 2025 are compared with the initial situation in 2015. The specifics for the Icelandic case/management is:

1. Current Icelandic management: ITQs between but with no trade between stern trawlers and pelagic vessels (except mackerel that can be traded from stern trawlers to pelagic vessels). 4% limit on yearly adjustment in number of vessels in each segment;
2. Free ITQ trade of all species between all fleet segments. 4% limit on yearly adjustment in number of vessels in each segment;[5]
3. Current Icelandic management with no limit on yearly fleet adjustment;
4. Current Icelandic management with a 4% limit (as in scenario 1) and extra taxes on 10% of the landing value.[6]

Two forecasts are made for each scenario. First the total socio-economic return is maximized over time with the results being presented in Table 14, while total profit of the fleet is maximized with the results in Table 15. The net present value of all future earnings is maximized through variation in number of vessels and days at sea per vessel. The forecast results are shown in the tables for 2025 compared to the initial situation. 2016 represent the initial year since haddock "choke" the results, meaning that if trade limits are maintained the vessels need to reduce their effort in the first year

[5] Note that demersal fishing with pelagic vessels is technically infeasible. Hence, forecasts are made under the limitation that stern trawlers of fresh and frozen fish can only trade quota with each other, and trade mackerel quota with pelagic vessels. And pelagic vessels of fresh and frozen fish can only trade with each other and trade mackerel quota with pelagic vessels.

[6] While the shrimp tax revenue in 2013-2014 period formed 5.8% of the landing value, scenario 4 impose an extra tax on 10% of the landing value.

considerably to keep within the quota limits both for stern trawlers and pelagic vessels. Moreover, catch opportunities are predicted to be reduced in 2015, as well as the Icelandic fleet has taken more than the haddock Total Allowable Catch in the years leading up to the modelling. Hence, comparison of 2016 with 2025 gives a more realistic development than comparing 2015 and 2025. Where socio-economic return measures the extraordinary economic contribution of fisheries to the socio-economy, profit is the surplus for the private fishing companies.

The biological foundation of the forecasts is for the main species haddock, capelin, herring, mackerel and whiting founded on the estimation of functions where recruitment of fish increases in spawning stock biomass until the MSY, after which it falls. This function is identified in a way such that the stock will not come above the maximum observed in the period 1995–2014. Catches are then determined at the MSY level by fleet size and total days at sea, thereby assuming a MSY quota setting policy. The Total Allowable Catch of capelin is held constant throughout the period, due to lack of information.

The forecasts founded on the estimated recruitment functions gives room for reduced catch opportunities in 2016–2015 compared to the base period 2012–2014. The reason is that catches were at a higher level in 2012–2014 than over the 1995–2014 period the biological forecasts are made. The predicted catches decrease until 2025 both when maximizing socio-economic return and profit, as well as for all scenarios. While future recruitment of fish is subject to uncertainty, the economic forecasts are also subject to uncertainty. The relative forecasts between scenarios are, however, not obsessed with the same uncertainty.

The forecasts are made under the following assumptions: i) Prices on fish and all inputs to production, such as fuel, salary and interest rate, are assumed constant, ii) Maximum catch per vessel per year restricted to 9,000 tons fresh fish (whole round weight) and 12,000 tons frozen fish for stern trawlers, and to 60,000 tons fresh fish and 25,000 tons frozen fish for the pelagic trawlers, iii) the profit maximisation is performed with the expected value of future purchased permanent quota shares included as a cost, identified as the average of quota buyers and sellers willing to pay/accept.

Table 14: Forecast of socio-economic return, fleet and employment adjustment in 2025 by maximizing socio-economic return

	DEM FF_TR	DEM FR_TR	PEL FF	PEL FR	Total
Socio-economic return (mill EUR)[1]					
2016 initial situation [2]	44.65	65.50	20.53	32.72	163.40
2025 results:					
1. Current management	51.85	78.88	32.81	39.23	202.77
2. ITQ management free quota trade	34.92	104.76	48.15	23.56	211.39
3. Current management full adjustment	52.43	89.81	42.97	39.67	224.89
4. Current management 10% landing tax	51.85	78.88	32.81	39.23	202.77
Number of vessels					
2016 initial situation [2]	26	24	20	7	77
2025 results:					
1. Current management	18	17	14	8	57
2. ITQ management free quota trade	18	17	14	4	53
3. Current management full adjustment	12	7	5	8	33
4. Current management 10% landing tax	18	17	14	8	57
Employment (full-time)					
2016 initial situation [2]	596	1,152	302	281	2,331
2025 results:					
1. Current management	413	798	209	344	1,764
2. ITQ management free quota trade	413	798	209	175	1,595
3. Current management full adjustment	279	356	80	351	1,066
4. Current management 10% landing tax	413	798	209	344	1,764

Note: 1. The socio-economic return includes fishing taxes, while the socio-economic return is maximized with respect to socio-economic return excluding taxes.
2. 2016 is used as the base year with 2015 being a model calibration year.

5.5.1 Socio economic return and profit

The Icelandic ITQ system is matured. Trade within the fleet segments represented in this study has been unlimited since 1991. Large gains in profitability are not expected during the coming decade, since the ITQ system has already resulted in consolidation of the fleet. However, Table 14 still shows that with current management (scenario 1) the total social-economic returns increases by about 24%. Still further increases in socio-economic return from this base scenario seem possible if all limits on quota trade are removed and adjustment of the fleet is to its full level (scenarios 2 and 3). The increase for scenario 2 is 4% compared to scenario 1, indicating the cost of the current management on e.g. fleet consolidation are restrictive on optimal fleet development. The model further predicts that full adjustment would result in an increase in socio-economic returns of about 7% compared to scenario 2. The model predicts that consolidation will continue along a similar pattern as already seen during the last decades (see e.g. Figure 9 and Tables 9 and 10). The number of vessels and employees in the fishing sector is set to continue decreasing. The number of freezer trawlers is predicted to continue declining compared to fresh fish trawlers, regardless of scenario. Similarly, the model predicts that pelagic fresh fish vessels will maintain their strong position, with the exception of scenario 3. The comparison of scenarios 1 and 2 is interesting from an Icelandic policy perspective.

Table 15: Forecast of profit, fleet and employment adjustment in 2025 by maximizing profit

	DEM FF_TR	DEM FR_TR	PEL FF	PEL FR	Total
Profit (mill EUR)[1]					
2016 initial situation[2]	20.29	24.61	-1.16	7.77	51.51
2025 results:					
1. Current management	23.03	33.93	10.42	9.22	76.59
2. ITQ management free quota trade	10.52	51.97	15.27	6.06	83.83
3. Current management full adjustment	21.87	-0.10	17.47	8.95	48.19
4. Current management 10% landing tax	18.09	28.87	7.61	5.44	60.01
Number of vessels					
2016 initial situation[2]	26	24	20	6	76
2025 results:					
1. Current management	18	17	14	7	56
2. ITQ management free quota trade	18	17	14	4	53
3. Current management full adjustment	19	0	6	7	31
4. Current management 10% landing tax	18	17	14	6	54
Employment (full-time)					
2016 initial situation[2]	596	1,152	302	281	2,331
2025 results:					
1. Current management	413	798	209	305	1,725
2. ITQ management free quota trade	413	798	209	172	1,592
3. Current management full adjustment	427	5	85	297	814
4. Current management 10% landing tax	413	798	209	238	1,658

Note: 1. Note that profit of sold quota capitalizes in the model and comparison with current situation is difficult.
2. 2016 is used as the base year with 2015 being a model calibration year.

Table 15 shows the development of the fleet under pure profit maximization. The model indicates increases profits, especially for the freezer vessel groups. The overall profits are predicted to increase by 50% over the decade of the study. This is despite the fact that the model underestimates profit, since the model assumes that profits are capitalized in the model as quota is sold during consolidation and decreased vessel numbers. Many companies own more than one vessel and consolidation within company will not lead to capitalization. Therefore actual profits may increase even more. The results point to an important property of ITQ systems – that although quota trade leads to increased productivity, industry profitability does not necessarily increase as capital is shifted to other investments. Socio-economic returns may therefore increase although industry profitability falls, as seen from results in Table 14. The starkest difference is for scenario 3 – full adjustment – where profits fall due to consolidation of quota, where trade leads to substantial capitalization. This case however leads to the largest increase in socio-economic returns and will free up large amounts of capital for investment in other profitable endeavours.

The results in Table 15 support the previous conclusion that current restrictions on quota trade have a negative impact on profitability. Comparing scenarios 2 and 3 indicates that these restrictions have a negative impact on profits of about 9%.

The predicted development is generally similar as for maximization of socio-economic return. The model predicts continued reduction in fleet size and the maintained dominance of fresh fish vessels over frozen fish vessels, especially for pelagics. The extreme is scenario 3, which predicts the disappearance of freezer trawlers.

5.6 Policy considerations

The Icelandic ITQ has had free quota trade within fleet segments since 1991. The system is therefore mature. Most of the consolidation is already done. The data on recent development shows that the ITQ system has allowed the industry to consolidate and increase efficiency. The number of vessels has gone down, as well as the number of factories. It has led to fewer and larger companies, especially in the pelagic sector, and most of the quotas are in the hands of just a handful of enterprises. The model supports that this development is not over.

Quota trade leads to capitalization of profits. This is clearly visible from the results of the model. There are no predicted gains in profitability, but rather reductions. The model predict substantial gains in socio-economic returns from changing current policy. Current Icelandic management sets an upper limit on quota holding that aims to set a limit to concentration, keep ownership spread and maintain domestic competition in the fishing sector. Many companies have reached this limit and it sets a limit to their future growth and therefore overall increases in profitability. The results from the model support that this management comes at a cost. The results suggest that the loss in socio-economic returns is about 4–7% and about 9% in industry profits. Further, relaxing these restrictions will, according to the model free up capital, currently bound in the industry that can be used for other profitable investments.

Iceland has currently a fishing fee system, aimed at capturing some of the resource rent generated by Icelandic fisheries. The amount of the fee is currently 6% of landed value. Scenario 4 is therefore particularly interesting for the Icelandic case. According to the model the impact on fleet development is minimal. Difference between scenarios 1 and 2 and scenario 4 in terms of fleet development is minimal. The model therefore seems to suggest that the impact of the fee is not limiting to fleet development.

Simulations are good exercises to access how economic factors affect development. There are however other forces at play as well, both technical and political. Full relaxation of the limits on quota concentration in Iceland would probably speed up consolidation and create few powerful companies in Icelandic fisheries. The development under such a free system would, in all probability be in the direction predicted by the model. However, the most extreme predictions are probably not technically feasible, such as the complete disappearance of freezer trawlers from the Icelandic fleet. It is not feasible to fish certain fishing grounds and species using only fresh fish trawlers. Also, the political atmosphere in Iceland is unlikely to support this development. The fishing industry is the fundamental industry in many rural areas in Iceland and allowing full consolidation will meet with a strong political opposition in Iceland. It is, however, very useful to have an estimate of the cost of current restrictions so that the benefits to local communities can be compared to the costs such policies are likely to have.

6. Danish Demersal fishery in the North Sea

6.1 Introduction

The purpose of this chapter is to forecast the development in the Danish demersal fishery in the North Sea until 2025 with the current management, and to assess the effects of possible future policy changes approaching 2025.

ITQs was introduced in the Danish fishery for herring in 2003, followed by other pelagic stocks in 2004. In 2007, ITQ management was implemented for the remaining fleet covering the demersal species. Hence, ITQs prevail today for all commercial active vessels. The reason for introducing ITQs was to adjust the Danish fishing capacity to the catch opportunities, making the fisheries more sustainable both from a biological and economic point of view. The ability of the system to improve vessel economy and remove earlier overcapacity seems broadly acknowledged and accepted today. However, the debate on how the fish resource should be distributed among fishermen to avoid concentration has recently received some attention. However, the question of using other regulatory systems than ITQs has not filled much in the public debate.

Since the introduction, a continuous debate about special arrangement for small scale coastal vessels has been the main focus of the debate. Thus, the coastal fishery arrangement has been revised several times. For the large vessels the issue of concentration of quotas has gained strong public attention after this issue was debated in a report from the Danish Parliamentary Auditors in 2017. Hereafter new rules have been implemented on concentration. Taxation of fishing rights has also been suggested as part of the solution in 2018.

The demersal fleet in the North Sea is chosen, since it consists of small, medium and large sized vessels that use both trawl and nets. Therefore, it is well suited to reveal and debate main concerns of Danish fishery management today.

This case study is performed[7] by Ayoe Hoff, Rasmus Nielsen, and Max Nielsen, Institute of Food and Resource Economics, University of Copenhagen, Denmark.

In the following, a literature review of studies assessing fishery policy reforms in Denmark over the last decade is provided in section 2, while section 3 describes management of Danish fishery. Section 4 present data and section 5 the results of the scenarios. Section 6 concludes the Danish case with policy considerations.

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[7] Associate professor emeritus Hans Frost has contributed with valuable comments and discussions.

6.2 Literature review

Theoretically, the aim of introducing ITQs in the Danish fishery was firstly to encourage more sustainable exploitation of fish stocks, through adaptation of fishing capacity to existing fishing opportunities. Secondly, the aim was to give individual fishermen improved possibilities to operate and plan their fishery, given their fishing capital and activities. Finally, the aim was to increase and secure the total earnings of the Danish fishery. Andersen *et al.* (2010) used a linear programming model covering the total Danish fishery to investigate possible short and long run effects of ITQs management for the Danish fishery. They predicted that gross profit would increase with between 30 and 38% in the short run, depending on the degree of which quotas can be traded between vessels above and below 18 meters. This increase in gross profit is accompanied by an expected decrease in number of vessels of between 9 and 30%.

Mearyo *et al*. (2018) uses a descriptive approach, analysing the development of the Danish fishery during the period 2002–2014, to investigate economic, social and environmental effects of introducing ITQs in the Danish fishery management. They base their analysis on observed key indicators for the Danish fishing fleet. In line with Andersen *et al.* (2010) a decline in the Danish fleet capacity has been observed, with a reduction of 62% in the number of commercially active vessels between 2002 and 2014, accompanied by a reduction of 68% in number of full-time workers (equivalent) on the commercially active fleet. Correspondingly a decrease is observed of 25% in the total profit of the fleet over the period, resulting from the reduced catch opportunities (reduction in the Total Allowable Catch). However, the profit per vessel increased by 96% over the same period.

Before the introduction of ITQs, Denmark has since 1988 applied decommissioning programs extensively. These programs were designed to alleviate the fishing pressure on stock for which the quotas were reduced and for fleets for which the profitability deteriorated. Hence the decommissioning programs caused a reduction in fleet capacity. Since 1987 until 2003 the number of vessels was reduced by 51% and the gross register tonnage (GRT) and the horsepower were reduced by 40% taking into account the changes in statistical recording and measurement of capacity, see Frost and Kjærsgaard (2002). When the ITQ system was introduced the decommission system was abandoned.

Thus, these studies indicate that the introduction of ITQs led to a continuous reduction in overcapacity, which have been economically beneficial for the remaining fishermen. A question remaining is what happens to the workers that left the fishery. The general unemployment rate in Denmark decreased from 2002 to 2007 but then increased again towards 2014 (Mearyo *et al*. 2018), however with an overall decrease over the period. When examining the unemployment rate in the largest Danish fishing municipalities this has decreased more than the overall Danish average for all municipalities but one, indicating that the redundant fishers should have had possibilities to find alternative employment locally. This is supported by Nielsen *et al*. (2017) who investigate factors that influence why coastal fishermen leave the sector. It is shown that around 2007 (the introduction of ITQs in the demersal fishery) there is a strong incentive for coastal fishermen owning fishing vessels to sell quotas and leave the fishery, but that income from other sources also has a strong influence on this decision. I.e. a part of the fishermen left knowing they could earn a living in alternative ways. Moreover, the analyses showed that the possibility to obtain social benefits only to a lesser degree influenced the decision to leave over the period 2004–2009, and not significantly so after 2007, indicating that coastal fishermen have not left the fishery to base their future income only on social benefits. These results only applies for the coastal fishery, however given that this segment have been perceived to be under the greatest pressure economically and with regards to capacity reduction when ITQs was introduced, the study is believed to reflect the behaviour of the rest of the sector.

6.3 Management, current and historical

Management of the Danish fisheries is part of the Common Fisheries Policy of the European Union (Holden and Garrod 1996). The Common Fisheries Policy sets Total Allowable Catches for managed fish stocks in European waters. These Total Allowable Catches are allocated to each member state according to the relative stability principle. Moreover, technical conservation measures including mesh size and minimum fish size limits are set centrally by the Common Fisheries Policy.

Before 2003, management of Danish fisheries was performed through a license system combined with individual non-transferable weekly and monthly vessel quotas. Limits were also set on the days at sea and engine power for each vessel, cf. Andersen et al. 2005. Based on comprehensive investigations and discussions in the years before ITQs were introduced for herring in 2003, followed by mackerel and fish for reduction in 2004, cf. Frost and Løkkegaard (2001) and Løkkegaard *et al*. (2001), Subsequently, the ITQ system was extended to the entire Danish fleet in 2007 (Danish Ministry of Food, Agriculture and Fisheries, 2005). At the introduction of the ITQ programs, individual quota shares were allocated to individual vessels by the grandfathering principle (Danish Ministry of Food, Agriculture and Fisheries, 2008), i.e. based on landing shares in 2003–2005. Based on these shares, individual vessel quotas are set each year based on the Total Allowable Catches. The quota shares are fully tradeable between all vessels, regardless of size and gear used. However, there is a personal limit on the share that can be held, to avoid concentration (Danish Ministry of Food, Agriculture and Fisheries, 2008). On the other hand, vessels are allowed to construct quota communities, within which quotas can be transferred with a minimum of administration.

A special arrangement was set up in 2007 for the coastal fisheries (Danish Ministry of Food, Agriculture and Fisheries, 2005). Vessels below 17 meters, with at least 80% of their fishing trips being less than three days could enter this arrangement, in which they had to stay enrolled for at least 3 years. If entering, vessels were allocated extra quotas of cod and sole, but could then only trade quotas and quota shares with other vessels in the arrangement (Nielsen *et al.* 2013). This scheme has been revised in 2016 and an amended scheme introduced in 2017. Under the new scheme there will be additional quotas added for cod, sole and plaice, and moreover, for the first time, Norway lobster, turbot, sprat, herring and saithe. The new rules distinguish between two coastal segments; an open segment (vessels less than 17 meters, with 80% of the fishing trips shorter than 2 days) and a closed segment (vessels less than 15 meters, landing at least 70% of each quota covered by the scheme available through their initial transferable fishing concession allocation). Vessels in the closed segment can only trade quota (permanent quota shares and annual quotas) with other vessels in the same segment, but receive an extra premium compared to vessels participating in the open segment. As of 2017, vessels that once have joined the closed segment will not be able to return to the open segment.

Finally, the Danish fishery is subject to the landings obligation, which has been obligatory through the Common Fisheries Policy for all European fisheries since 2015 (EC, 2013). In Denmark, the landings obligation is being rolled out from 2016 to 2019.

6.4 Data

Table 16 displays key indicators for the historical development of the total Danish fleet over the period 2002–2014. Numbers are shown for the years 2002, 2007 and 2014, i.e. the year before introduction of ITQs in the herring fishery, the year of introduction of ITQs in the demersal fishery, and 7 years after this last change in management. Moreover, Figure 12 shows the development in the capacity (number of vessels) in the Danish fleet over the period 1995–2015. Table 16 firstly shows that the total number of vessels in the Danish fleet has been reduced by 36% from 2002 to 2014. Looking at active vessels and at commercially active vessels (having an income from fisheries above EUR 33,500), the reduction is even higher, being 62% for the commercially active vessels. Figure 16 shows that this decrease is a continuation of a general trend in the Danish fishery during the last 20 years. The reduction in the fleet is explained by reduced fishing opportunities both before and after the introduction of ITQs. Decommission schemes and other initiatives were introduced to reduce capacity. However; the adaption of the fleet to the reduced fishing opportunities, was not happening fast enough before the introduction of ITQs because the technological development and increased productivity within the Danish fleet was occurring faster than the fleet were able to adjust under the former regulatory framework without transferability of quotas. Figure 12 shows that the decrease in number of vessels accelerated just after the introduction of ITQ management in 2007 in the Danish demersal fishery (with a fall of 23% in the total number of vessels), but then levelled out. This indicates an instant adjustment in the fleet just after introduction of ITQs in the demersal fishery.

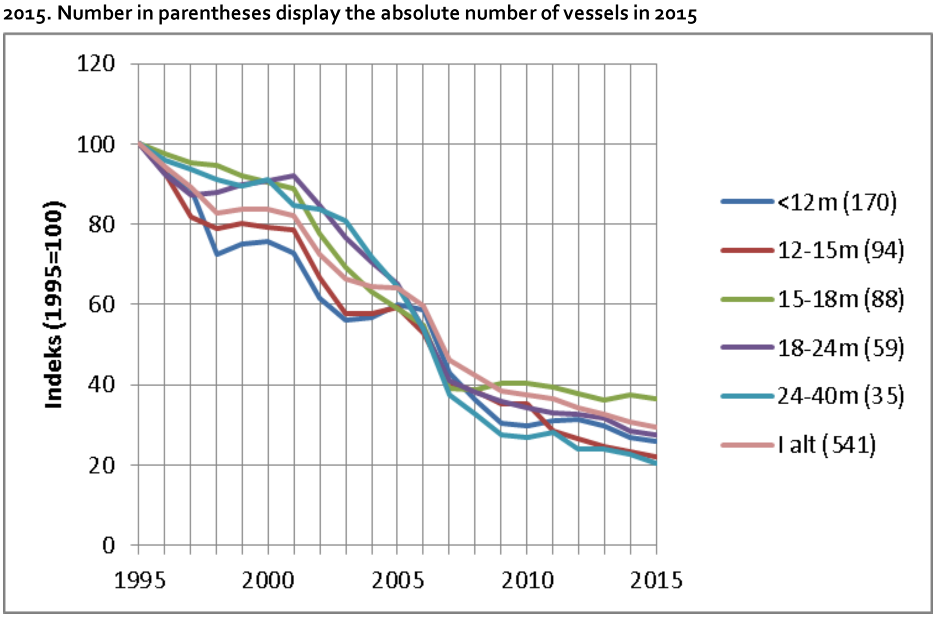
Table 16: Historical fleet development for the Danish fleet 2002–2014

	2002	2007	2014	% change 2002-2014
No. vessels[1]	3,816	2,957	2,442	-36
No. active vessels	2,699	2,087	1,578	-42
No. commercially active vessels	1,321	760	506	-62
% landing value from commercially active vessels	92	85	89	
Days at sea, commercially active fleet				
Total	214,160	100,305	71,582	-67
Average per vessel	162	132	141	-13
Tonnage (GT), commercially active fleet	90,465	61,118	59,844	-34
Quota utilization%				
Total	71	77	78	+10
Industrial fishery	67	74	74	+10
Fishery for human consumption	93	84	86	-8

Note: 1. "No. vessels" includes the entire fleet. All other numbers only include commercially active vessels except those in the mussels and horse/brown shrimps fishery sector.

Source: Statistics Denmark (2002, 2007, 2014); The Danish Agrifish Agency (2002, 2007, 2014). This Table has been adapted from Merayo *et al.* (2018).

Figure 12: Development (indexed) in number of vessels in the Danish fleet during the period 1995–2015. Number in parentheses display the absolute number of vessels in 2015



Following the decrease in number of commercially active vessels the total Days at Sea is also reduced by 67% from 2002 to 2014, while the days at sea per vessel is only reduced by 13%, thus indicating that the major fall in total effort is caused by a fall in number of vessels. The reduction in days at sea can also be seen as a consequence of a reduced "race for fish" and that fishermen now fish when the weather or season allows them the best opportunities to utilize the vessels capacity leading to higher catch efficiency among the remaining vessels. The tonnage (GT) has been reduced by 34% between 2002 and 2014, but this fall predominantly lie between 2002 and 2007, even though the dominant reduction in number of vessels lie between 2007 and 2014. Merayo *et al.* (2018) explains this seemingly paradox through two effects. Firstly, vessels over 24 meters have a slight increase in tonnage from 2007 to 2014. These segments mainly target pelagic and industrial species, for which both prices and stocks experienced a positive development after 2014. Secondly, the average tonnage per vessel has increased for all vessel groups, except vessels less than 12 meters, suggesting that it is the smallest vessels that have left the fishery in each vessel group. Finally, Table 16 show that the quota utilisation has increased in the industrial fishery while it has decreased in the fishery of species for human consumption. These effects may to a large degree be explained by uneven development of fish stocks over the period.

Table 17 displays the historical development in key economic and social indicators. The Table firstly shows that the total fleet profit decrease from 2002 to 2007, but then increase again, ending 25% below the 2002 level. The average profit per vessel displays the same trend, but here the increase after 2007 is more pronounced, ending with an overall increase of 96% from 2002 to 2007. The overall profit decrease is carried by vessels below 24 meters, while vessels above this length have an overall increase over the period (Merayo *et al*. 2018). For average profit vessels below 18 meters experience decrease while vessels above 18 meters have increasing profits per vessel. These trends may to some degree be based in the introduction of ITQ management, but will also be influenced by other factors too, mainly by stock status (reflected in quotas) and by market dynamics (prices).

Table 17: Historical development in economic and social data for the Danish fleet 2002–2014

	2002	2007	2014	% change 2002–2014
Private economic indicators:				
Profit[3]	74.0	33.9	55.6	-25
Average profit per vessel	0.1	0.0	0.1	+96
Profitability[3]%	11.7	6.9	12.6	+8
Capital intensity[3]	0.2	0.4	0.5	+116
Total value of fishery assets[3]	634.2	840.2	1,219.0	+92
Value of quotas[3]	-	351.1	777.7	+122 (2007-2014)
Value of material fishery assets[3]	634.2	489.2	441.3	-30
Socioeconomic indicator:				
Socio-economic return[2,3]	74.6	49.2	73.0	-2
Social indicators:				
No. workers, total fleet	4,258	2,573	1,988	-53
No. full-time workers (equivalent), commercially active vessels	2,949	1,260	954	-68
Average annual wage, per full-time fisher, thousand DKK	43.0	44.6	39.9[a]	-7
Unemployment rate%, general, Denmark	4.8	2.7	4	-17

Note: 1. Million EUR. Commercially active vessels, excluding shrimp beam-trawlers and mussel dredgers. Monetary values adjusted for inflation (base year 2002). Profitability=% of profit in relation to fishery assets (excluded fishing rights). Capital intensity=Fishery assets (excluding fishing rights)/no. workers.
2. Socio-economic return includes the producer surplus, as defined in the appendix.
3. Total for fleet. [a] Data for 2012 instead of 2014. This Table has been adapted from Merayo *et al.* (2018).

Source: Statistics Denmark (2002, 2007, 2014).

The profitability (percentage change in profit relative to physical fishery assets) follows the same trend as the profit, i.e. a decrease towards 2007 and a subsequent increase, leading to an overall increase of 8% from 2002 to 2014. The increase is carried by the large vessels (>18 meters) while the smaller vessels experience decreasing profitability (Merayo *et al.* 2018).

The capital intensity is defined as the material fishery assets relative to the number of full time workers. Table 17 shows that the capital intensity increases with 116% from 2002 to 2014, corresponding with the observed decrease of 68% in number of full time workers.

Table 17 further shows that both the quota values and the total fishery assets value increases over the period, reflecting that under an ITQ system the value of quotas will reflect the expected future earnings of the fishery, according to economic theory. This is confirmed by the decrease in physical fishery assets (excluding quotas), indicating that part of the quota values is embedded in total vessel assets. This also explains why profits, everything else being kept equal, have not increased more given the introduction of ITQs; profit has been capitalised in permanent quota shares.

The socio-economic return, representing the social welfare that the fishery comprises for society when compared with how the resources used in the fishery sector could be used in other sectors, is positive over the period, decreasing from 2002 to 2007, however; increases towards 2014 to almost the same level as in 2002. As the profit, the socio-economic return will be influenced by several factors, nevertheless; it is interesting to notice the recovery of this indicator after the introduction of ITQs in the demersal fishery.

Finally, Table 17 displays the development of labour and wages on the Danish fishing fleet. Following the decreasing number of vessels (cf. Table 16) the total number of workers and the equivalent number of full-time employed decrease by 53% and 68%, respectively. However, given that the Danish unemployment has decreased over the period, a trend that is also observed for the large fishing communities (cf. Merayo *et al.* 2018), it must be assumed that the redundant fisheries labour have managed to find work on land. The annual wages decrease over the period, but given that wages are usually paid as part of the landed value, this indicator will vary with quota and market fluctuations. Thus, given the increased profit earned from 2007 to 2014, it seems that there has been a redistribution of welfare from labour to capital, which has been capitalized in the quota shares.

6.4.1 The Danish North Sea demersal fishery

The Danish North Sea fishery constitutes a major part of the total Danish fishery. In 2012–2014 this fishery harvested 68% of the total Danish landed value. The landings of demersal species constituted 25% of the landed value from the North Sea in the same period. The Danish demersal fleet consists mainly of netters and trawlers below 24 meters, with the exception of the larger trawlers (24–40meters) fishing for human consumptions.

The Danish fleet targeting demersal species in the North Sea[8] is parametrised using data from (i) the Danish Fisheries Analytical Database provided by the Danish Agrifish Agency, which comprises landings (weight and value), and effort data at trip level for the individual vessels in the fleet, and (ii) fleet cost data from Statistics Denmark's Account Statistics for Fisheries. Model parametrisation data are based on averages for the period 2012–2014, i.e. the three years leading up to the modelled period. Thus, it is assumed that the cost, price and catch patterns in the projection period (2016–2025) are identical to the structure in the years leading up to this period.

Vessels included from the Danish Fisheries Analytical Database to parametrize the model are vessels that have a turnover of more than EUR 37,000. This threshold excludes small vessels owned by part time fishermen, however; the total turnover of these vessels constitutes less than 2% of the total Danish turnover. Six fleet segments were identified for which the value of landed demersal species caught in the North Sea constituted more than 20% of their total landed value in 2012–2014. Table 18 presents base physical and economic indicators, averaged over the calibration period 2012–2014, for these fleet segments. The average number of vessels and days at sea per vessel, together with the cost data given in Table 18 has been used to initialize the model in 2015 for each segment

Table 18: Average base indicators for the fleets included in the analysis over the calibration period 2012–2014

Average 2012-2014	Net 0–15m	Net 15–24m	Trawl 0–15m	Trawl 15–24m	Traw 24–40m	DK Sein 15–24m	Average per vessel[5]
Physical data							
FTE[1]/segment	41.1	74.9	5.5	67.1	133.9	36.9	44.2
Number of vessels	46	19	5	30	28	19	147
DAS/vessel in NS[3]	81	56	242	48	206	62	97
1st important species[2,4] NS	COD (44%)	PLE (46%)	HER (56%)	PLE (60%)	COD (27%)	PLE (44%)	PLE (32%)
2nd important species[2,4] NS	PLE (33%)	SOL (25%)	PLE (31%)	COD (13%)	SAI (17%)	COD (34%)	COD (26%)
3rd important species[2,4] NS	SOL (13%)	COD (21%)	COD (8%)	NEP (9%)	HKE (14%)	SOL (20%)	SAI (11%)
Account data (1000EUR/ vessel)							
Turnover	135	650	328	784	1,798	466	702
Fuel Costs	9	58	38	111	379	34	111
Crew costs	59	285	82	209	452	174	210
Variable costs	23	108	27	92	218	117	98
Fixed costs	33	118	49	112	237	75	105
Capital costs	24	130	32	113	391	77	133
Opportunity labour cost	46	187	63	116	258	103	97
Opportunity capital cost	22	113	34	101	328	75	79
Profit	-12	-49	101	147	121	-10	45
Socio-economic return	1	51	137	228	315	64	127

Note: 1. "FTE"=Full Time Employment.
2. Relative importance of landed species is measured in value.
3. The vessels also operate in other waters than the NS.
4. "COD"=cod, "PLE"=Plaice, "HER"'=Herring, "SOL"=Sole, "SAI"=Saithe, "NEP"'=Nephrops, "HKE"=Hake.
5. For "Number of vessels" this column result represent the sum and not average.

[8] Comprising the Northern, Central and Southern North Sea.

Table 18 shows that the most profitable segments in 2012–2014 were the trawlers, while the netters and seiners operated with losses. Likewise, the socioeconomic return, i.e. the social welfare that the fishery represents for society, was largest for the trawlers and smallest for the small netters. The largest turnovers were obtained by fleet segments larger than 24 meters, given that these segments have larger capacity and can thus catch larger amounts. However, these segments also carry the highest costs. Table 18 further shows that the most important species, in terms of value were plaice and cod in the period 2012–2014, followed by saithe, the latter because saithe constitutes 17% of the catch value of the large trawlers 24–40 meters.

Table 19 displays the status of the major demersal stocks included in the model projections. Spawning stock biomass, Total Allowable Catches and fishing mortality corresponding to MSY are displayed, together with the status of the stocks in 2015.[9] It is seen that most stocks were sustainable in 2015 with the exception of Cod that was above Bpa but below MSY-Btrigger, and Nephrops in Functional Units 6 and 7. The spawning stock biomasses and Total Allowable Catches displayed in Table 19 are used as initiating values in 2015 for the model projections.

Table 19: Status, illustrated through Spawning Stock Biomass (SSB), Total Allowable Catch (TAC) and fishing mortality at MSY (F-MSY) of the main North Sea stocks included in the analysis in the start year 2015

2015	SSB (tonnes)	TAC (tonnes)	F-MSY	Status 2015[1]
Plaice (NS)	770,556	128,376	0.21	Above Bpa[3], Above MSY-Btriggger[4]
Cod (NS)	134,323	29,189	0.31	Above Bpa, Below MSY-Trigger
Saithe (NS)	220,918	66,006	0.36	Above Bpa, Above MSY-Btriggger
Hake (NS)	272,795	90,849	0.28	Above Bpa, Above MSY-Btriggger
Sole (NS)	45,650	11,900	0.20	Above Bpa, Above MSY-Btriggger
Nephrops (NS)	-	17,843	-	Above MSY-Btrigger in FU[2] 8, 9, below MSY-Btrigger in FU 6, 7
Haddock (NS)	142,921	40,711	0.194	Above Bpa, Above MSY-Btriggger

Note: 1. According to ICES advice 2017.
2. "FU"=Functional Unit.
3. "Bpa"=The precautionary biomass level that triggers ICES to take action to raise the stock above this level.
4, "MSY-Btrigger"=The Biomass level that triggers ICES to recommend a fishing mortality below F-MSY.

6.5 Results

As described in the introduction of this report 4 forecast scenarios are considered. The results obtained in 2025 are compared with the initial situation in 2015. The specifics for the Danish case/management are:[10]

1. Current Danish management: ITQs with quota trade restrictions between vessels above and below 15 meters, and 4% limit on yearly adjustment in number of vessels in each segment;

[9] Source: ICES advice 2017, http://standardgraphs.ices.dk/stockList.aspx

[10] The constant recruitment scenario has been left out in the Danish case, given that it leads to unrealistic results, including extinction of the Haddock stock.

2. Free ITQs with no trade limits. 4% limit on yearly adjustment in number of vessels in each segment;
3. Current Danish management: ITQs with quota trade restrictions between vessels above and below 15 meters. No limit on yearly fleet adjustment;
4. Scenario 1 with taxes on 10% of prices.

As discussed in the introduction two forecasts are made for each scenario: Maximization of the total socio-economic return and maximization the total profit, both over the period 2016–2025 (2015 being held constant), through variation in number of vessels and days at sea per vessel.

Table 20 display the model outcomes from the projection maximizing socio-economic return. The Table displays total socio-economic return (summed over all included fleet segments), together with the total number of vessels and the total fulltime employment. Table 20 displays the corresponding indicators from the projection maximizing profit. Results are shown for the base year 2015 and for each scenario for the final projection year 2025.

Table 20: Forecast of socio-economic return, fleet and employment adjustment in 2025 by maximizing socio-economic return

Scenarios	Net 0–15m	Net 15–24m	Trawl 0–15m	Trawl 15–24m	Trawl 24–40m	DK Sein 15–24m	Total
Socio-Economic return (mill EUR)							
2015 initial situation	-1.47	1.97	0.68	7.35	12.14	1.71	22.38
2025 scenarios:							
1. Current management	-0.35	2.73	1.25	14.99	7.09	1.90	27.60
2. ITQ management free quota trade	0.67	2.28	1.28	14.97	7.09	1.80	28.09
3. Current management full adjustment	0.89	4.11	1.28	15.84	11.15	2.04	35.31
4. Current management constant recruitment	-	-	-	-	-	-	-
5. Current management 10% landing tax	-0.35	2.73	1.25	14.99	7.09	1.90	27.60
Number of vessels							
2015 initial situation	46	19	5	30	28	19	147
2025 scenarios:							
1. Current management	30	13	6	34	19	13	115
2. ITQ management free quota trade	30	13	7	34	19	13	116
3. Current management full adjustment	8	6	7	50	7	8	86
4. Current management constant recruitment	-	-	-	-	-	-	-
5. Current management 10% landing tax	30	13	6	34	19	13	115
Employment (full-time)							
2015 initial situation	40	66	5	71	134	36	352
2025 scenarios:							
1. Current management	27	44	7	76	89	24	267
2. ITQ management free quota trade	27	44	8	76	89	24	268
3. Current management full adjustment	7	20	8	105	33	15	187
4. Current management constant recruitment	-	-	-	-	-	-	-
5. Current management 10% landing tax	27	44	7	76	89	24	267

Table 21: Forecast of profit, fleet and employment adjustment in 2025 by maximizing profit

Scenarios	Net 0–15m	Net 15–24m	Trawl 0–15m	Trawl 15–24m	Trawl 24–40m	DK Sein 15–24m	Total
Profit (mill EUR)							
2015 initial situation	-1.21	-0.30	0.29	3.54	5.07	0.30	7.69
2025 scenarios:							
1. Current management	-0.90	0.10	0.67	9.76	1.90	0.70	12.23
2. ITQ management free quota trade	0.52	-0.66	0.70	9.73	2.05	0.63	12.96
3. Current management full adjustment	0.31	1.58	0.70	11.05	7.25	1.07	21.97
4. Current management constant recruitment	-	-	-	-	-	-	-
5. Current management 10% landing tax	-0.97	-0.25	0.54	7.87	0.75	0.53	8.47
Number of vessels							
2015 initial situation	46	19	5	30	28	19	147
2025 scenarios:							
1. Current management	30	13	5	34	19	13	114
2. ITQ management free quota trade	30	13	6	35	19	13	116
3. Current management full adjustment	6	5	6	62	7	11	97
4. Current management constant recruitment	-	-	-	-	-	-	-
5. Current management 10% landing tax	30	13	5	33	19	13	112
Employment (full-time)							
2015 initial situation	40	66	5	71	134	36	352
2025 scenarios:							
1. Current management	27	44	6	77	89	25	267
2. ITQ management free quota trade	27	44	7	77	89	25	269
3. Current management full adjustment	6	17	7	124	34	20	208
4. Current management constant recruitment	-	-	-	-	-	-	-
5. Current management 10% landing tax	27	44	5	72	89	24	261

6.5.1 *Socio economic return and profit*

The tables firstly show that given the current management (scenario 1) the total demersal fleet will be better off in 2025 than in 2015. The total socio-economic return increases by 23% and the total profit by 59%. Thus, both the social welfare that the fishery represents for society (through the socio-economic return) and the actual surplus obtained in the fishery after subtraction of all costs (including quota trade) is expected to increase considerably over the period given the current management system, and assuming a certain rigidity in investment/disinvestment speed. This effect is seen for most fleet segments, except the large trawlers 24–40 meters. The large trawlers take around 40% of the catches of the included segments and have a large catch of hake. This segment discarded a large amount of undersized hake before the introduction of the landings obligation and will have choke problems after 2019 where the landings obligation is enforced. It would therefore be optimal to buy hake quotas from other segments. However, given that this segment is the largest it is not possible to buy enough hake to avoid the choke problem and thus this segment has a decrease in the socio-economic return and profit over the period given the current management system.

The tables further show that removing the trade barrier between small and large vessels (scenario 2) will increase the economic outcome, but only marginally so, in 2025 both with respect to socio-economic return and profit (when comparing to scenario 1).

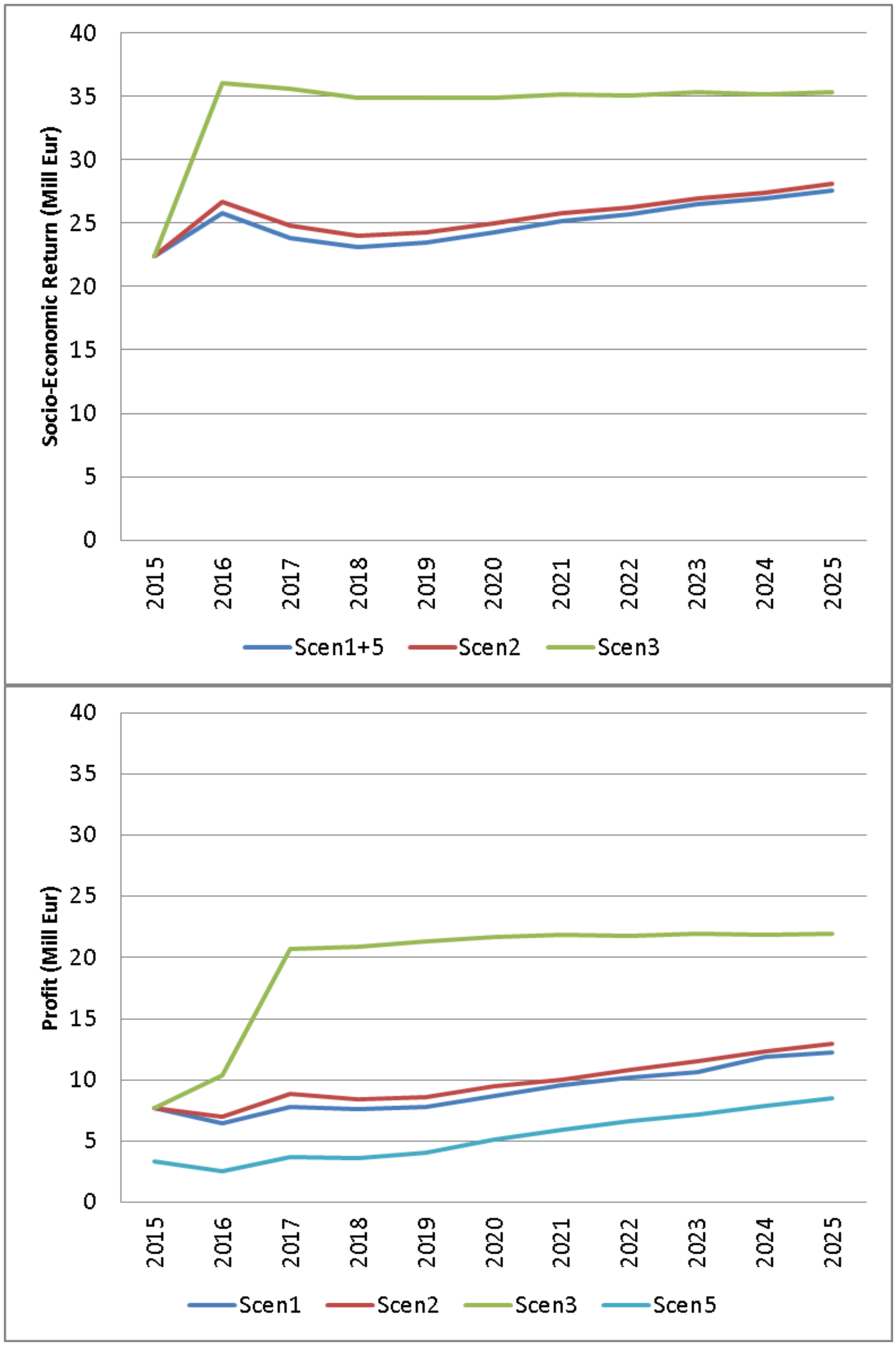
Considering individual segments the picture is more mixed, as some segments have increasing socio-economic return and profit while others half have decreasing socio-economic return and profit. It is interesting to notice that the small netters less than 15 meters is expected to make a profit if the trade barrier is removed between small and large vessels, i.e. it is predicted that only the most efficient vessels are left to fish the available resource.

Assuming instant capacity adjustment (scenario 3), as opposed to a 4% limit on yearly capacity change, will lead to a considerable profit increases compared to scenario 1: 28% increase in socio-economic return and 80% in profit, when compared to scenario 1. This increase is carried by all fleet segments, and especially the large trawlers 24–40 meters and large netters above 15 meters benefit. This illustrates how reduction of overcapacity may generally make fleet segments (i.e. the remaining vessels) more efficient and thereby more profitable.

Introducing a landings tax of 10% (scenario 4) results in the socio-economic return being identical to what is obtained in the current situation (scenario 1) given that this tax is an income to society and as such will cancel out in the socio-economic return. However, the total profit decreases with 31% relative to the current situation (scenario 1). This decrease is carried by all fleet segments.

Figure 13 displays the development of profit and socio-economic return over the projection period of the total socio-economic return, respectively the total profit resulting from each projection. The trends shown in the figures are very similar to the final 2025 results, i.e. throughout the period the most profitable scenario, both with regards to socio-economic return and profit is scenario 3 (free capacity adjustment), followed by scenario 2 (no trade barriers between small and large vessels, i.e. free ITQ trade) and scenario 1 (current management system), while scenario 4 (10% tax) lies well below the other scenarios in the profit maximisation case. The decrease in the socio-economic return and profit observed towards 2018 is caused by the landings obligation being phased in between 2016 and 2018. The large trawlers for human consumption is predicted to be severely affected by this, as discussed above, and the reduction in their profit and socio-economic return is reflected in the total profit and socio-economic return.

Figure 13: Development in Socio-Economic Return (top) and Profit (bottom) in each of the two projections



6.5.2 Number of vessels and full time employment

Tables 20 and 21 also display the total number of vessels respectively full time employed (FTE) resulting from maximizing socio-economic return and profit. The two tables firstly show that a reduction of ~22% (equal for the socio-economic return and profit maximizations) is expected in number of vessels from 2015 to 2025 given the current management regime (scenario 1). Similar reductions are seen in scenarios 2 and 4, given that the fleet is allowed to change a maximum of +/-4% a year. Looking at individual fleet segments, similar reductions in number of vessels, relative to 2015, is seen for most segments. However, trawlers 15–24 meters, experience an increase in number of vessels, illustrating that even though capacity reduction is optimal for most fleet segments, this segment profits to such a degree from quota transfers that it is optimal for new vessels to enter.

When assuming instantaneous capacity change (scenario 3), the total number of vessels is expected to decrease by 42% in the socio-economic return projection and by 34% in the profit projection relative to 2015. Comparing the situation in 2025 with the current management scenario (scenario 1), the reduction of vessels are 25% for the socio-economic return projection and 15% within the profit projection (Table 20). These significant decreases are carried by most segments except the trawlers 0–15 meters and 15–24 meters, that are both expected to increase the number of vessels, again illustrating how transfers of quotas may make some fleet segments more profitable and thus create incentives for new vessels to enter.

Given that full time employment is proportional to the number of vessels, the results for full time employment are identical to the results for number of vessels. I.e. it is generally expected that there will be a reduction in full time employment from 2015 to 2025 in all scenarios, with an approximately equal decrease in scenarios 1, 2 and 4 and with a more pronounced decrease in scenario 3.

6.6 Policy considerations

The above results firstly shows that given that the Danish management continues as today, i.e. with transferable vessel quota shares, and limits on trade between vessels in the coastal fishery arrangement, then both the outcome for society (socio-economic return) and for the fishermen (profit) will continue to improve towards 2025 compared to 2015. The improvement is 23% in socio-economic return 59% in profit when it is assumed that the adjustment of the fleet is constrained (scenario 1). If it is on the other hand assumed that the adjustment of the fleet can happen instantaneously, given the profitability of the segments (scenario 3), a further increase, relative to scenario 1, of 28% in socio-economic return and 80% in profit is observed. The actual outcome for the Danish fishery must be assumed to be in between these two extremes, however; it may be closest to the restricted capacity change outcome, acknowledging that (i) an average capacity decrease of ~4% has been observed in the Danish fishery for the past decade and (ii) instantaneous capacity change given changes in fishing fleet profit seems unrealistic, given that there will be a natural lag between changing profits and ensuing investments/disinvestments in capital/capacity.

The Danish management can to a large degree be expected to continue in line with scenario 1, i.e. quota trade and lease,, but with limits between vessels within and outside the coastal fishery agreement. A further development of the coastal fishery agreement is currently being implemented with restriction on transferability in exchange for higher quota shares of specific species as mentioned in the introduction.

It is also expected that restriction on how much a single quota holder can own will be more strictly enforced, given the recent discussion of quota concentrations raised by the Danish Public Accountant Committee. These limits have been in place from the introduction of the tradable quota system, however, the way they have been enforced was criticized in a report by the Danish Public Accountant Committee (Rigsrevisionen 2017).

Danish fishery is also subject to the Landings Obligation that is being rolled out from 2015 with full implantation in 2019 together with the rest of the EU fishing fleets. The current status of the Landings Obligation, and its expected implementation in Denmark, has been included in the projections presented in this chapter. Thus in scenario 1, and to some degree 3, must be expected to present the best possible prediction of the economic situation for the Danish fishery in 2025, however with the reservation that quote trade and lease may be more restricted in the future given possible new legislation aiming at preventing quota concentration.

However, it may be speculated how much could be gained, both for the society and for fishery in Denmark, if free quota trade is allowed (scenario 2) with no limits on trade with coastal fishery vessels or limits on quota concentration. Here the analyses indicate that the possible gain in 2025 is only marginally higher than what can be expected under the current management regime given rigid capacity adjustment (scenario 1), both with respect to the outcome to society and to the fishing fleet.

In scenario 4 a 10% tax on the landed value is examined. The result shows that this would leave the fishery worse off in 2025 than its current status in 2015. With regards to society, the outcome is the same as in scenario 1, i.e. as what can be predicted under current management with no taxes. The reason behind the emerging discussion of putting a tax on fish landings/fishing rights is that the fishermen (especially the large fishing enterprises) have had a substantial increase in earnings after the introduction of ITQs. The resource was given to the fishermen (for free) using grandfathering because the fisheries were in a very poor economic situation. However, this has changed and it now seems more and more reasonable that the exploitation of the common resource should also benefit the rest of the society (like exploitation of oil etc.) or at least be able to cover the cost that society have in regards to establishing, monitoring and enforcing rules and regulations.

In all the results in this chapter indicates that the Danish fishery, under its current management, is developing positively from an economic point of view, both with regards to the outcome to society and with regards to the outcome to the fishery. The fishery could be marginally better off if free quota trade (without protection of small scale fishermen) was allowed, and given that this may happen at the expense of increased quota concentration. However, given the recent debate in Denmark concerning quota concentration and "slipper skippers" (fishermen that rent out quotas without fishing them self) it seems realistic to assume that there will be a tightening of the rules rather than an opening for more free trade. For the moment, it is actually possible to take part in the quota trading no matter the size of the vessels, if you are not a part of the two existing coastal quota schemes set up to preserve/protect the small scale coastal fishermen.

The debate about preserving the coastal fisheries has been going on since before the introduction of the ITQ schemes and focus mostly on the social dimension of the fisheries sector, keeping employment in fisheries depended communities and other social values related to having active fishermen in the local community/harbour (Nielsen *et al.* 2013 and 2017; Merayo *et al*. 2018). If the fishery sector is used as a political tool in regional development preserving employment in fisheries depended communities it is important that the cost of such interventions is known and compared to other alternative policies. Furthermore, the small scale fisheries are mostly targeting demersal species where the large vessels, where there have been issues of quota concentration, are targeting pelagic species (herring, mackerel and fish for reduction). Thus, some of the arguments presented againsts the ITQ system (quota concentration) and for increasing the coastal fishery (employment, environmental sustainability etc.) in the debate seem to be based on myth rather than facts (Nielsen 2013 and 2017; Merayo *et al*. 2018).

The above results are good indicators of where the economic outcomes of the Danish fishery are heading towards 2025. However, some caution must be taken when interpreting the results. Firstly, the model applied runs at a yearly level. This omits seasonal changes in gear and catch patterns, and through this possibility for trading/swapping quotas not only between fleet segments but also between seasons. Thus the model underestimates the possible economic outcomes of the fishery. Secondly, the model is parametrized on data from 2012–2014. As such a constant price and cost structure is assumed over the total period, something that must be expected to change with market fluctuations and stock availability. Finally, quota prices are determined based on previous year's profitability of the buying/renting and selling/leasing fleet segments, as real quota prices are not known. Thus it must be expected that all these factors affect the absolute results. However, the relative difference between the results must be expected to be robust to these biases as all absolute numbers will change by the same amount if the biases are corrected.

7. Finnish large-scale pelagic fisheries

7.1 Introduction

ITQ system in the Finnish pelagic fisheries containing Baltic herring and sprat was introduced in the beginning of 2017. It covers the both large-scale trawler fleet and small-scale costal fishing. The pelagic trawler fleet is the most important fleet segment in Finland in terms of volume and value and accounts for 96 percent of all pelagic landings. The ITQ system was primarily designed for the pelagic trawler fleet but it also covers the small-scale coastal trap net fishing: ITQ systems for these two fisheries are separated. In the Finnish case study we concentrate to analyse the development of pelagic trawler fleet.

7.2 Literature review

The only study on ITQs in the Finnish Baltic Sea herring fishery is by Lindroos *et al.* (2007). They carried out a bio-economic analysis of the in the Finnish trawling fisheries with two management options – an ITQ system and non-tradable IQ system – to examine possible economic, biological and social effects.

The results follow the realized development in other Nordic countries that ITQs leads to a marked decrease in capacity and number of vessels with improved economic performance leading to a balance between fishing opportunities and fleet that follows the ultimate objective of the Common Fishery Policy (Regulation (EU) No 1380/2013).

The poor economic performance of the Finnish pelagic trawler fleet has been recognized in the Economic Reports since late 1990s (Anon. 2001). The socioeconomic return of the fleet has showed continued zero profits: even with reasonable gross profits they have not been high enough to cover the opportunity costs of capital leading to decreasing number and aging fleet.

7.3 Management

The Finnish fisheries management was based on command and control quota-based regime until 2017. National Total Allowable Catch allocated to Finland was open for all licensed fishermen. This resulted into race to fish until the quota was fully utilised and the fishery was closed. The Ministry of Forestry and Agriculture was sometimes forced to regulate fishing with separate regulations in order to ensure balanced fishing opportunities throughout the year. Especially specific regulations were set to close sprat fishery if the quota uptake created risk of premature closure of herring fishing due to sprat bycatches in the main fishing grounds in the Bothnian Sea.

In the beginning of 2017 ITQ system was implemented in the Finnish pelagic fisheries: Baltic herring and sprat. The initial quota share allocation was based on grandfathering system based on 2011–2015 track records: accounting for 3 highest annual catches during the 5 year period. Separate quota shares were allocated for coastal fishing to secure the continuance of the small scale coastal fishing.

The implemented ITQ system is valid for ten years with an option of extension. Quota shares in the pelagic fleet are fully transferable with a limitation of concentration: no individual unit may exceed 20% of total quota.

The implemented ITQ system is valid for ten years with an option of extension. Quota shares in the pelagic fleet are fully transferable with a limitation of concentration: no individual unit may exceed 20% of total quota.

7.4 Data

7.4.1 The Finnish national fleet

Table 22 presents the basic data on the development of Finnish national fleet in 2008–2014. The Finnish fishing fleet consisted of 3,144 registered vessels of which 1,460 were inactive in 2014; the active fleet consisted of 1,684 vessels, with a combined gross tonnage of 16 thousand GT. The number of active vessels shows an increase from 2008 to 2014 that is partly due to a change in statistical procedure that increased the number of active vessels in the small scale segment: since 2012 fishermen reported all vessels used during a year.

Total employment was estimated at 1,384 in 2014 jobs. The majority of the jobs are created by the small scale fleet that is a seasonal fishery. Therefore, the employment in that sector is usually only part-time and in terms of full time equivalent the total fleet added up to 355 FTEs. The number of fishermen has been dropping for long time.

The Finnish fishing fleet is dominated by small scale coastal fishing vessels: 1,621 out of 1,684 (96%) active vessels were operating in small scale coastal fisheries. However the 63 trawlers accounted for two thirds in terms of gross tonnage of the total fleet tonnage.

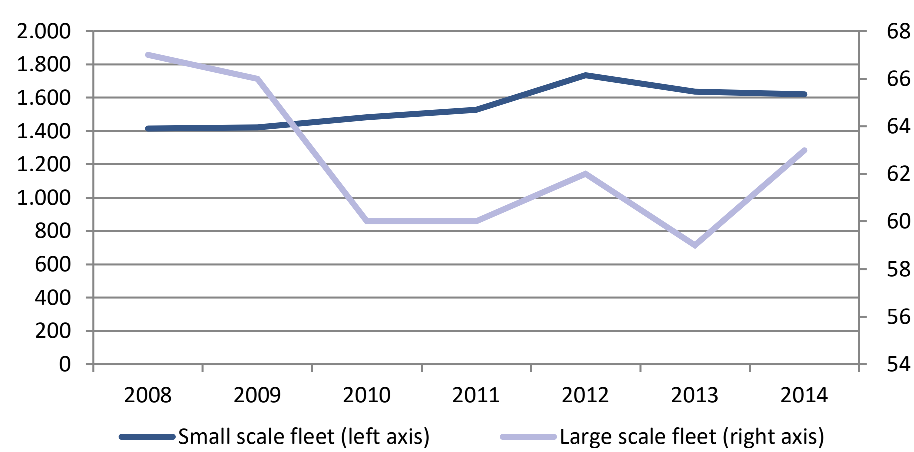
Table 22: Data on capacity, employment and Finnish national fleet

VARIABLE	2008	2011	2014	%Δ 2008
Structure				
Total No. Vessels	3,240	3,365	3,144	-3%
No. of Inactive vessels	1,758	1,777	1,460	-17%
No. of Active vessels	1,482	1,588	1,684	14%
Vessel tonnage (thousand GT)	16	17	16	0%
Employment				
Total employed	1,376	1,449	1,384	1%
Full Time Equivalent (FTE)	264	324	345	31%
Effort				
Days at sea (thousand days)	130	148	123	-5%
Output				
Landings weight (thousand tons)	112	120	148	33%
Landings value (EUR Million)	26.3	34.7	48.7	85%

The small scale coastal fishing fleet consists of diversified vessels targeting mainly freshwater fish species; European whitefish, pike-perch and perch. In 2014, the total value of landings of small-scale fishery was EUR 11.5 Million, generating EUR 6.6 Million in Gross Value Added and reasonable Gross profit margin of 25%. However there are a large number of low activity vessels and accounting the value of opportunity cost of capital of all these vessels turned the segment net profit negative.

Pelagic trawlers are divided into two length group segments, with the 24–40 meter segment being the most important economically. The fleet targets Baltic herring and sprat and these vessels accounted for over 70 percent of the total value landed by the Finnish fleet and employed 73 FTE. On average, these vessels generate a landings income of EUR 1.3 Million and employing 3.5 FTEs. The fleet segment generated EUR 7.8 Million in Gross Value Added or EUR 107 thousand per FTE. In 2012–2014 the Gross profit margin was 20% that was just high enough to cover the estimated opportunity cost of capital and the fleet was making zero profits (Table 23).

Figure 14: The development of number of vessels in the Finnish small scale coastal fishing fleet and large scale trawler fleet 2008–2014



The number of vessels has remained rather stable during the last 10 years. Number of trawlers was decreasing but the anticipation of the planned ITQ system turned the development (Figure 14).

7.4.2 The Finnish pelagic trawler fleet

Table 23 presents the basic data of the Finnish pelagic trawler fleet used in the initial setting of the modelling. In 2013–2014 there were 63 vessels that are divided into two segments: under and over 24 meter. The number of Finnish pelagic trawlers has been fairly stable during the past years (Figure 14).

Table 23: Data of the Finnish trawler fleets included in the model, 2012–2014

	TM < 24m	TM > 24m
Physical data		
Full Time Employment per segment	33	77
Number of vessels	41	22
No. of Sea Days per vessel	60	150
Most important species (value)	HER (92%)	HER (91%)
Second important species (value)	SPR (8%)	SPR (9%)
Account data (1000 EUR per vessel)		
Turnover	175	981
Fuel Costs	15	395
Labour costs	54	147
Variable costs	7	79
Fixed costs	52	176
Capital costs	10	164
Opportunity labour cost	24	195
Opportunity capital cost	57	267
Financial Net Profit	37	21
Socio-economic return	61	-130

Table 23 shows that Finnish pelagic trawlers are exclusively fishing for herring and sprat. The fishery is currently profitable, but only smaller trawlers are creating resource rent while larger trawlers show negative socio-economic return when considering the opportunity costs of production factors: labour and capital. This indicates that the larger trawler segment is not economically sustainable in the long term. However, one should notice that this data is from the race fishing period, when fishermen targeted highest possible catches in order to receive large individual quotas for future fishing

Currently the pelagic stocks in Baltic Sea harvested by Finnish fleet are at the MSY level. Especially the strong state of herring stock in the most important fishing ground for Finnish fleet, Bothnian Sea, have resulted record high catches year by year even the annual Total Allowable Catch was not fully utilized.

7.5 Results

This section presents the FishRent model simulations after introducing ITQ system in the Finnish pelagic fisheries until 2025 for the five scenarios presented earlier. However the scenario 2 is not relevant for the Finnish case due to the fact that the current ITQ management does not have any restrictions on quota trade between segments; therefore the scenario 2 results are the same as those in scenario 1 and hence not presented here. Thus, the scenarios for the Finnish case are:

1. Current management in Finland: ITQs and 4% limit on yearly adjustment in number of vessels in each segment;
2. Free ITQ trade between segments, not presented for the Finnish case;
3. Current management with full adjustment and no limit on yearly fleet adjustment;
4. Scenario 1 with taxes on 10% of prices.

For each scenario model simulated the fleet and economic development maximizing the socio-economic return accounting for opportunity costs for capital and labour and the financial profitability with actual capital and labour costs respectively.

7.5.1 Socioeconomic return

Here we present the model results where the socioeconomic return from the fishery is maximized. In here we consider the opportunity costs of labour and capital and hence the resource rent generated by the fleet. The development of the fleet capacity, employment, and socio-economic return between 2015 and 2025 are presented in Table 24 below.

Table 24: Forecast of socio-economic return, fleet, and employment in 2025 by maximizing socioeconomic returns

Scenarios	TM 12–24 m	TM > 24 m	Total
Socio-Economic return (mill EUR)			
2015 initial situation	0.85	-2.86	-2.02
2025 scenarios:			
1. Current management	3.46	-0.96	2.49
3. Current management full adjustment	3.61	3.10	6.71
4. Current management constant recruitment	4.51	1.53	6.04
5. Current management 10% landing tax	3.46	-0.96	2.49
Number of vessels			
2015 initial situation	41	22	63
2025 scenarios:			
1. Current management	27	15	42
3. Current management full adjustment	27	5	31
4. Current management constant recruitment	32	15	47
5. Current management 10% landing tax	27	15	42
Employment (full-time)			
2015 initial situation	33	77	110
2025 scenarios:			
1. Current management	22	51	73
3. Current management full adjustment	21	16	37
4. Current management constant recruitment	26	51	73
5. Current management 10% landing tax	22	51	73

In the initial situation the Finnish pelagic trawler fleet is making overall negative profits i. e. the fleet as whole is not creating resource rent that indicates a long term unbalanced fleet with the fishing opportunities available i.e. economic overcapacity: gross profit generated by the fleet does not cover the opportunity cost capital and labour. However the smaller trawlers are generating positive resource rent and therefore evidently in balance.

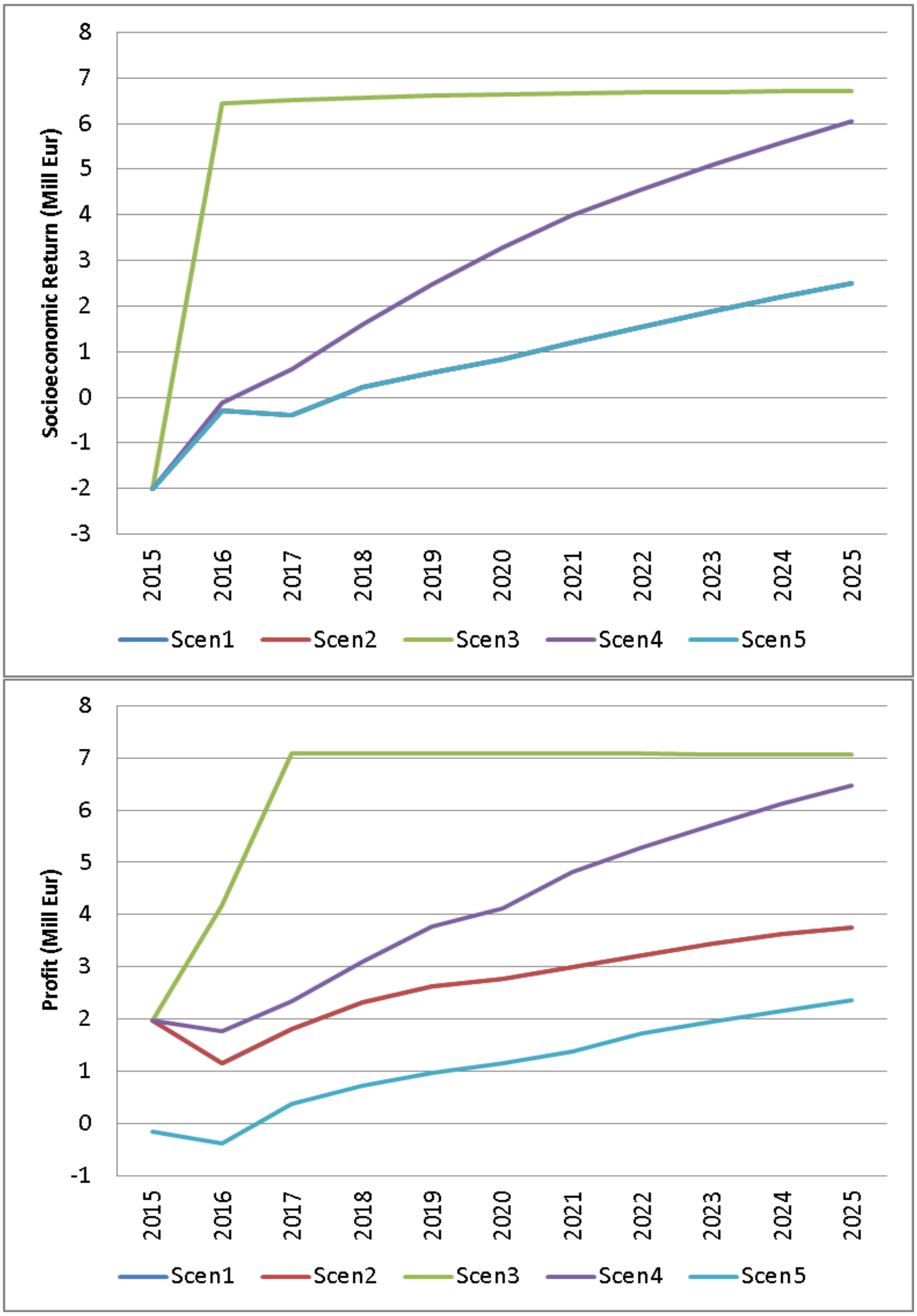
Scenario 1 presents the outcome of introducing ITQs with a 4 percent annual limitation of fleet restructuring. The results show that in 10 years the number of vessels have decreased one third from the initial number. However in 2025 due to the adjustment limitation the larger trawler fleet is far from long term equilibrium size and will continue to decrease as seen in the scenario 3 below. At the same time the profitability has improved significantly and the total socioeconomic return has turned positive indicating that the fleet is generating resource rent. Once again the larger trawlers are not making positive result. The employment follows the trend of fleet size with a drop of one third.

Scenario 3 shows the results without restriction on the speed of adjustment that is relevant for the Finnish case where the ITQ system is just introduced. Therefore the ten year simulation allows a marked restructuring of the fleet and the number of vessels drop further down to half of the initial level. Now also the larger trawlers are settled to the long term equilibrium size same as the smaller vessels. The drop of fleet size down to half follows the experiences of introduction of ITQs in other Nordic countries: Sweden and Denmark.

The profitability improved significantly with improved efficiency of the fleet. Now also the larger trawlers are generating a generous resource rent – almost 40 percentage of the revenue. The whole fleet is generating EUR 7 Million resource rent and contributing to the society total value of EUR 9 Million in net value added: that is benefit to society as income in terms of resource rent and wages.

In scenario 4 where 10 percent landing tax is introduced the socioeconomic return is by definition the same as in scenario 1 since this is the maximum possible economic return from the fishery for society as whole. This would mean that the society would in this case tax EUR 2 Million out from resource rent of EUR 2.5 Million in 2025. It would be heavy burden for the sector in the beginning but after full adjustment the improved profitability generating profits of EUR 7 Million (see in scenario 3) would counterbalance the burden of additional tax. In this scenario, it is assumed that fishermen do not change behaviour due to taxation and thus allocate resources in order to maximize the socioeconomic return. The private profit will however change, as discussed below.

Figure 15: Development in Socio-Economic Return (top) and Profit (bottom) in each of the two projections



7.5.2 *Financial profitability*

In here we present the simulation results for financial profitability maximization that relates to actual costs paid by fishing enterprise from the initial reference year. The development of the fleet capacity, employment, and socio-economic return between 2015 and 2025 are presented in Table 25 below.

Table 25: Forecast of profit, fleet and employment in 2025 by maximizing financial profit

Scenarios	TM 12–24 m	TM > 24 m	Total
Financial return (mill EUR)			
2015 initial situation	1.52	0.46	1.98
2025 scenarios:			
1. Current management	3.63	0.11	3.74
3. Current management full adjustment	3.73	3.33	7.06
4. Current management constant recruitment	4.40	2.08	6.48
5. Current management 10% landing tax	2.87	-0.50	2.37
Number of vessels			
2015 initial situation	41	22	63
2025 scenarios:			
1. Current management	36	15	51
3. Current management full adjustment	42	5	47
4. Current management constant recruitment	33	15	48
5. Current management 10% landing tax	32	15	47
Employment (full-time)			
2015 initial situation	33	77	110
2025 scenarios:			
1. Current management	29	51	80
3. Current management full adjustment	33	18	51
4. Current management constant recruitment	27	51	78
5. Current management 10% landing tax	26	51	77

Introducing ITQs lead to a major restructuring of the fleet same as in the socioeconomic analysis. In scenario 1 the outcome for larger trawlers in number of vessels is the same as in previous analysis. However the decrease of small trawlers is slightly more lenient than in socioeconomic scenario due to a reasonable good profitability of the segment. Respectively the economic performance improve but not in the same extent as earlier. However the smaller trawlers gain a marked improvement in profitability while the larger ones are worse of in 2015 before the full adjustment to the long term equilibrium.

Scenario 3 shows the full adjusted situation where the number of small trawlers has increased by one vessel but larger ones are reduced to 5. However due to the improved efficiency of the large trawlers the profitability increased to the same level as that in smaller trawlers. Total net profit realized of the fleet raised to EUR 7 Million. Again employment follows the number of vessels and is halved from the initial situation in 2015.

Regardless of underutilized herring quota the increased fishing opportunities improve the economic performance significantly from the scenario 1 situation. Now the smaller fleet segment decreases in numbers slightly and the improved profitability resulted in net profits of EUR 4 Million, higher than in the full adjustment scenario 3.

Larger trawlers fleet remains the same size as in scenario 1 but the profitability improved significantly to EUR 2 Million.

In scenario 4 with 10% landing tax together with ITQs (with 4% limit on yearly adjustment in number of vessels in each segment as scenario 1) improves the profitability compared to initial situation. However compared to scenario 1 profits are lower due to the taxes. By 2015 the smaller trawlers make net profits of EUR 3 Million that is lower than that in scenario 1 and the larger trawlers result turned negative. However in longer run after full adjustment the larger trawlers become very profitable. Total tax revenue to society is EUR 3 Million that will in the long run be well counterbalanced by the improved profitability that increase to EUR 4 Million after tax.

7.6 Policy considerations

The fundamental objective of the Common Fishery Policy is the balance between the fishing capacity and fishing opportunities. Evidently the Finnish fleet has operated for long time at zero profit level that was enabled by the fisheries management. This has leads to slowly decreasing and aging fleet. The ITQ system was introduced in the pelagic fisheries in the beginning of 2017 and this created a framework for the fleet to restructure and achieve a long term sustainable fleet both in economic and biological sense.

The results suggest that the balance will be achieved. Evidently the results rely on the assumptions that the model is based. However in the bio-economic model used all scenarios in both socioeconomic and financial analysis showed improved profitability with decline in number of vessels. At the same time the spawning stock biomass was rebuilt to enable more efficient fishing. The results follow the economic theory that supports more conservative fishery management than that following the MSY stock level.

In general the outcome of different scenarios in two analyses follow each other quite closely, especially the full adjusted outcomes are similar. In the long run after full adjustment both segments are creating reasonably high resource rent. And even introducing landing tax that would be heavy burden in the beginning would in the end be outweighed by the improved profitability. The tax revenue would be around EUR 2 Million while the improved profitability would increase the resource rent to EUR 6.5 Million.

The forecast induce a choking situation, due to the full uptake of the sprat quota while herring quota was still available. This resulted from the model assumption of fixed catch composition. In practice fishermen can influence the catch composition: studies show that sprat by-catches are highly dependent on area and season. Furthermore, ITQ systems by definition facilitate opportunity of efficient catch composition if the quota markets are efficient: those with highest marginal profitability had highest willingness to pay for adequate by-catch quota and with efficient ITQ market would allocate the harvesting efficiently.

Summa summarum: the results here support that the ITQ regime introduced in Finnish pelagic fisheries will enable the fisheries to achieve the objective of long term biologically and economically sustainable fishery with balance in fishing capacity and fishing opportunities.

8. Swedish large-scale pelagic fisheries

8.1 Introduction

The Swedish case study contains an analysis of large-scale pelagic fisheries. This pelagic fleet is currently the only Swedish fleet managed with ITQs. The ITQ system was introduced in 2009 in a situation where the fleet was characterized by overcapacity and low economic performance (SWaM, 2014). The purpose with the ITQ system was to improve the structure of the fleet which should contribute to an economically, environmentally, and socially sustainable fishery. Less efficient fishermen should be provided with a way out of the fishery without public support. Also, the reform was intended to improve the timing of landings to match the demand from the processing industry. However, while the purpose of the ITQ reform was to change the structure of the fleet there was still some features of the existing fleet that was considered important to maintain also after the reform. Thus, coastal fisheries were left out of the system and special rules were applied to parts of the Baltic Sea fleet in order for the fleet to keep landing in Baltic harbours.

The case study is performed by Staffan Waldo and Cecilia Hammarlund, AgriFood Economics Centre, Department of Economics, SLU, Sweden

8.2 Literature review

Several studies of the Swedish large-scale pelagic fisheries and the ITQ system have been published. The poor economic performance of the pelagic fleet before the ITQ system was studied by Nielsen et. al (2012) who found the resource rent in the fishery to be low (3% of catch value) despite a high potential. The result was compared to a set of other management systems in Nordic countries where higher performance was shown for the Icelandic ITQ system (30%), a Danish small-scale co-management system for mussels (51%), and the Faroese system with tradable fishing days (28%).

Two public evaluations of the pelagic ITQ system have been made; one by the Swedish Agency for Marine and Water Management (SwAM, 2014) and one by the Swedish Parliament (2017). SwAM (2014) finds that the number of vessels in the pelagic fishery has been reduced with 55% between 2009 and 2013. In the same period, the overall decrease in the Swedish fleet was about 12%. The decrease in the pelagic fleet was larger for vessels above 24 meters than for those below. The regional distribution of pelagic vessels has not changed significantly during the ITQ system. Of special political interest is the potential concentration to the Gothenburg area, where the evaluation shows that the share of the fleet from Gothenburg has decreased somewhat from about 58% in 2008 to 54% in 2013. Increasing the economic performance of the pelagic fleet was one of the objectives of the system, and the segment currently has the highest value added and the highest return on invested capital in the Swedish fleet (SwAM, 2014).

The evaluation by SwAM has been criticized by Stage *et al*. (2016) for not performing a counterfactual analysis, i.e. an analysis of the performance of the pelagic compared to a fleet where the ITQ system had not been introduced. This would be necessary in order to separate the effects of the ITQ system from other effects such as changes in other regulations, stock development and price levels. The authors also put forward a number of deviations from the "classic" ITQ model that have affected the possibility of the Swedish ITQ system to achieve the main objective of re-structuring the fleet. The deviations are the limitation of the system to ten years, the possibility for pelagic fishermen to enter other fisheries, ownership caps on quotas (maximum allowed shares of quotas), that ITQs are not possible to use as collaterals for bank loans, and the role of the coastal quotas.

The Swedish Parliament (2017) concludes in their evaluation that the pelagic fleet is currently economically viable. Further, the objectives that the ITQ system should reduce fleet size and enable improved possibilities to match landings with the demand from the processing industry have been met. The evaluation stresses the importance of the continued existence of small-scale fisheries and local landings serving local markets. They do not find the system to solve problems with access to local landings of pelagic species, and stress the importance of the special quotas set aside for small-scale coastal fisheries ("coastal quotas"). Further, the authors conclude that new fishermen (not previously involved in pelagic fisheries) face increased barriers for entering the pelagic fishery due to necessary investments in quotas.

The coastal quotas set aside to small-scale fishermen have been analysed by Waldo *et al*. (2013) in a case study on the western Baltic Sea herring fishery with gill-nets. This fishery takes place in the Öresund between Sweden and Denmark and was originally allocated about 5% of the Swedish quota in 2007. Coastal quotas are fished jointly by all coastal fishermen. The quota was attractive at the time and fishing increased, especially in the early season in the southern part of the sound. The traditional fishermen landing in the northern parts of the Öresund in late autumn receive about 30% higher prices since they sell on the market for Christmas herring, but faced quota restrictions due to competition for the joint quota. As a response the SwAM increased the coastal quota successively step by step until 2010 where it reached 20%, after which the share has been fixed.

Björk (2017) study the efficiency of quota trade using network analysis. She shows that trade with permanent quotas was more frequent in the early years of the system, while leasing is more frequent in recent years. She also finds a concentration of quotas to the Swedish west coast. This shows the potential regional imbalance in quota trade that was the motivation for assigning regional non-transferable quotas (these are not part of the analysis). Björk further point out that there is a lack of a transparent market for quota trade that will cause inefficiency since prices paid are private information. This increases transactions costs and the results show that trade is more likely to occur between actors that are more likely to physically interact (geographically close and have the same distribution channels) which reduces transaction costs. A less transparent market with high transaction costs might cause inefficient trading patterns. Thus, despite a high degree of reduced capacity during the initial phase of the Swedish ITQ system there might be a potential for further rationalizations within the pelagic fleet.

8.3 Management

Sweden is part of the European Union, and thus all Swedish fisheries management is within the framework of the Common Fisheries Policy. An important aspect of the Common Fisheries Policy is to find a balance between fleet capacity and fishing opportunities, and the Common Fisheries Policy states that the member states can choose its own measures to achieve this objective (EU, 2013; Article 22). The Swedish government has chosen ITQs for the pelagic fleet, and has opened for an expansion to other fisheries although the system has not been expanded yet. A system with leasable quotas has, however, been introduced in the demersal fishery in 2017 (SwAM, 2016) mainly as a response to the landing obligation adopted in the Common Fisheries Policy (Article 15).

8.3.1 The pelagic ITQ system

Before the ITQ system the pelagic fishery was managed by vessel catch limits designed as short term quotas lasting for two weeks at the time. Unutilized fish was returned to a common quota and redistributed among all fishermen. When the total Swedish quota was filled, the fishery was stopped (Nielsen et al., 2012). As a transition to ITQs, a system with individual non-transferable quotas was introduced in 2007, followed by the ITQ system in September 2009 (SFS 2009:866).

Transferable quotas have been introduced for herring, sprat, mackerel, Sand eel, and Blue Whiting. Since Swedish fisheries are geographically dispersed, this includes several quotas in both the Baltic Sea and the North Sea for herring and sprat. Quota trade is only possible among licensed fishermen, i.e. it is not possible for individuals or companies outside the fishing sector to own quota. To avoid ownership concentration, a cap of 10% of the total quota is applied.

An important feature of what is commonly called "the pelagic system" is that the Swedish pelagic quotas are divided into three parts. The first, and major, part is allocated to individuals and potentially traded within the system. The second part is a "coastal quota" that is set aside for coastal fisheries. This part of the quota is jointly utilized by small scale vessels primarily using gill-net, although small-scale trawling is allowed in some cases. These vessels are not allowed to simultaneously own tradable quotas. The share of total quota set aside for coastal fisheries vary with stocks, ranging from 0.5% to 20% of the total quota. The third part of the quota is a regional share for

Baltic Sea vessels. This part is allocated to vessels that fish in the Baltic Sea and land in Baltic Sea harbours. These vessels are larger than the coastal vessels and are included in the ITQ part of the pelagic system, although the additional regional quotas they get are not tradable. The regional quota is approximately 10% for Baltic sprat and 15% for Baltic herring.

8.4 Data

This section contains two parts. The first is a background describing the Swedish national fleet including a historical review of the development of the fleet. The second part focuses on the pelagic fleet (i.e. large-scale pelagic vessels included in the ITQ system) and contains the data used in the economic modelling.

8.4.1 The Swedish national fleet

Swedish fisheries consist of both marine and fresh water fisheries. The fisheries in marine water landed about 172 thousand tons of fish and crustaceans in 2014, where a majority (61%) was caught in the Baltic Sea (Statistics Sweden 2015a). The total catch value in 2012 was EUR 77 Million (SEK 700 Million, exchange rate 2014 is SEK/EUR 9.1), where herring, sprat, cod, Norwegian lobster, and North Sea shrimp are economically important species. The fresh water fishery is considerably smaller; total landings in 2014 were 1,598 tons at a total value of EUR 9 Million (SEK 82.7 Million; Statistics Sweden, 2015b).

The development of the Swedish national fishery from 2002 to 2014 is presented in Table 26.

Table 26: The Swedish national fleet, 2002, 2007 and 2014 and change between 2002 and 2014

	2002	2007	2014	% change 2002–2014
Physical indicators				
No. vessels	1,818	1,527	1,266	-30%
Days at sea (DAS)	122,300	152,700	77,700	-36%
DAS per vessel	67	100	61	-9%
Tonnage (GT)	44,900	43,300	29,000	-35%
Economic indicators				

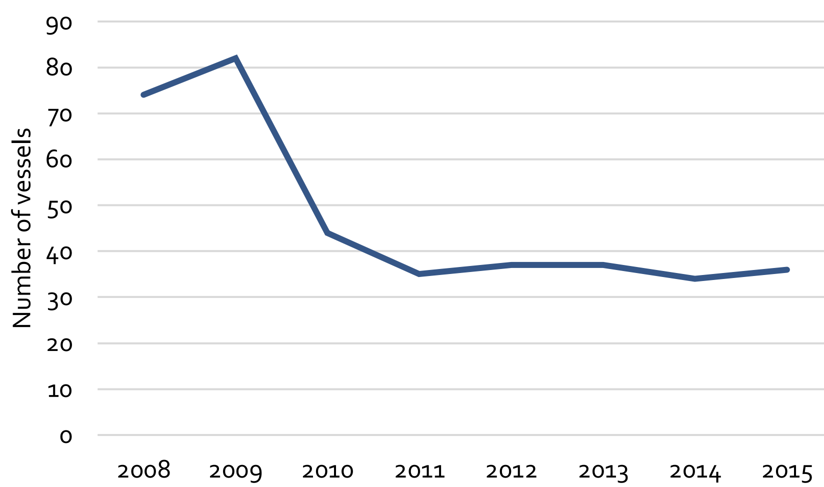
Source: Data for 2002 and 2007 are from *The 2011 Annual Economic Report on the EU Fishing Fleet* (STECF-11–16). Data for 2014 is from *The 2017 Annual Economic Report on the EU Fishing Fleet* (STECF 17–12).

As is clear from the table, Swedish fisheries have a negative trend with fewer vessels, lower total tonnage, lower profitability, and less employment.

8.4.2 The Swedish pelagic fleet

The number of vessels in the pelagic fleet dropped significantly after the introduction of the ITQ system in 2009 as is shown in Figure 16. After the initial drop in fleet size, the number of vessels has been stable around 35.

Figure 16: Number of vessels in the pelagic fleet, 2008–2015



In the analysis of the segment only commercially active vessels are included. In 2013–2014 there were 30 such vessels as presented in Table 27. Data is split into vessels 18–24 meters and vessels that are larger than 24 meters.

Table 27: Data of the fleets included in the model, 2013–2014

	PEL 18–24	PEL > 24 m
Physical data		
Full Time Employment per segment	22	145
Number of vessels	9	20.5
No. of Sea Days per vessel	99	115
Most important species (value)	HER (52%)	HER (52%)
Second important species (value)	SPR (21%)	SPR (27%)
Account data (1000 EUR per vessel)		
Turnover	412	2,355
Fuel Costs	73	484
Labour costs	119	338
Variable costs	116	410
Fixed costs	27	108
Capital costs	63	429
Opportunity labour cost	46	151
Opportunity capital cost	89	658
Profit	14	585
Socio-economic return	61	543

The table shows that the most important species for both fleets are herring and sprat. Other important species, especially for the larger vessels, are mackerel and sand eel. The fishery is currently profitable, as opposed to the general trend for Swedish fisheries presented in Table 26 above. Notably, the opportunity cost for labour is lower than the accounting costs indicating that fishermen in the segments have higher income in fisheries than expected in alternative employment.

Total allowable catch and MSY fishing mortality is presented in Table 28 for each of the utilized stocks. Further, the stock size in relation to MSY b-trigger is presented. This is the biomass level that triggers ICES to recommend a fishing mortality below F-MSY. The pelagic stocks utilized by the modelled fisheries are all above MSY b-trigger where this is defined.

Table 28: Biological data, 2015

	SSB (tonnes)	TAC (tonnes)	F-MSY	Comment
Mackerel	4,886,564	1,229,000	0.22	Stock above MSY B-trigger.
Herring Autumn	2,215,525	445,000	0.27	Kattegat, Skagerrack and North Sea. Stock size undefined for MSY B-trigger.
Herring Spring	129,845	65,800	0.28	Kattegat, Skagerrack and Western Baltic Sea. Stock size above MSY B-trigger.
Sprat North Sea	370,460	350,000	1.20	Stock size above MSY B-trigger.
Sprat Baltic Sea	889,000	240,200	0.29	Stock size above MSY B-trigger.
Herring Baltic Sea	1,013,132	186,351	0.26	ICES areas 25-29 + 32. Stock size above MSY B-trigger.
Herring Bothnian Bay	773,747	158,000	0.15	ICES area 30. Stock size undefined for MSY B-trigger.

Source: All data is from the ICES advice.

8.5 Results

This section presents the results from the model runs using the FishRent model. As presented earlier in the report, four scenarios have been considered for the analysis. Of these, scenario 2 has not been run for the Swedish case. The reason is that the scenario is defined as a relaxation about quota trade restrictions between segments. There are no such restrictions in the Swedish case. However, coastal and regional quotas will be discussed in the discussion section, although it has not been possible to explicitly model these. Thus, the specific scenario characteristics for the Swedish case are:

1. Current Swedish management. Maximum annual change in fleet size is 4%;
3. Current Swedish management with unlimited fleet adjustment. The change in fleet size is not limited;
4. Current Swedish management with a 10% landing tax. This scenario is the same as scenario 1, but the fishery is taxed with 10% of the landing value.

Each of the scenarios are runs calculating the socio-economic return and the profitability respectively.

8.5.1 Socioeconomic return

This section contains the model results where the socioeconomic return from the fishery is maximized. The result for 2015 and 2025 for the fleet size, employment, and socio-economic return is presented in Table 29 below.

Table 29: Forecast of socio-economic return, fleet, and employment in 2025 by maximizing socioeconomic returns

Scenarios	PEL 18–24 m	PEL > 24 m	Total
Socio-Economic return (mill EUR)			
2015 initial situation	0.8	10.6	11.4
2025 scenarios:			
1. Current management	2.0	20.2	22.2
3. Current management full adjustment	2.1	23.9	26.0
4. Current management 10% landing tax	2.0	20.2	22.2
Number of vessels			
2015 initial situation	9	21	30
2025 scenarios:			
1. Current management	8	17	25
3. Current management full adjustment	8	14	22
4. Current management 10% landing tax	8	17	25
Employment (full-time)			
2015 initial situation	23	146	168
2025 scenarios:			
1. Current management	19	122	141
3. Current management full adjustment	21	99	120
4. Current management 10% landing tax	19	122	141

Both segments show a positive socio-economic return in the initial situation. This implies that the fishery contributes to society with wages and return to capital that is larger than if the same resources were used in other parts of society. Notably, this was not the general case before the ITQ system, and many Swedish fleet segments outside the ITQ system still have negative socio-economic returns (Waldo and Wingård, 2010; Waldo and Paulrud, 2013). Further, the model predicts a substantial increase in the returns for the two fleet segments in 2025. The reason for this is an expected improvement in stock development (i.e. stocks are closer to what is economically optimal) and an increased efficiency in the fleet, i.e. the fishery is in a situation closer to economic optimum. Increased efficiency could be due to improvements in the quota market (Björk, 2017) or due to better utilization of the vessels (more days at sea per vessel occurring when e.g. some fishermen choose to leave the fishery). The stock development implies that many stocks increase to (or even above) their historically observed maximum levels. This might not be biologically achievable simultaneously for all stocks, which is not considered in the model. Thus, the absolute values of the predicted socio-economic return should be viewed as an upper limit. In line with this, we do not further discuss the development compared to the current situation, but focus on comparisons between the different management scenarios discussed above.

Comparing the different scenarios, the first conclusion is that the fleet size is approximately the same in all cases ranging from 22 to 25 vessels. 22 is for scenario 3 where the model does not have any limitations on fleet development. This scenario also has the highest socio-economic return, EUR 26 Million. The result is due to the fleet rapidly adjusting to a long-run equilibrium fleet size that is economically more efficient than the current fleet. Such development has been observed historically in 2009–2011 when the ITQ system was introduced. However, after that the fleet has adjusted only slowly and a rapid change in fleet structure is less likely to occur. Thus, scenario 3 can be viewed as the potential development in a fully efficient system. As modelled in scenario 1, such changes might take time in practice, but could be expected to occur eventually.

Turning to scenario 4, where 10% of revenues are taxed, the socioeconomic return is by definition the same as in scenario 1 since this is the maximum possible economic return from the fishery for society. However, in this scenario part of the rent is allocated to government through the landing tax. Total taxes would be approximately EUR 7 Million out of the EUR 22 Million in socioeconomic return. In this scenario, it is assumed that fishermen do not change behaviour due to taxation and thus allocate resources in order to maximize the socioeconomic return. The private profit will however change, as discussed below.

8.5.2 Profitability

This section contains the model results where the private profitability of the sector is maximized. The results showing the profitability of the sector in the different scenarios are presented in Table 30 below.

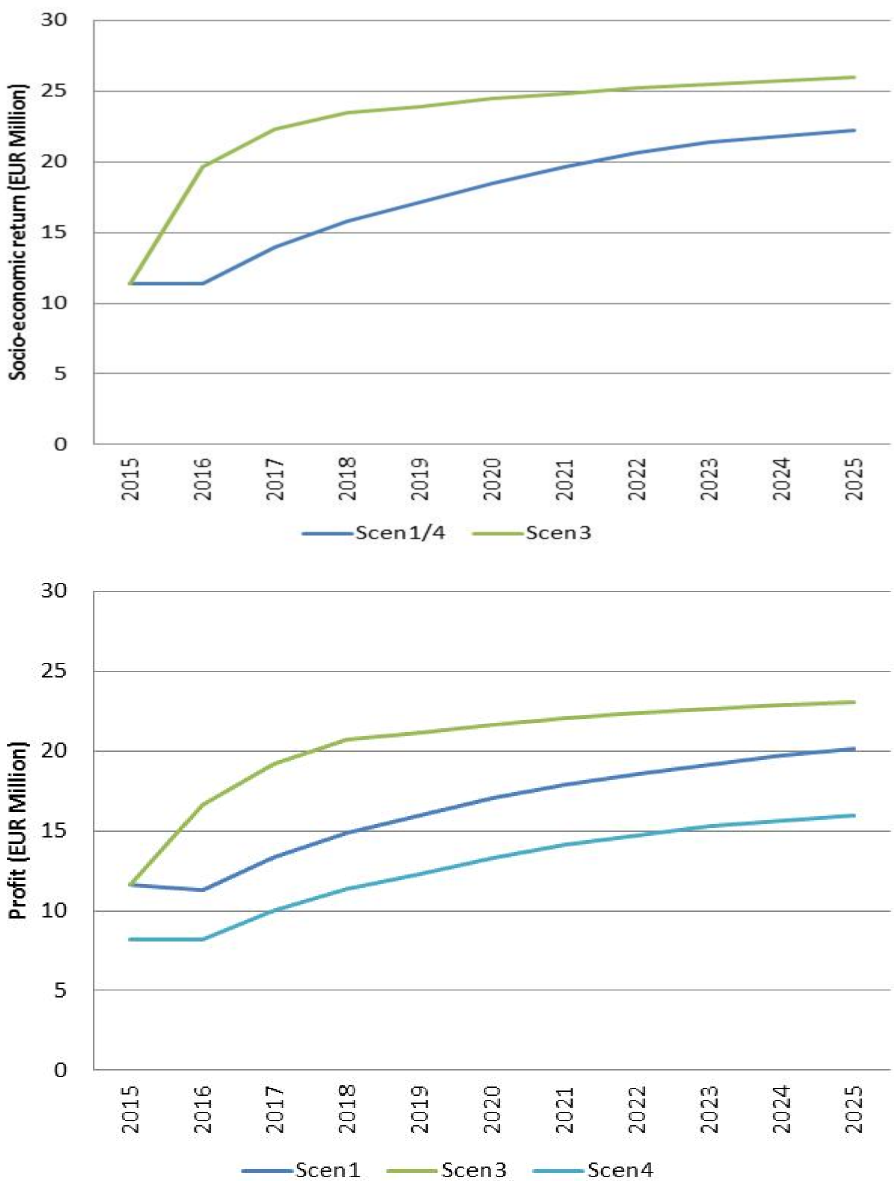
Table 30: Forecast of profit, fleet and employment in 2025 by maximizing profit

Scenarios	PEL 18–24 m	PEL > 24 m	Total
Profit (million EUR)			
2015 initial situation	0.24	11.41	11.65
2025 scenarios:			
1. Current management	0.79	19.33	20.11
3. Current management full adjustment	0.44	22.67	23.11
4. Current management 10% landing tax	0.58	15.42	16.00
Number of vessels			
2015 initial situation	9	21	30
2025 scenarios:			
1. Current management	6	17	23
3. Current management full adjustment	2	15	17
5. Current management 10% landing tax	6	17	23
Employment (full-time)			
2015 initial situation	23	146	168
2025 scenarios:			
1. Current management	15	123	137
3. Current management full adjustment	5	105	110
5. Current management 10% landing tax	15	122	137

Starting with the fleet development, the fleet is expected to decrease during the period. This is similar to the development in the model runs for socioeconomic returns. However, in scenario 3, where the fleet is allowed to develop without limitations, the reduction in the segment for vessels 18–24 meters is more severe in the profit maximization case. In this case, the vessels are assumed to pay the crew a specific share of revenues as wages. This share is higher for the smaller vessels, and when the fleet is rationalized the wages per worker will increase more for the smaller vessels than for the larger. Thus, if labour contracts are not possible to re-negotiate, it might be more profitable to sell the quotas to fishermen with larger vessels.

Turning to profits, the profitability is lower than the socioeconomic returns in all cases. This might be due to several causes. One is that labour and capital has higher remuneration in the fishery than in alternative use, e.g. when workers are better paid than in other industries. This is a cost to the fishermen that will reduce profitability. Further, the fishermen will have to buy quotas if expanding their fishing which will reduce the private profits. The largest deviation from the socioeconomic return is for scenario 4. In the case of private profits, the outcome is negatively affected by the taxes and the profits are thus considerably lower than for socioeconomic returns which include both private profits and tax revenues. In Figure 17, the socioeconomic return and profitability for each scenario are presented for the entire studied time period.

Figure 17: Forecast of socio-economic return (top) and profit (bottom) 2015–2025, EUR Million



Both socioeconomic returns and profitability show very similar patterns, although the absolute values differ as discussed above. Scenario 3 has the highest values and deviates from the others by a much faster adjustment towards high profitability/socioeconomic returns. This is the scenario with no adjustment restrictions, and thus this could be viewed as an upper limit to possible adjustments. Scenario 4 is identical to scenario 1 for socioeconomic return, but for profit it is clear that the private profitability for a taxed fishery is below the other scenarios for all years.

8.6 Policy considerations

A fundamental result from the analysis is that it supports the view of the Swedish ITQ system generating an economically viable pelagic fleet. Before ITQs the fleet showed considerable over capacity and profitability was low. The purpose of the management system was to support a change in the fleet structure that would sustain fish resources and be economically and socially sustainable. The ITQ system has been evaluated twice since the introduction in 2009. SwAM (2014) concluded that "the effects observed in the pelagic system after the introduction of transferable fishing concessions do to a high degree coincide with the objectives of the system" (p31, author's translation). A few years later the Swedish Parliament (2017) concluded that "The purpose of the pelagic system with transferable fishing concessions has been fulfilled regarding changes in the fleet structure. The pelagic fishery has become more economically sustainable, but it is unclear if the fishery has become more environmentally and socially sustainable" (p 172, author's translation). Based on these evaluations, the pelagic system was made permanent in 2017 (Swedish government, 2017). The results from this study not only confirm that the fleet is economically sustainable, but also predicts that it will continue to be so over the studied period. The fleet is actually predicted to increase profitability over the studied period, but this depends on the possibilities of increasing stock sizes and further rationalizations of the fleet.

A profitable fleet contributes economically to society through the tax system. Tax revenues to society are thus expected to be higher today than before the ITQ system when profitability was low. However, it is possible to further tax fishing companies motivated by the public ownership of the fish resource that is used for fishing. The result from scenario 4 shows that a 10% landing tax would reduce profitability in the sector, but that fishing patterns would stay approximately the same. The sector would still be profitable. Taxation has not been a major topic in the Swedish debate and it was not discussed in the process of making the system permanent in 2017. If introducing taxes in a mature ITQ system (that is already decided to be permanent), it is important to take into account that additional taxation might be problematic for companies that have made major investments under the assumption of no taxation.

An important feature of the management system is the allocation of quotas to the Baltic Sea regional fleet, and the specific quotas for small-scale fisheries not modelled above. The purpose of the latter is to assure access to quota for the coastal fleet. The share depends on stock, but is most commonly only a few percentages of the total quota. An exception is the spring spawning herring in the western Baltic Sea where small-scale fisheries have been allocated a share of approximately 20%. This system is strongly supported by the industry and the SwAM (2014) concluded that the small-scale fleet has been able to continue its fishing using this exception. The shares of the quotas allocated to small-scale fisheries have increased since the introduction of the ITQ system. The size of the coastal quota is still discussed since this is an important aspect of the development of the small-scale fishing fleet.

Recently, quota swapping between small- and large-scale fisheries has taken place in order to improve quota utilization. Regional quotas for the Baltic Sea pelagic fleet is allocated outside the ITQ system, constituting 10% of sprat quota and 15% of the herring quota. Vessels with regional quotas may also own ITQs on top of the regional allocations, but the regionally allocated quotas are not possible to trade. The purpose of this is to maintain a pelagic fleet based in the Baltic Sea. According to SwAM (2014) the regional balance of the fleet has been maintained. From a theoretical perspective it could be argued that the regional quotas decrease economic efficiency in the fleet. Whether it is a preferred policy depends on the value of having a regional fleet, how important the regional quotas are for maintaining that fleet, and the economic loss of restricting trade.

In 2014 the Swedish parliament delegated to the government to decide whether ITQs should be introduced in other fleets than the pelagic (Prop. 2013/14:184). This opened for an extension of the ITQ system in the future. There is currently no decision to do this, but the SwAM has introduced a management system with individual leasable quotas for the demersal fishery. The background is the landing obligation decided in the 2013 reform of the Common Fisheries Policy (EU, 2013). In fisheries with multiple species caught at the same time, a landing obligation implies that all fishing must stop when the first quota is fully utilized. This is called a choke species. With common pool quotas, the incentive for the fishermen might be to fish as much as possible before this quota is full rather than investing in selective gear to avoid catching the choke species. Thus, individual quotas were allocated to all fishermen with the possibility of leasing quota on a yearly basis. Leasing was allowed for fishermen to be able to adjust their quotas to their catches in order to minimize the impact of choke species (SwAM, 2016). While it is clearly stated by the SwAM that this is not an ITQ system and trading of permanent quotas is not allowed, it is still possible to own multiple vessels and it is possible to make long-term contracts on quota leasing. Thus, the system has some similarities with an ITQ system. However, the new management system has not been in place long enough to see any long-term patterns with regard to this. If an ITQ system is introduced in Swedish demersal fisheries it might increase profitability substantially, even if small-scale fisheries are protected by trade restrictions similar to those in the pelagic ITQ system, as found in Waldo and Paulrud (2013).

Model results like the ones presented in this chapter should always be interpreted with caution since the development of the fleet and economic performance is highly dependent on assumptions. In the Swedish case the stock development for some of the stocks are very favourable and a combination of multiple stocks increasing might not be realistic from an ecosystem perspective. Thus, the development from today to the 2025 situation could be considered an upper limit. The strength of a model is the comparison between different scenarios. This shows how policy changes affect the sector under the same common development trends (e.g. stocks). In the scenario with instant adjustment, it is shown that there is a potential for further rationalization of the pelagic fleet that is less obvious in the other scenarios where the change in fleet adjustment is limited. Such efficiency gains might not be possible in the short run though, since current ownership structures, past fleet investments etc. set the baseline for the development until 2025. However, the model predicts that in the long run further rationalizations might take place. Also, potential changes in the system itself, such as the possibility to take bank loans based on quotas, might increase rationalizations.

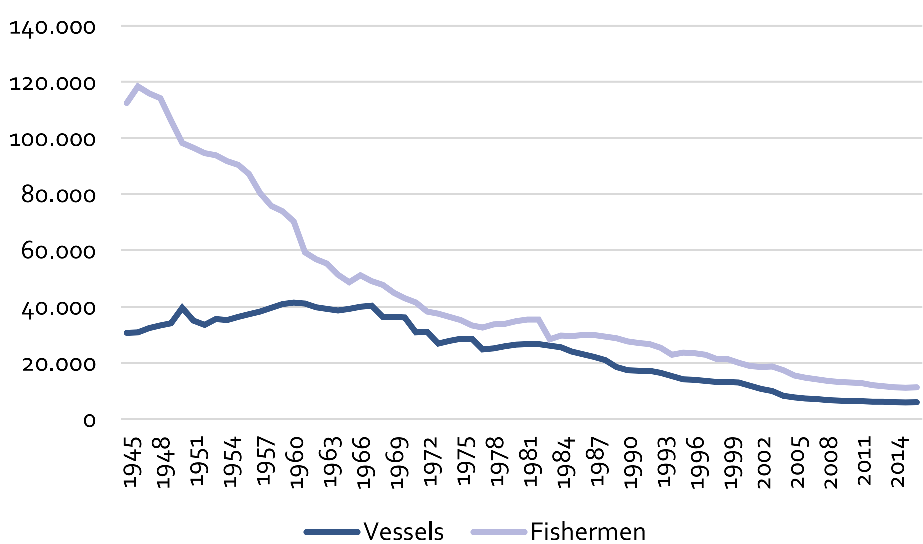
The conclusion from the Swedish case study is that the pelagic fleet is economically viable and seems to continue being so during the studied period, although profitability in the sector will decrease if a landing tax is imposed.

9. Norwegian Groundfish Fishery North of 62°

9.1 Introduction

The long Norwegian coastline is home to very rich fishing ground, making Norway one of the world's biggest fishing nation. The fishery sector has always played an important role both economically and socially, regionally and nationally, and has been important for settlement and employment along the Norwegian coast. In 2015 the total landings were 2,334,564 tons, with a first-hand value of approximately NOK 16,928 Million (SSB 2016). In many coastal areas the fishing industry is very important, as a considerable number of people rely on the fishing industry for employment. There were in 2015 registered 5,884 fishing vessels in Norway, and 11,130 persons were register as fishermen, by these 9,259 fishing was the main occupation. Figure 18 shows the overall development in number of registered fishing vessels and persons occupied in fishing over time. As seen from the Figure the number of vessels and fishermen has decreased steady since the 1940s. Despite the continued decline in number of vessels, overall engine power, and hence catching capacity is about unchanged. The reason is that the players invest in new vessels with larger catch capacity that replace the older and less efficient vessels

Figure 18: Development of vessels and fishermen 1945–2016



Source: (SSB 2016).

The main species in the Norwegian fishery include herring, cod, capelin, mackerel saithe, blue whiting and haddock. A number of additional species are caught in smaller quantities, but have high commercial values. The Norwegian fishing fleet is subdivided into two main fisheries; Demersal fisheries (i.e. cod haddock and saithe etc.) and pelagic fisheries (i.e. herring, mackerel, capelin, Norwegian pout and blue whiting etc.). While the pelagic fleet is largest in terms of landings, the demersal fishery is the most valuable. The Norwegian groundfish fisheries are by far the most valuable fisheries in Norway. They operate year-round, although with substantial seasonality in catches. Cod (*Gadus morhua*) is the main species, but large quantities of saithe, haddock, and Atlantic redfish are also harvested.

The fishing fleet working the ground fisheries is diverse, ranging from smaller coastal vessels fishing with gill nets, handlines, and Danish seines, to large, modern, oceangoing vessels. The ocean-going fleet is defined as vessels over 90 feet or 28 meters "hjemmelslengde", it is mainly trawlers and large conventional vessel using long-line. The conventional coastal vessels are the vessels under 28 meters, and load capacity below 500 m^3 that uses mainly conventional gears to fish (such as nets, longlines, Danish seines, traps and hand lines) (NOU 16, 2006). While most of the coastal fleet operates in a relatively seasonal inshore fishery, the ocean-going vessels operate year-round in the North Atlantic. The ages of the vessels also differ substantially, leading to large variation in capital cost. Beside differences in size, gear type and age, individual vessel within this fishery are managed quite differently. Like most modern management systems, this fishery divides the fleet into groups. These groups are managed differently, to maintain fleet diversity and various social objectives, i.e. regional policy and planning.

The purpose of this chapter is to forecast the development in the Norwegian ground fishery North of 62° until 2025 with the current management, and to assess the effect of possible future policy changes approaching 2025. We have chosen to focus on this fishery since it is the biggest fishery in Norway in terms of value, further it is highly diverse in terms of vessel size, management and gear utilized. In this study we are focusing on vessels from six different fleet segments; Trawlers, Conventional ocean-going vessels, and four length-groups of coastal vessels; and the four most important species: cod, haddock, saithe and herring.

The case study is performed by Kristin H. Roll from the business school at University of South-Eastern Norway, Norway in collaboration with Ayoe Hoff from Institute of Food and Resource Economics, University of Copenhagen, Denmark.

9.2 Literature review

Several studies have been conducted to investigate different aspects of the Norwegian fishery management. Maurstad (2000) compare small-scale fishermen's practices before and after vessel quotas were introduced to Norway, and pose interesting questions concerning the models for resource management on which these regulations are based. Armstrong and Sumaila (2001) *study the allocation rule (the trawl ladder)* *applied to split the Norwegian total allowable catch for cod between coastal and trawler vessels. Further, they explore the bioeconomic implications of an ITQ management system for this fishery. They find that an ITQ system for this fishery is likely to result in economic losses, as the biological advantages of harvesting with the two vessels types may be lost.* Standal and Aarset (2008) analyse the Norwegian Individual Vessels Quota system and discuss whether the aggregate effects of the Individual Vessels Quota regime are congruent with the models' profound ideals of a diverse fleet structure and decentralized ownership of scarce cod resources. Guttormsen and Roll (2011) demonstrate how a heterogeneous fleet, both in terms of catch capacity and management regimes, can contribute to variations in vessel performance. The results indicate substantial variation in technical efficiency both between and within vessel groups and concludes that both managerial skills and an inefficient management regime contribute to heterogeneity in the Norwegian ground fish fleet. Gordon and Hannesson (2015) investigate the empirical impact of technological shocks on herring stocks in Norway. They illustrate that it was the unmanaged use of new technology (such as power block) in an unmanaged fishery that allow for the demination of the herring stock and argue that regulation of the new technology would have resulted in less stock depletion.

Hannesson (2013; 2014) argue that the fisheries management in Norway has some unmistakable characteristics of an *ITQ* system. In the paper the development of this system in the purse seine fleet and the fleet fishing for cod and similar species is traced, and the concept of resource rent is discussed. The results show that the resource rent has become capitalized in quota values, which show up as a rise in value of long term assets of the fishing industry. This is further discussed in Hannesson (2016) where prices of fish quotas in Norway are estimated. It is found that quota prices in most cases exceed the resource rent and are more consistent with a willingness to pay for additional quotas bought to improve the utilization of existing equipment. Asche, Bjørndal, and Gordon (2009) also investigate rent generating proses for a fishery managed with individual vessel quotas – Norwegian trawlers with onboard processing. In a reason paper Pincinato *et al.* (2018) investigates the impact of transferable fishing quotas on cost, price and season length, for the smallest Norwegian coastal vessels.

Earlier studies have also compared the fishery management in the Nordic countries. Arnason, Hannesson, and Schrank (2000) investigate management costs in the fisheries of Iceland, Newfoundland and Norway and discusses the question of whether management costs should be paid by industry. Eggert and Tveterås (2013) analyses the Total Factor Productivity (TFP) performance of fisheries in Iceland, Norway and Sweden during the period 1973 to 2003. Their hypothesis is that rapid diffusion of fishing technology innovations contributing to productivity convergence, and that innovations in the public regulation and the industrial organization may also have influenced productivity growth during the period. The results reviled however, no evidence of productivity convergence among the three countries.

9.3 Management

The aim of the Norwegian fishery management is two-sided; The goals of the regulations is not only to prevent overfishing and maintain a sustainable fishery, but also to ensure that fisheries play an important part in Norwegian regional policy and planning. (Guttormsen and Roll, 2010). Hence, the regulatory system has, to a certain degree, been developed to maintain coastal communities and traditional small-scale coastal fisheries, in addition to avoid the depletion of stocks.

Norwegian fisheries management system dates back to the 18-century. The regulations have however progressed gradually. Through interaction between industry and management, and trial and error teaching the Norwegian fishing industry has evolved into a highly regulated industry with both output- and input regulation. Input regulation means that the regulators restrict the access to fishermen, by restricting how many vessels that are allowed to participate, and also season length. It can also be technical regulations – such as gear restrictions. In Norway all vessels (except for a group of the smallest coastal vessels) require a license to participate in the fishery.

Output regulation means that regulators restrict how much fish that can be landed every year, by setting a Total Allowable Catch. In general, the quota system process starts with the Norwegian Government establishing the Total Allowable Catch for the main species for the domestic fleet based on ICES advice, which is supported by scientific stock assessments. The Total Allowable Catch is then allocated among the different fleet segments. For cod North of 62° there are seven fleet segments. Figure 19 gives a simplified sketch of the quota allocation for Norwegian cod North of 62° in 2016 (Nofima and Norwegian directorate of fishery).[11] First the total Norwegian quota are divided between trawlers and conventional vessel. The Norwegian cod quota is allocated between trawlers and the conventional vessels using an instrument known as the "trawl ladder". The objective of this management tool is to give a high degree of predictability and stability to the smaller vessels, and hence contribute to Norwegian regional policy goals. The "trawl ladder" stabilizes the quota for coastal vessels by allocating coastal vessels a larger part of the total fishing quota in years with modest biomass than in years with higher biomass and higher total quota. If the total quota of cod is low, the trawlers get 27% of the quota, rising to 33% at high quota levels. This keeps coastal vessels yearly quota relatively stable compared to the larger vessels. Larger vessels are then granted a relatively smaller quota in years with a smaller total quota, and hence the size of their group quota fluctuates more than the total quota. The ladder is mainly based on historical rights between different gear and vessel groups. A similar system exists for Norwegian spring-spawning herring.

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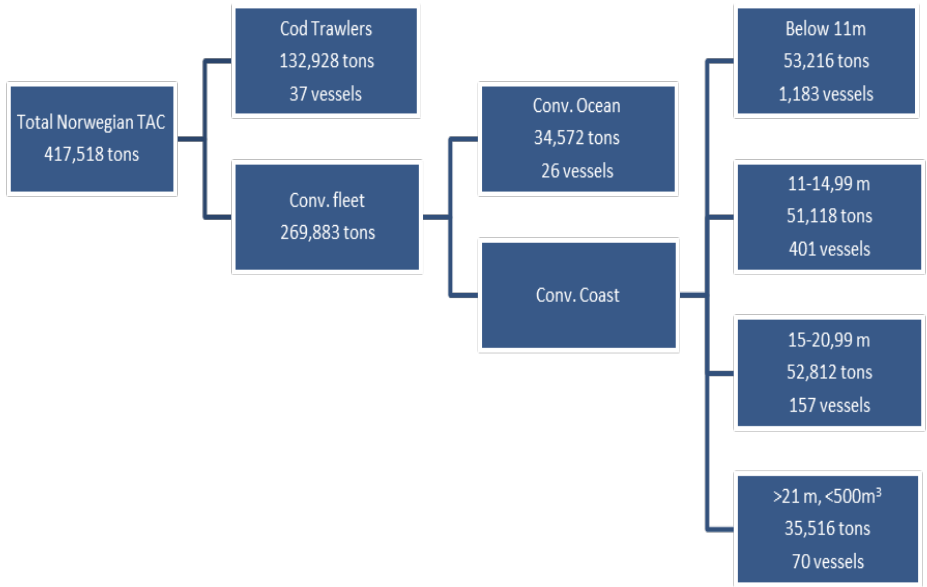
[11] For the distribution of the total quota, a smaller quantity is used for various purposes, such as recreational fishing, R&D quota bonuses, etc. There is also a seventh regulatory group that is not included in the figure; an open group for conventional vessels with load capacity below 500 m^3.

Figure 19: Quota allocation for Norwegian cod North of 62° in 2016



Source: Nofima and Norwegian Directorate of fishery.

The quota allocated to the conventional fleet are then subdivided between offshore and coastal vessels, before the coastal quota is subdivides into four different size groups. The background for the four-different size segment was to to shield the smallest coastal vessels and prevent the transfer of fishing opportunities from small to large vessels. Therefore, from 2003, the conventional gear vessels were grouped in four ranges size: 1) 8–9.9m, 2) 10–14.9m, 3) 15–20.9 and 4) 21–27.9m up to 2007, when a revision took place and rearranged the sizes to 1) <10.9m, 2) 11–14.9m, 3) 15–20.9m, and 4) 21m to a hull capacity of 500 m^3. The classification of each vessel in these groups was based on their actual size in a specific date regardless later changes on the vessel. For the vessels smaller than 28 meter fishing for cod, the cutting date was on December 1998, while for the coastal vessels fishing for saithe and haddock that had access to participate in this group from 2003 the cutting date was on November 2002 (St. Meld 21).

The allocation of quota between different vessels within a group has varied over time. In the coastal fleet historical length is used as a criterion, while in the ocean going fleet weight and quota factors determine the distribution. As early as 1984, a system with vessel-specific quotas was introduced for parts of the fleet. However, as the quota for a vessel group was smaller than the sum of the vessel quotas, the vessel quota primarily acted as the maximum catch for each vessel but without significantly reducing competition in the fishery. Further, the quotas have frequently been distributed in packages, which include several species (i.e. cod, saithe and haddock). This forces vessel to diversify instead of specializing on one species. The coastal fleet can, however, to some degree decide if they want to fish both whitefish and pelagic fish or if they want to specialize in one of the sectors, while ocean going vessels do not have the right to have quotas in both the whitefish and pelagic sectors.

In order to reduce overcapacity and to increase the productivity in the sector two schemes were proposed by the Government: decommissioning and structural quotas. Structural quotas allow fishermen to transfer their vessel's quota to another vessel in the same group and region of the country. The premise is, however, that the vessel that sells its quota is actively removed from the fleet, and that the quota itself is returned to the resource base after a fixed period. In addition, an upper limit is set for how many quota factors each vessel could hold. By this system a vessel can acquire additional quotas and hence better utilize its capacity. As argued by Hannesson (2013) this system is similar to an ITQ system, but with more restrictions to it.

The trawlers were the first vessel group that implemented this system. From 1996, the vessel quotas added up to the total quota for the trawlers, and structural quotas were implemented. The aim of this system was to reduce overcapacity; however, according to Standal and Aarset (2008), as technological changes in the same period increased the capacity per vessel, capacity was not actually reduced. It was not until 2004, when quota tenure was increased, and smaller vessels were included in the same system, major capacity reduction took place. The first coastal vessel group to have a structural quota system were conventional coastal vessels over 14.9 meter in 2004. In 2006, the Government stopped processing new applications for the structural quota while evaluating this new measure. In 2007, after this review, also vessels over 10.9 meter were included under the structural quota system.[12] In 2007 there were also established a time limit for holding the structural quota. Structural quotas allocated before 2007, can be hold for 25 years, while structural quotas awarded after 2007, can hold for 20 years.

To prevent geographical distribution and concentration of quotas among the largest and most capital strong players, the regulators has put some restrictions to this system. The quota exchange is limited to within the same vessel size group.[13] Therefore, if one vessel group develops a technology that makes it more efficient, it cannot obtain quotas from a less efficient vessel group to increase the efficiency of the total fishery. This restriction, which effectively prohibits changes in the composition of the fleet arising from vessel-specific innovations, has potentially led to a loss in efficiency for the industry as a whole. Further, the system also incorporates a regional preference as the quota exchange is limited to vessels within the same region. Southern vessels cannot buy quotas from northern vessels, but vessel owners in the northernmost part of Norway are allowed to buy vessels with quotas from the whole country.[14] There is also an abbreviation of the quota transfer, as the regulator retains part of the quota from the removed vessel. When exchanged only 80% of the original quota is transferred to the buying vessel, while the remaining 20% is shared

[12] The smallest coastal group (vessels under 11 meter) are still not included in the structural quota scheme. This group is unattended because of their special importance for settlement, employment, geographical distribution and varied fleet structure. Instead of the structural quota scheme, this vessel group have instead an access to a "fish together" scheme. The "fish together" scheme indicate that two vessels in the closed group under 11 meters can share their quotas.

[13] This has one exception; quota transfer is possible between the two large trawler groups (factory trawlers and fresh/freeze trawlers).

[14] Southern located trawlers can buy quotas from Northern located trawlers, but the abbreviation is 60%.

among all the vessels in the same group for conventional ocean and coastal vessels. For trawlers there are no abbreviation for transferring of quota within a region.

Table 31: Structure status, 19 January 2016

Vessel group	Quota roof (inkl. the vessels individual quota)	Degree of structuring (%)
Cod trawlers	4 quota factors	Cod/haddock: 61% Saithe: 62.5%
Conv. Ocean	Cod/haddock: 5 quota factors Saithe: 2 quota factors	Cod: 68.9% Haddock: 70.6% Saithe: 41.8%
Conv. Coast	For 15–27,99m: 3+3 or 4+2 For 11–14,99m: 2+2 or 3+1	Cod: 33%[1] Haddock: 33.6%[1] Saithe :33.6%[1]

Note: 1. This includes all size groups within the conventional coast fishery, also vessel groups that are not part of the structure quota scheme.

Source: NOU2016: 26.

There are also limitations in how many structural quotas that can be allocated a single vessel. This "quota roof" is set separately by vessel group. Determining "quota roofs" is a dynamic process, where "quota roofs" change when efficiency and profitability advocates. The size of the quota factor also changes from year to year dependent of the total yearly quota. Table 31 gives the quota roof per 19 January 2016. The Table also reports the degree of structuring, which is the share of the total quota from structural quota. It is not possible to sell parts of the quota within a year, but there exist a number of schemes to remedy this lack of flexibility. NOU2016:16 summarize these structures in tidy manner.

9.4 Data

The data are provided by the Norwegian Directorate of Fisheries, which each year collects data for all vessels larger than eight meters. All whole-year operating vessels are legally obliged to complete and return the questionnaire together with their annual accounts and are hence include in our data.[15]

The fleet segments included in the analyses for the Norwegian case is:

- Conventional coastal fishing vessel below 11 meters "hjemmelslengde";
- Conventional coastal fishing vessels 11–14.9 meters "hjemmelslengde";
- Conventional coastal fishing vessels 15–20.9 meters "hjemmelslengde";
- Conventional coastal fishing vessel 21 meters long and above;

[15] Whole-year operating vessels are defined as vessels that landed fish in at least seven months in a year, and that have an income from fishing above a specific threshold.

- Conventional ocean fishing vessels;
- Cod trawlers including trawlers in other bottom fisheries.

The first four are defined as coastal vessels, while the two last are defined as ocean going vessels. Summary statistics for the average vessels in each fleet segment are presented in Table 32. Model parametrization data is based on averages for the period 2012–20014, i.e. the three-year period leading up to the modelled period.[16] The average number of vessel and days at sea per vessel, together with the cost data given in Table 32 has been used to initialize the model in 2015 for each segment.

Table 32: Average base indicators for the fleets included in the analysis over the period 2012–2014

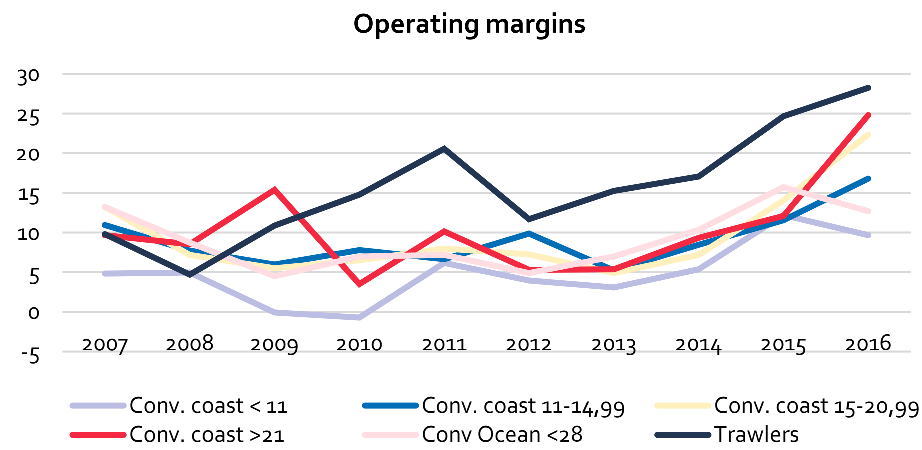
Average 2012–2014	Conv. Coast < 11	Conv. Coast 11–14,99	Conv. Coast 15–20,99	Conv. Coast >21	Conv Ocean <28	Trawlers	Average per vessel[4]
Physical data							
FTE[1]/segment	1.5	3.2	6.8	11.9	35.2	37.0	4.6
Number of vessels	687	288	119	34	25	39	1,192
Days at sea/vessel	149	159	168	201	315	294	163
1st important species[2,3]	COD (74%)	COD (69%)	COD (64%)	COD (51%)	COD (61%)	COD (57%)	COD (61%)
2nd important species[2,3]	HAD(19%)	HAD (16%)	HAD (18%)	HER (20%)	HAD (30%)	POK (23%)	HAD (20%)
3rd important species[2,3]	POK (7%)	POK (12%)	HER (11%)	HAD (17%)	POK (9%)	HAD (20%)	POL (16%)
Account data (EUR 1000/vessel)							
Turnover/Revenue	149	365	828	1,931	5,475	9,876	750
Fuel Costs	9	21	64	188	608	1,762	92
Labour costs	70	168	349	705	2,168	3,043	281
Variable costs	28	57	128	318	1,033	1,449	121
Fixed costs	25	61	140	336	658	1,093	102
Capital costs	7	13	29	54	43	412	26
Opportunity labour cost	1	1	2	3	6	7	2
Opportunity capital cost	77	164	354	616	1,818	1,914	238
Profit	10	45	118	330	965	2,117	127
Socio-economic return	9	61	140	470	1,352	3,651	195

Note: 1. "FTE"=Full Time Employment.
2. Relative importance of landed species is measured in value.
3. "COD"=cod, "HAD"=Haddok "POK"=Saithe, "HER"=Herring.
4. For "Number of vessels" this column result represents the sum and not average.

Despite its smaller size, the coastal fleet is still important because its rich number of vessels. The large number of licenses and vessels make the fleet important and it takes about 50% of the cod landings. The average profit is proportional to the size of the vessel. The profitability measured by the operational margin and returns of assets give a better picture of the average return within each vessel group. Figure 20 illustrates the development in operating margins and return of assets for the fleet segments over the last 10 years. Profitability varies over time and between vessels and vessel groups. As can be seen from the Figures, the trawlers are the most profitable for the most years, while the smallest coastal vessels are the least profitable. It should, however, be mentioned that this is average numbers and that there are large variations within each fleet segment.

[16] It is assumed that the cost, price and catch pattern in the projection period (2016-2025) are identical to the structure in the years leading up to the period.

Figure 20: Development in operating margins (in percent) and return of assets (in percent) for the fleet included in the model projections



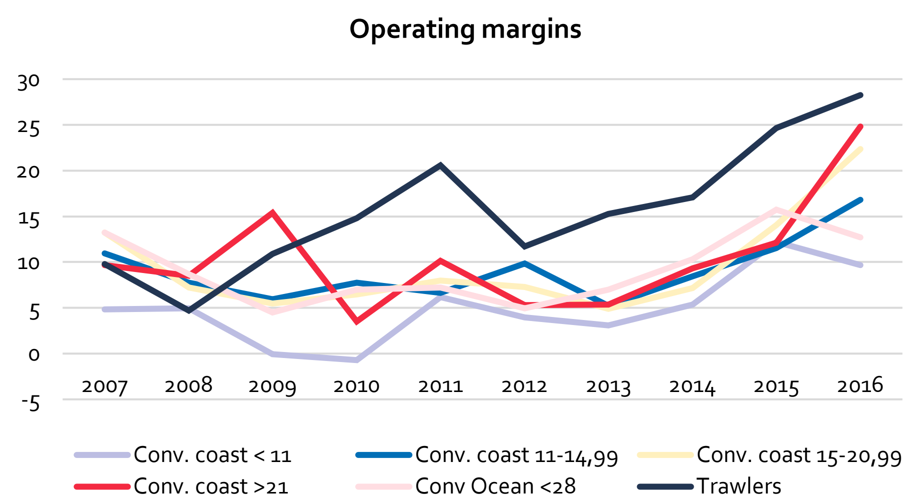
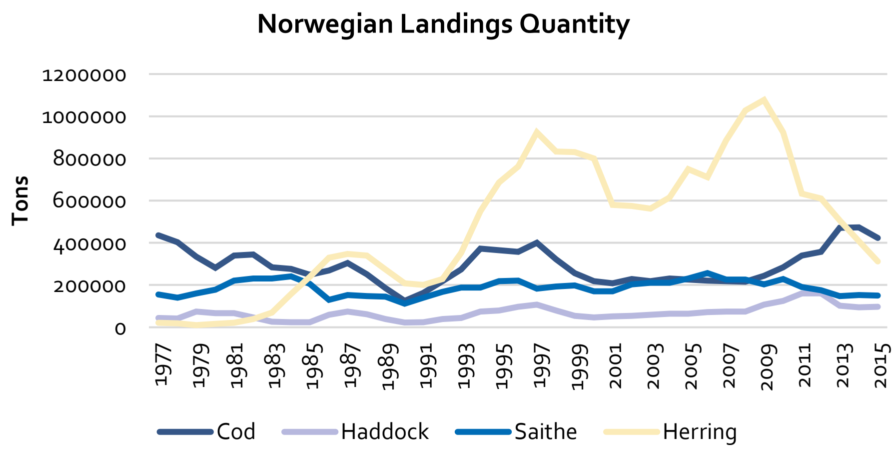


Table 32 further shows that the most important species in terms of value were cod (61%), followed by haddock (20%) and saithe (17%). It is worth to mention that herring would be ranked higher is the chosen fleet segment included the pelagic fleet. Herring is mainly landed by the pelagic fleet which is not included in this study. However, for the two largest coastal vessel groups, herring is the second most important species.

The development in total landing quantities and value for each of the included species is presented in Figure 21.[17] As seen from the Table herring has been the most important species in terms of volume from mid 1980s to 2014. From 2009 the herring landings have, however, declined steadily and were surpassed by cod in 2013. Cod has been the most important species in terms of landing over the entire time period, and its importance relative to the other species increases over time.

[17] This is for the entire Norwegian fleet, not only the chosen fleet segments.

Figure 21: Development in Norwegian landings quantity and value for the species included in the model projections



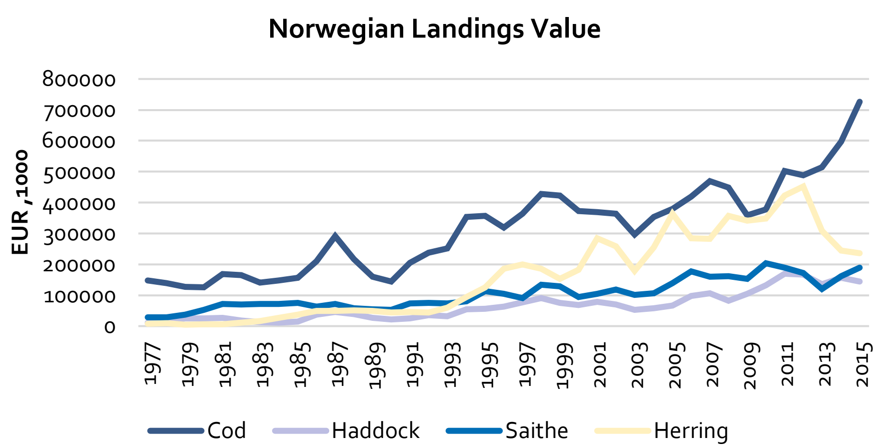


Table 33 display the status of the chosen stocks included in the model projections. Spawning stock biomass (SSB 2016), Total Allowable Catch and fishing mortality corresponding to the MSY are displayed, together with the status of the stocks in 2015. As seen from the Table herring has the largest spawning stock biomass, while cod has the largest TAC in 2015.

Table 33: Status of stock, fishing and management, 2015

2015	SSB (tons)[1]	TAC (tons)[2]	F_{MSY}3
Northeast Arctic cod	1,383,000	894,000	0.40
Northeast Arctic haddock	802,000	165,000	0.35
Northeast Arctic saithe	357,000	122,000	n.d.
Norwegian spring-spawning herring	5,264,000	283,013	

Note: 1 "SSB"=Spawning Stock Biomass and 2 "TAC"=Total Allowable Catch. 3 "FMSY"=Fishing mortality at the MSY.

9.5 Results

As described in the introduction of this report, 4 forecast scenarios are considered, the results of which in 2025 are compared with the initial situation in 2015. The specifics for the Norwegian case/management is:

1. Current Norwegian management: *ITQs* within (except for coastal vessels below 11 meters) but not between fleet segments. 4% limit on yearly adjustment in number of vessels in each segment;
2. Free *ITQ* trade of all species within and between all fleet segments. 4% limit on yearly adjustment in number of vessels in each segment;
3. Current Norwegian management (see scenario 1). No limit on yearly fleet adjustment;
4. Scenario 1 with taxes on 10% of prices.

As discussed in the introduction two forecasts are made for each scenario: maximization of the total socio-economic return[18] and maximization the total profit, both over the period 2016–2025 (2015 being held constant), through variation in number of vessels and days at sea per vessel.

A number of assumptions restrict the model. (i) Maximum catch per vessel per year is restricted below a maximum of 2 times the catch per vessel in 2015, (ii) for all species the stock recruitment functions are constructed such that the stock will not at any point increase above the maximum observed from 1995–2014. This to prevent unrealistic increase in these stocks, and (iii) profit maximisation is performed with values of quotas traded included in the maximisation.

In Table 34 the outcomes from the projection maximizing socio-economic return is displayed, while indicators from the corresponding projection maximizing profit is displayed in Table 35. Table 34 displays total socio-economic return (summed over all included fleet segments), and total profit. The Table report the predicted total number of vessels and the total fulltime employment for each scenario. Results are shown for the base year 2015 and for each scenario for the final projection year 2025.

[18] The socio-economic return, representing the social welfare that the fishery comprises for society when compared with how capital and labour used in the fishery could have been used in other sectors.

Table 34: Forecast of socio-economic return, fleet and employment adjustment in 2025 by maximizing socio-economic return

Scenarios	C.coast < 11	C. coast 11–14,99	C. coast 15–20,99	C. coast >21	C. Ocean <28	Trawlers	Total
Socio-Economic return (mill EUR)							
2015 initial situation	-9	24	23	18	44	133	234
2025 scenarios:							
1. Current management	5	24	23	6	34	106	198
2. ITQ management free quota trade	6	24	17	-2	45	127	218
3. Current management full adjustment	5	35	34	18	42	134	267
4. Current management 10% landing tax	5	24	23	6	34	106	198
Number of vessels							
2015 initial situation	687	288	119	34	25	39	1,192
2025 scenarios:							
1. Current management	457	191	79	23	17	26	792
2. ITQ management free quota trade	457	191	79	23	17	26	792
3. Current management full adjustment	324	94	43	9	12	17	498
4. Current management 10% landing tax	457	191	79	23	17	26	792
Employment (full-time)							
2015 initial situation	1,019	911	814	405	879	1,444	5,471
2025 scenarios:							
1. Current management	677	606	541	269	584	960	3,637
2. ITQ management free quota trade	677	606	541	269	584	960	3,637
3. Current management full adjustment	480	296	292	102	437	625	2,232
4. Current management 10% landing tax	677	606	541	269	584	960	3,637

Table 35: Forecast of profit, fleet and employment adjustment in 2025 by maximizing profit

Scenarios	C.coast < 11	C. coast 11–14,99	C. coast 15–20,99	C. coast >21	C. Ocean <28	Trawlers	Total
Profit (mill EUR)							
2015 initial situation	5	11	10	11	21	80	138
2025 scenarios:							
1. Current management	-2	8	9	4	16	64	100
2. ITQ management free quota trade	7	12	3	1	18	72	112
3. Current management full adjustment	0	16	16	10	20	82	144
4. Current management 10% landing tax	-3	6	7	3	13	50	75
Number of vessels							
2015 initial situation	687	288	119	34	25	39	1,192
2025 scenarios:							
1. Current management	457	191	79	23	17	26	792
2. ITQ management free quota trade	457	191	79	23	17	26	792
3. Current management full adjustment	0	94	43	9	12	17	175
4. Current management 10% landing tax	457	191	79	23	17	26	792
Employment (full-time)							
2015 initial situation	1,019	911	814	405	879	1,444	5,471
2025 scenarios:							
1. Current management	677	606	541	269	584	960	3,637
2. ITQ management free quota trade	677	606	541	269	584	960	3,637
3. Current management full adjustment	0	297	293	103	439	628	1,760
4. Current management 10% landing tax	677	606	541	269	584	960	3,637

The Tables firstly show that given the current management (scenario 1) the total Norwegian groundfish fishery North of 62° would be worse of in 2025 than in 2015.[19] The total social welfare that the fishery represents for society (socio-economic return) is estimated to decreases with EUR 37 Million (16%). This effect is seen for all fleet segments except the coastal vessels below 11 meters, which goes from a negative contribution to a positive. Especially for the three largest vessels group, the decline in socio-economic return is severe; the conventional coastal vessel over 21 meters will have a decline of EUR 12 Million (66%) and trawlers a decline of EUR 27 Million (20%). The situation is similar for the actual surplus obtain in the fishery after the subtraction of cost. The total profit is estimated to decline by EUR 38 Million (27%) in 2025 compared to 2015 with the current management system. All vessel groups reduce its profit, and the smallest coastal vessels go from a positive to a negative profit.

Table 34 and 35, further display the numbers of vessel and full time employed for the different scenarios. As seen from the Table the number of vessels will decline by 400 vessels (34%) and 1,834 fulltime employed (34%) in 2025 compared to 2015. The decline in number of vessels and full time employed are quite evenly distributed among the fleet segment all segment has a decline of between 32% and 34%. This decline is the outcome of a trend that has lasted for decades.

In scenario 2 the trade barriers between all fleet segments are removed, but the capacity change is limited to 4% a year. As seen from the Table, this will improve the situation from scenario 1 by an additional EUR 20 Million (10%) increase in socio-economic return and EUR 12 Million (12%) increase in profit, but the total socio-economic return and profit is still significantly lower than in 2015. The two largest fleet segments among the coastal vessels (vessel between 15–21 meter and over 21 meter) are doing significantly worse in this scenario with a profit and socio-economic return significantly lower than in scenario 1. It is, however, interesting to notice that for the smaller coastal vessels, profit and socio-economic return will increase relative to the current management. The predicted number of vessels and numbers of full time employed are however equal to scenario 1.

In scenario 3, we assume instant capacity adjustment (no yearly limit to capacity change). While this scenario is interesting, from a theoretical perspective (to quickly find the optimal steady state solution), the realism in this is more questionable. In this scenario, the forecasted total socio-economic return and profit in 2025 are as expected even higher than for scenario 2, with an estimated total socio-economic return that is EUR 70 Million (35%) higher than in scenario 1 and an estimated total profit that is EUR 44 Million (44%) higher. The conventional vessels under 11 meters do worse in this scenario, profit decline to zero and socio-economic return to 5, but still this scenario is better than the results under the current management.

The predicted number of vessels and numbers of full time employed are significantly lower for this scenario than for the rest. The predicted total number of vessels decrease by additionally 78% when maximizing profit and 37% when

[19] The 2015 initial situation results are overestimated in this report. This is due to the low herring quotas in 2015. Using this as a basis for comparison can therefore be slightly misleading.

maximizing socio economic return compared to scenario 1. The situation is most dramatic for the smallest vessel groups, and most for the conventional vessel under 11 meter, which disappear when maximizing profit in this scenario. When maximizing socio economic return, the situation is less dramatic for the conventional vessel under 11 meter, with a decrease of 29%. The results for the numbers of full time employees are closely related to the results for the number of vessels, since the full time employees are proportional to the number of vessels.

The last scenario (scenario 4) is also based on today's management but assumes a landings tax of 10%. This will give a socio-economic return equal to scenario 1 but decrease the total profit by EUR 25 Million (25%), but the retribution of the wealth will change. All the vessel groups will suffer under this management but maybe most the smallest conventional coastal vessel that get a highly negative profit. The predicted number of vessels and number of full time employed are equal to scenario 1.

Figure 22: Forecast of socio-economic return (top) and profit (bottom) 2015-2025, EUR Million

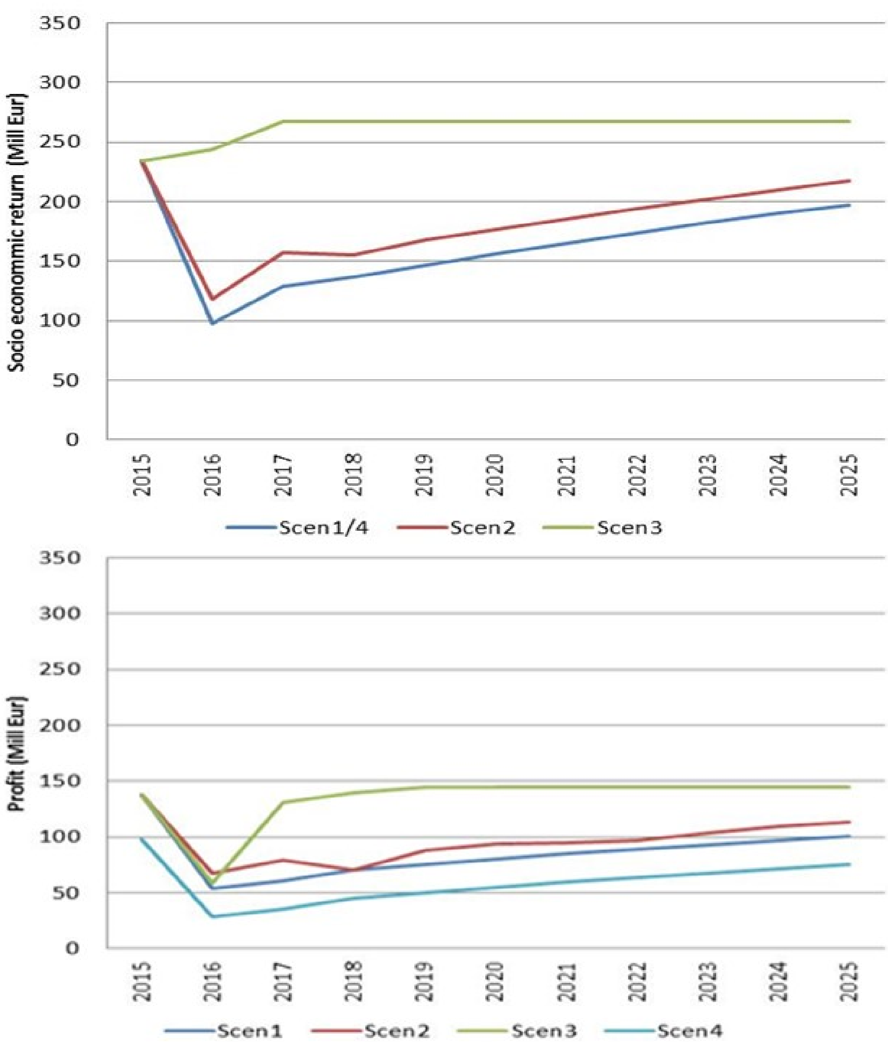


Figure 22 display the development over the projection period of the total socio-economic return, and the total profit resulting from each projection. The Figure shows that for all scenarios the profit will decline sharply from 2015 to 2016, since the main catches are predicted to drop over the coming decade. From 2016, the trend is more mixed; scenarios 3 shows a sharp increasing profit until 2017 and from then on stabilize, while the rest of the scenarios shows a more moderate increase profit towards 2025. The development in socio-economic return is more mixed between the scenarios. For scenario 3, the socio-economic return increases from 2015 to 2017 and stabilize after this. For the other scenarios we see a sharp drop in socio-economic return from 2015 to 2016, and a after that a gradual improvement towards 2015.

9.6 Policy considerations

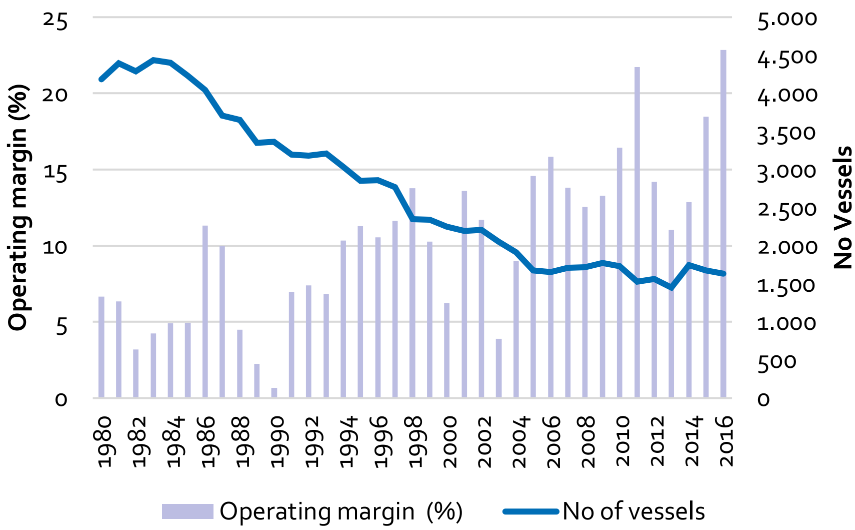
What makes a quota system good depends both on its practical functionality and to what extent it reflects and maintains key societal values. However, it is also recognized that there are trade-offs between economic efficiency and the achievement of societal goals (Kroetz *et al*., 2015). The Norwegian authorities' responsibility to manage common fish resources has to be in accordance with the objectives of the fisheries legislation. "Havressursloven" (The marine resources act). § 1 states that the purpose of the act is to ensure a sustainable and socio-economically profitable management of wild marine resources, and to secure employment and settlement in coastal communities. The design of the regulations will be decisive for how this is done and what instruments are used.

The goals of sustainable resource management, maximum profit and to secure employment and settlement in coastal communities may be contradictory. Traditionally, the importance of sustainable management has been prioritized by Norwegian governance. So, when sustainability has come into conflict with profitability or employment, resource management has been prioritized. An example of this is the introduction of a total quota regime and closure of fishery to the public.

When the objective of profitability and employment and settlement in coastal communities has been contradictory, Norwegian management practices tended to prioritize societal objectives to the extent that many fishermen where heavily subsidized. However, since the early 1990s, economic efficiency and profitability in the industry has increasingly been prioritized (Standal and Asche, 2018).[20] Still, the regulations are heavily influenced by the importance of maintaining coastal communities and a differentiated fleet. An example of this is how the structural quota schemes are designed, as the previously mentioned transfer can only occur within vessel groups and with limitations on trade between certain geographical regions.

[20] What is economically optimal depends on several other factors, such as competition from other industries and the need for labour. If capital and labour cannot be utilized better in other industries or that there are no alternative jobs, it will be economically profitable to prioritize high employment in fisheries.

Figure 23: The development of vessels and profitability in the Norwegian fishery



Increased productivity, competitiveness in the output market as well as paying competitive wages are not always easy to combine with small coastal vessels and maintaining coastal communities. In 2013 a committee where appointed by the Fisheries Minister in Norway at the time, Lisbeth Berg-Hansen, to give an account of how the seafood industry in Norway could become more efficient and profitable. The committee included a large number of recommendations that could contribute to improve profitability in the industry. A common thread in these recommendations was to give business players greater freedom to choose which economic and organizational models work best for the individual company in its market (NOU2014:16). Some of the suggestions, i.e. to reduce or remove the Participant Act (in Norwegian *Deltagerloven*) which limits who can own fishing vessels and to allow transfer of quota between vessel groups, might however lead to a change in today's structure, and many stakeholders are afraid that this would lead to an extinction of small coastal communities along the coast. As a consequence, few of the committee's proposals have been implemented.

Looking at the result from this study, profitability can be increased significantly by relaxing some of the restrictions the industry faces today. By lifting all trade barriers between fleet segments (scenario 2) but limiting how fast the fleet adjusts, the predicted socio-economic return will be 10% higher and profit 12% higher in 2025, compared to continuing today's management scheme. Assuming instant capacity adjustment, leading us directly to the steady state solution, the benefit is predicted to be even larger with an average socio-economic return that is 35% higher and profit that is 44% higher in 2025 compared to continuing today's management scheme.

These results are largely as expected, since a segmented management where one cannot transfer quotas between vessel groups or different areas will lead to inefficiency. This is because existent efficiency differences between vessel groups or vessels in the different regions, will with today's management system be preserved, since the regulatory system protected the inefficient groups. The results also show that even though returns are increasing for fisheries as a whole by opening up for trade between vessels in different groups and areas, some groups are getting worse at least in the short run. Particularly the largest coastal vessels get their returns reduced. However, in the long run, it seems that all the vessel groups are doing better, except for the smallest coastal vessels that will not be viable, and accordingly disappear under the profit maximation scheme.[21] Hence, the analysis gives those stakeholders that are concerned about the future of the smallest coastal fleet right in that they have no future if they are not protected. However, it is important to note that there will continue to be a coastal fleet even with free transfer of quotas between vessel groups, it will just not contain the smallest vessels.

As shown also in other countries (Kroetz *et al*., 2015), preserving a segmented fleet therefore has a cost in terms of lost revenue and profitability, and thereby also a loss of tax revenue for the society. A relevant question that the society must consider is therefore; are the price one must pay acceptable given the importance of preserving a heterogeneous fleet and maintaining the coastal communities?

In 2015 an expert committee appointed by the Fisheries Minister in Norway at the time was settled to discuss the development of Norwegian fishery management (NOU 2016:26). The committee concluded that it would be beneficial to rationalize and simplify Norwegian quota system and give the industry opportunities to do short- and long-term adjustment. At the same time, they point out that one should pursue the objectives of an industry exercised and owned by active fishermen, and a varied fleet with regard to vessel size and regional affiliates. A gradual and controlled adaptation to community development should be sought.

The reliability of this model is a matter that should be mentioned, and in particular how well it fits the Norwegian structure. The model is as all models a simplification, and a lot of strong assumptions are made. A major weakness of the model is that it assumes that the vessels within each vessel group are homogeneous. Previous research has shown that this is far from true. Guttormsen and Roll (2011) finds substantial variation in technical efficiency both between and within vessel groups in the Norwegian ground fish fleet. The results also indicate that none of the vessel groups dominate the others in terms of efficiency. Based on these results, there is therefore little indication that some of the vessel groups would disappear even if they were no longer protected by the quota distribution system with different vessel groups. The similarity of the results for many of the scenarios indicates that the adjustment restriction is binding in most cases. This is a consequence of how far the Norwegain fishing management system is from optimum in any dimension, and accordingly, how inefficient it remains when only moderate changes are carried out.

[21] We also see a sharp reduction in the number of vessels in all groups (especially tied to the smallest vessels), and for the individual fisherman this will be dramatic, especially if there is no alternative work.

10. The Faroese Demersal fishery in Faroe area

10.1 Introduction

In this chapter, we forecast the development in the Faroese demersal fishery in the Faroe area until 2025, with the planned implementation of a quota system in 2019.

The Faroes have since 1996 had an effort regulation of the demersal fishery in the Faroe area, but this is planned to be changed in 2019 in a new law on fisheries management. The new fisheries management passed through the Faroese parliament in late 2017, and came into force 1 January 2018. But in this law, the proposed quota system for large vessels in the Faroe area was postponed to 2019, while there are still plans to keep the effort regulation for the small-scale coastal vessels also after 2019. In this chapter, we look at the two groups of larger vessels with trawls and hooks that fish in the Faroe area for demersal species.

The new Faroese fisheries management law has been heavily debated in the Faroes over the last couple of years. Most of the debate has been about the allocation of fishing rights, but there are also still debates in the Faroes whether the quota system should be implemented at all for the demersal fleet in the Faroe area. The fishermen of the demersal fleet are not in favour of a quota system as well as many politicians. Their view is that a quota system will lead to a large discard of fish, which is practically non-existing in the current fishing days system.

Our choice of the demersal fleet in the Faroe area is partly based on that there still is debate on this part of the new law and partly because, in our view, this fleet as it is, does not function the way it should economically and biologically, as we will see in this chapter. This fleet in this study consists of medium sized vessels that use both trawl and hooks.

Hans Ellefsen of the Ministry of Fisheries[22] and Heri á Rógvi independent advisor perform this case study.

In the following, a literature review of studies assessing fishery policy reforms in Faroes over the last decades is provided in section 2, while section 3 describes management of Faroese fishery. Section 4 present data and section 5 the results of the scenarios. Section 6 concludes the paper with policy considerations.

[22] The paper reflects solely the view of the author, not in any way of the employer institution.

10.2 Literature review

The Faroe Islands have a high degree of dependency on fisheries. In economic terms the fisheries sector accounts for almost 20% of GDP and around 95% of goods exports of the Faroes are fish products (Hagstovan, 2018) (The Faroese statistical office). The fisheries sector of the Faroes is diverse and consists of fish farming, fish factories and fishing. The fishing part is divided into the pelagic fishery, distant water fishery, and the local demersal fishery. Historically local demersal fish stocks have been an important part of the total fishery, but in recent years the stocks of demersal stocks have declined and the other fisheries are much more important economically, when we look at the landing values. However, the demersal fishery is still a big part of the economy (GDP) and the basis for many fish factories around the islands.

The history of Faroese fishing of demersal species goes back more than 100 years. The main demersal stocks around the Faroes are cod (Gadus morhua), haddock (Melanogrammus aeglefinus), and saithe (Pollachius virens). With the 200 nautical mile Extended Economic Zone coming into force in 1977 the Faroese fishermen was forced to focus on the Faroese area and foreigners fishing in Faroese waters were not welcomed any more. However, until the beginning of the nineties, the fishing in the Faroe area was only managed by licenses. And in the eighties huge subsidies to the fishery were part of the Faroese fisheries. Following the crash in the main species in the early 1990ties (and de facto the Faroese economy) an ITQ system was introduced by creditors, but that system was in place for only two years. After the main stocks miraculously returned in the mid 1990ties the ITQ system was abolished and the current fishing days system was introduced in 1996. This system regulates the effort instead of the catch and is coupled with a large system of closed areas on the Faroe shelf with gear restrictions. The fishing days are in principle transferable, but there has not been an effective market for fishing days since its introduction. From about 1996 to about 2002, this system was rather successful in an economic and a biological sense. However, this system has not been successful either economically or biologically since then, as we will see later.

Many studies have been made on the Faroese fishing days system over the years. However, not many of these are made of fisheries economists, and are many of a more descriptive nature. These articles have often been made as inspiration for other counties on how to make a fisheries management system that is different from the usual quota system.

In 2007 Løkkegaard *et al.* made a report describing and analysing the Faroese fishing days system until 2004 (Løkkegaard, Andersen, Boje, Frost, & Hovgård, 2007). The report was a comparison between biological and economic results in the Faroese system and the results in Denmark from the EU regulatory system. Their conclusion was that the Faroese system was not outperforming the Danish. This analysis was made before the collapse of the cod and haddock stocks in 2004 and forward, so if this analysis was made today the conclusion probably had been that both the economic and biological results are much worse in the Faroese system than in the Danish.

In 2007 Jákupstovu *et al.* made a 10-year appraisal of the fishing days system (from 1996–2006) (Jákupsstovu, Cruz, Maguire, & Reinert, 2007). Their perspective is biological and their conclusion is that the system of regulating effort does not have the desired effect on the biology of the fish since the fishing mortality had been well above biological safe limits. This was especially true for the two species cod and saithe. The idea from the beginning was that the system should induce the fleet to divert its fishing effort to more abundant species. However, this has not happened, according to Jákupstovu *et al.* (2007). Their "solution" to this problem of a too high fishing mortality is that the number of days were reduced significantly, which has however never happened.

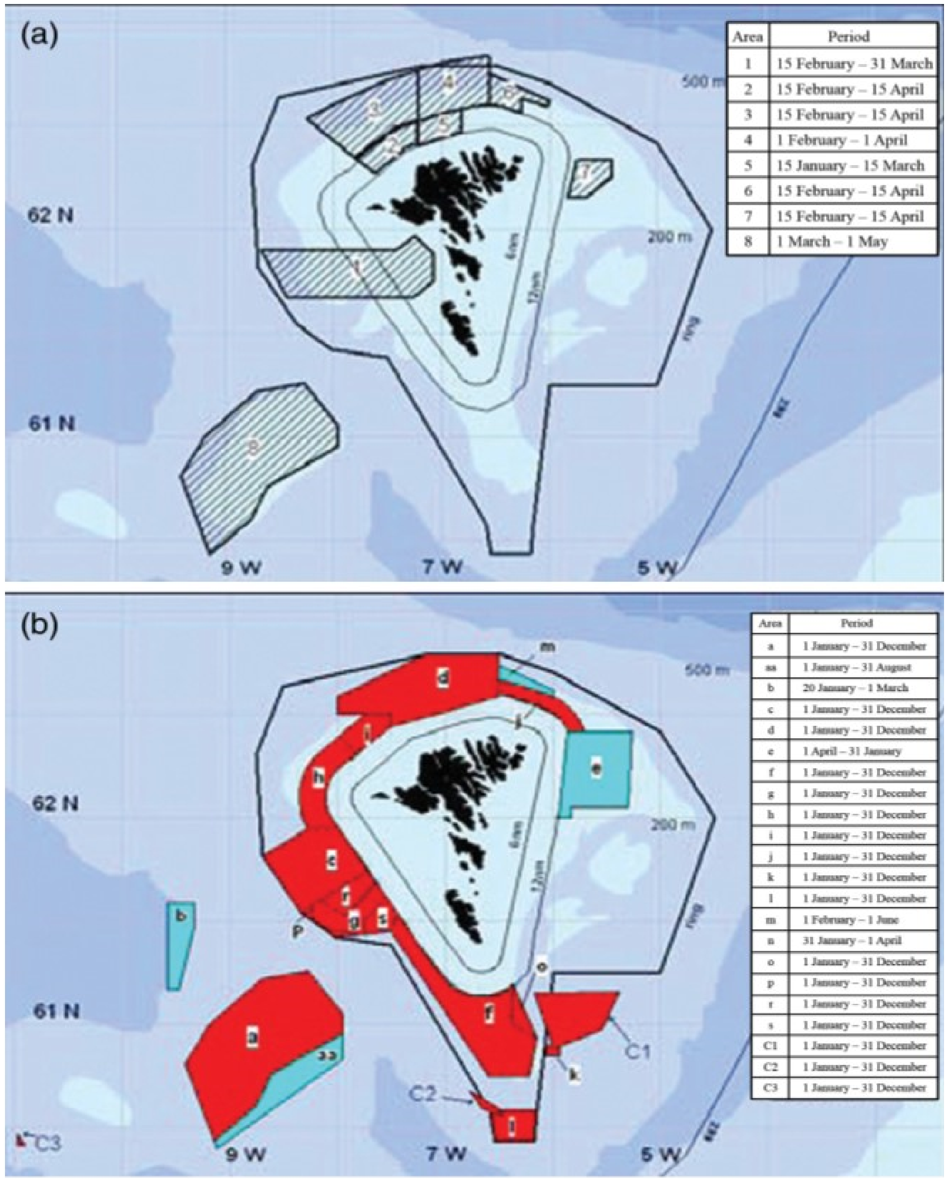
In 2010, Baudron *et al*. also studied at the biology of the stocks cod, haddock and saithe in the Faroe area (Baudron, Ulrich, Nielsen, & Boje, 2010). They conclude, "When stocks are considered in isolation, a total allowable effort system does not necessarily perform better than a Total Allowable Catch system. It depends on stock status and dynamics, the level of uncertainty, and the reactivity of the system to changes in scientific advice. When the stocks are considered together in mixed fisheries, effort management seems, however, to be appropriate, and inter-annual flexibility of the system appears to be the best compromise between short- and long-term objectives, as well as between biological sustainability and economic return". This paper therefore concludes that in some cases fishing effort regulation can be better than Total Allowable Catch management. But they also conclude that the number of days in the Faroese system should be reduced significantly in order for this to be the case.

FAO has made a report on effort regulation around the world (Squires, et al., 2012). Hans Ellefsen and Kjartan Hoydal, each have two chapters in this report about the Faroese system. Ellefsen studied the economic and biological data for the Faroese demersal fisheries. His conclusions were that the fishing days system does not perform well either economically or biologically, since the overall results for the companies in the fishery were negative and the stocks were below safe biological limits particularly in later years. Hoydal on the other hand concludes that there are many faults in a normal Total Allowable Catch system and the Faroese TAE system could solve some of these problems. But Hoydal further concludes that the Faroese system however has not been handled in the right way by the authorities in the Faroes, as the authorities have not monitored the development in effort. Hoydal also concludes that in the beginning the number of days were set too high and in the years after that, the fishing days have not been reduced nearly enough to compensate for the increased catchability in the fleets.

10.3 Management

Before the early 1990s the fishing management system in the Faroe Islands was a combination of limited licenses, area closures and mesh size limits (Jákupsstovu *et al*., 2007). In the early 1990s, there was a collapse in the main demersal stocks around the Faroe Islands. To reduce the fishing mortality (F) and rebuild the stocks, a quota system was introduced in 1994 as part of an agreement with the Danish government (Løkkegaard et al., 2007). However, the fishing industry and the politicians were not that happy with this arrangement. The quota system was criticized for leading to extensive discards when reaching the quota limits. Thus, in 1995, the industry and the government came up with a new system based on fishing effort. This system has been in place since 1996. The fishing days system was set up by a committee ("skipanarnevndin") consisting of managers, scientists, and key fishing industry representatives (Jákupsstovu *et al.*, 2007). The main goal of the committee was to design a system such that the fishing mortality of the three key stocks were kept at 0.45 (corresponding to that approximately one-third of the stock was to be fished) as the recommendation from International Council for the Exploration of the Sea (ICES) then stipulated. A basic assumption of the system was that the effort applied to each of the three main stocks would change according to the relative abundance of the stocks. This does not seem to have happened though, as the more valuable specie cod was over-utilized compared to saithe (Jákupstovu *et al*., 2007).

Figure 24: The top figure (1a) shows the areas that are closed for spawning, and the bottom figure (1b) shows areas closed for trawling



In addition to the management of effort more area closures and mesh size regulation were implemented in 1996. Firstly there is a ring around the Faroes where the sea level inside generally is shallower than 200 meter. Outside that area vessels are encouraged to fish through getting two additional days for each one fishing in this area. Within the 6 nautical mile of the baseline only smaller vessels are allowed to fish and no trawling is allowed inside the 12 nautical mile zone. Figure 24a shows the areas that are closed during spawning for all fleet segments, and Figure 24b shows areas that are closed for trawling some part of the year. Generally, 60% of the Faroe plateau shallower than 200 meter depth is closed for trawling (Jákupstovu *et al*., 2007).

By 1st of January 2018 a new law on fisheries management in the Faroes comes into force, which reformed the Faroese fisheries management. One part of this reform was that the larger vessels in the demersal fleet around the Faroes were to convert to a quota system in 2019. The system is not an ITQ system in the traditional sense, since fishermen do not own the quotas (the government owns them), and can only dispose of them on an open market, which means an auction. On the other hand, if you wanted to get out of the fishery owners of companies can sell their company i.e. shares to another Faroese company/person without restrictions. This quota system does not apply for the smaller vessels (<110 grt), which are still under the fishing days system also after 2019.

10.4 Data

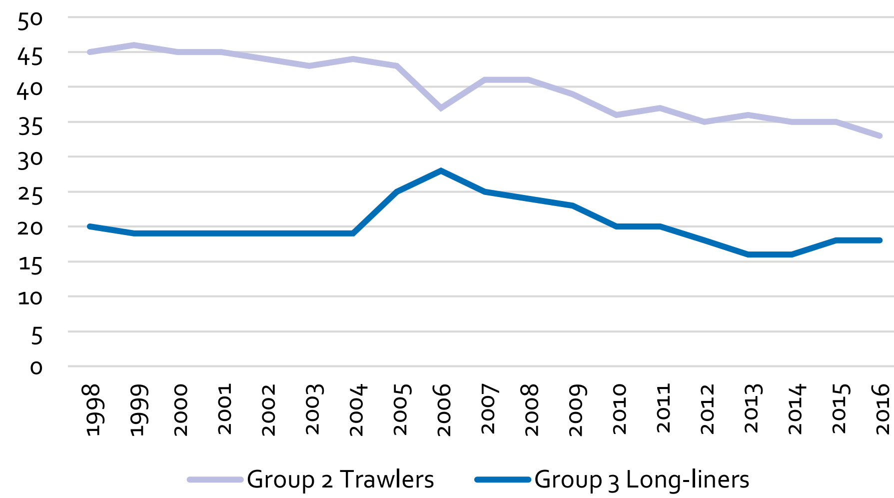
Table 36: The groups of vessels in the Faroese fishing days system

Group of fishing vessel	Licenses 2015	Landing value 2015 EUR Million	%
Group 2: Large trawlers >400 hp	35	73.5	18.3%
Group 3: Longliners > 110 grt	18	29.8	7.4%
Group 4: Large coastal vessels >15 grt			
- 4A: Longliners and jiggers 15–110 grt	9	1.2	0.3%
- 4B: Small coastal trawlers < 500 grt	13	4.9	1.2%
- 4T: Small trawlers > 55 grt < 500 hp	7	5.9	1.5%
Group 5: Small coastal vessels < 15 grt (longlining and jigging)			
- 5A: Full time fishermen	20	3.4	0.8%
- 5B: Part time fishermen	280	3.1	0.8%
Pelagic and distant water fishing	17	276.6	69.0%
Other (e.g. vessel for lobster and shellfish)	13	3.2	0.8%
Total	412	401.6	100%

Source: (Fiskidaganevndin, 2017) and (Vørn, 2018) (Faroe Islands Fisheries Inspection).

The number of vessels in the studied groups 2 and 3 has been declining for a long time but not so much as could be expected. Figure 25 shows the decline in the number of licenses in these groups.

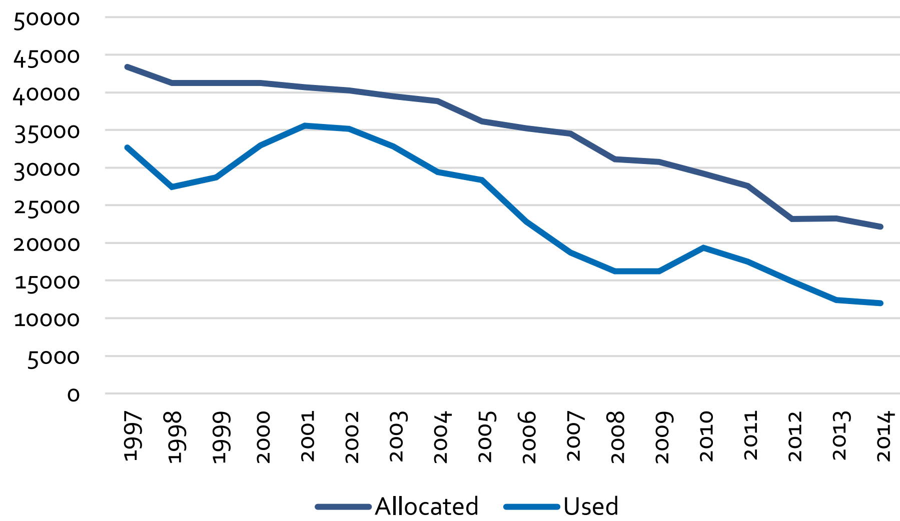
Figure 25: Number of vessels 1998–2016



Source: (Fiskidaganevndin, 2017).

We see that the number of trawlers declined from 45 to 35, while the number of long-liners has declined from 20 to 18. There were some years where the number of long liners was much higher and in 2006 there were 28 long-liners. Why there were so many vessels these years is not so clear, but maybe they were more optimistic on the state of the stocks back then with a series of good years, that ended around that time. Figure 26 shows the total amount of fishing days in the system compared to the days used. Each vessel in groups above are allocated a number of fishing days i.e. days that this vessel can be out on sea. This was set originally very high, and has been decreased since then, but not as much as the decline in used days. The total amount of used days is around 54% of the allocated days in 2014. We can say that in some cases there is in fact open access fishing in the Faroe area and could this explain the bad economic results of the fleets as we will see. The excess of days are not so big in all groups. For the trawlers around 90% of the days were used until 2010 cf. the article on the Faroese effort system in (Squires, et al., 2012). The longliners do not use so many days as the trawlers, and they have other fishing grounds to fish on e.g. Iceland and Flemish cap, and have in later years only used one third of the total days in the Faroe area.

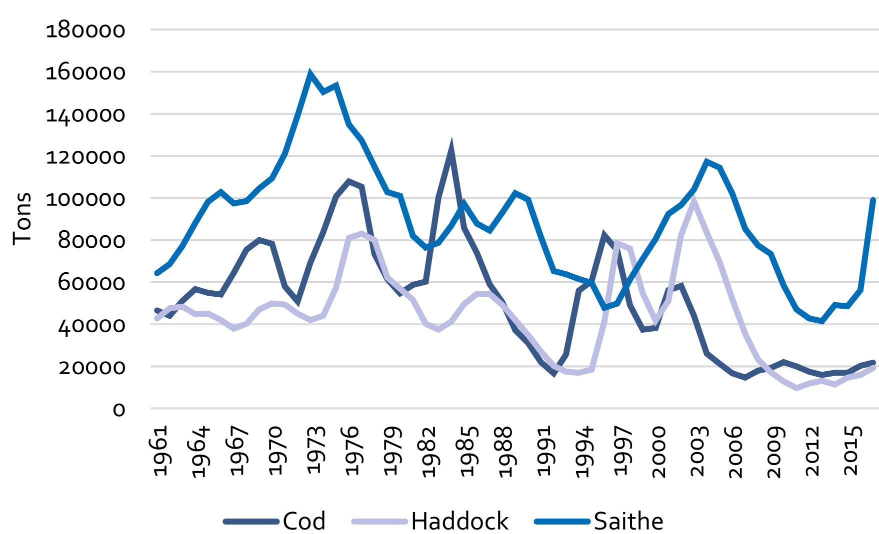
Figure 26: Allocated and used days 1997–2014



Source: (Vørn, 2018) (Faroe Islands Fisheries Inspection).

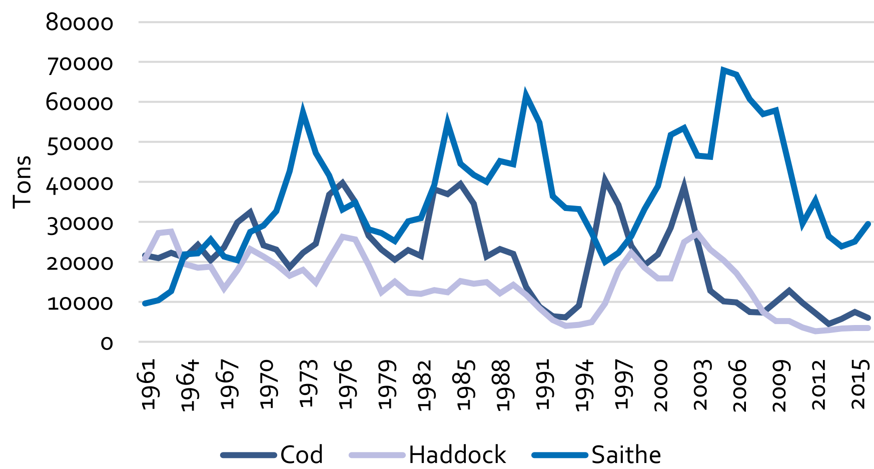
The stocks that we study in the chapter are the most important demersal stocks in the Faroese area. These are the cod, haddock and saithe. These three have all been on a low level for many years, especially cod and haddock while saithe seem to be increasing significantly in 2015. Figure 27 shows the spawning stock biomass for these tree stocks since 1961.

Figure 27: Spawning stock biomass 1961–2016 of main demersal species



Source: (Havstovan, 2018) *(Faroe Islands Marine institute).*

Figure 28: Catches 1961–2016 of main demersal species

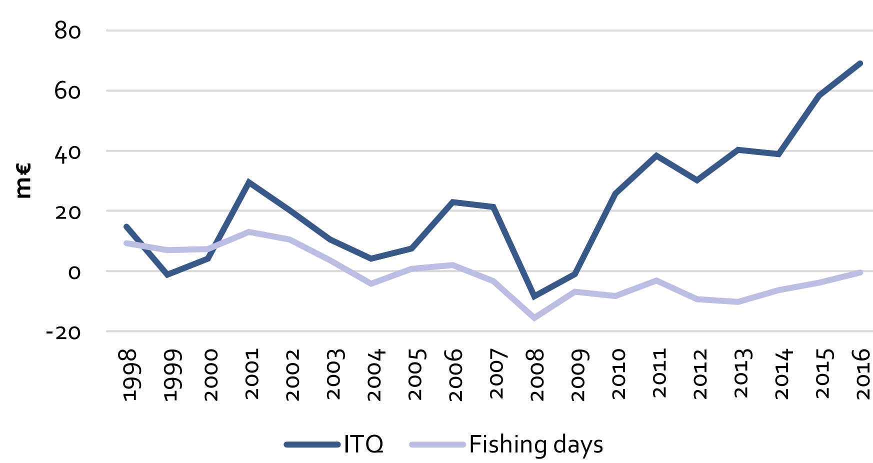


Source: (Havstovan, 2018) (Faroe Islands Marine institute).

Historically, the catch for cod in the Faroe area has been between 20,000 and 40,000 tons. However, for the last 10 years it has been below 10,000 tons. Also, haddock catches have been on a historically low level. The saithe has not been at such a low level the last couple of years, but compared to 10 years ago the catches of saithe are only half of what they were then.

The economic results of the vessels in the fishing days system has not been good since the introduction of the system. From 1996 to 2002 the outcome was encouraging, but this has not been the case the last 10–15 years. In Figure 29 we show the economic results for the fleets that we study in this chapter compared to the Faroese fleets that have an ITQ system (i.e. pelagic and distant water fishing).

Figure 29: Profits for vessels in ITQ system and vessels using fishing days system. Resource taxes are included in costs for the pelagic fleet



Source: (Januar, 2016) *(Accounting firm).*

We see that the fleets that are using the fishing days system has had much worse economic results than those that have used ITQ system. The Figure does not prove that the ITQ system implies good economic results; it can indicate such a theoretical result. The good economic results that we see in the ITQ sector the last years can also be attributed to the good economic results that the pelagic sector has had the last couple of years. And these good results for the pelagic fleet can largely be attributed to the large abundance and fisheries of mackerel in Faroese area since 2010.

Table 37 shows the accounts for the fleets that we examine in this chapter.

Table 37: Physical and economic data, annual average 2012–2014

	Group 2: Trawlers	Group 3: Longliners	Total
Physical data			
Fulltime employment/segment	218	197	415
Number of vessels[1]	31	14	45
DAS/vessel	261	228	250
Important species	Saithe (37%)	Cod (52%) Haddock (14%)	
Total account data (EUR Million)[1]			
Turnover	58	22	80
Crew costs	22	10	32
Other costs[2]	35	11	46
Capital costs	9	2	16
Opportunity labour cost[3]	14	12	26
Opportunity capital cost[4]	12	3	15
Profit	-1	-8	-9
Socio-economic return[5]	-3	-4	-7

Note: 1. The account data are retrieved from survey made by the Faroese accounting firm 'January'. Only vessels that are active are reported here. That is why the number of vessels from Table 36 does not match the numbers here.
2. The total fuel costs, variable costs and fixed costs are known, but the allocation between the three components is not estimated.
3. Total opportunity cost of labour is identified on the basis of an annual average salary of a fishermen in another sector on EUR 53,333 (400,000 DKK) multiplied by the number of full time employed.
4. Total opportunity cost of capital is calculated as 6% of the physical assets of the companies.
5. The socio-economic return = turnover – costs – opportunity costs of labour – opportunity cost of capital.

Source: (Januar, 2016) (accounting firm) and (Vørn, 2018) (Faroe Islands Fisheries Inspection).

Turnover of these two segments are EUR 80 Million, but after costs the profits are negative on average the years 2012–2014. Also, the socio-economic return is negative. Socio-economic return measures "The net-surplus that, at a given time, remains for the remuneration of capital and labor above the rate that is achieved in other businesses". The definition appears from Nielsen *et al.* (2012). The socio-economic return is calculated as turnover minus fuel costs minus variable costs minus fixed costs minus opportunity costs of labour minus opportunity cost of capital. In economic terms the socio-economic return is the sum of the resource rent and the producer surplus. While profit measures the net return a company have from their fishery, socio-economic return measures the net return a society have on the existence of a fishery, compared to if labour and capital had been used in other sectors than fishery.

The socio-economic return of these two fleets are EUR -7 Million on average for the three years 2012–2014. The opportunity cost of labour is lower than the actual costs for trawlers while they are higher for longliners. The opportunity cost of capital is higher than actual capital costs for both groups.

Table 38 displays the status of the major demersal stocks included in the model projections. Spawning stock biomass, catches and fishing mortality corresponding to MSY are displayed, together with the status of the stocks in 2015. It is seen that cod and haddock were not sustainable in 2015 as they both were below Bpa and above MSY-Btrigger. The saithe stock was sustainable, but fishing pressure was too high. The spawning stock biomasses and catches displayed in Table 38 are used as initiating values in 2015 for the model projections.

Table 38: Status, illustrated through Spawning Stock Biomass, Total Catch and fishing mortality at MSY (F-MSY) of the main Faroese demersal stocks included in the analysis in the start year 2015

2015	SSB (tonnes)[4]	Catch (tonnes)	F-MSY	Status 2015[1]
Cod (FP)	16,920	7,375	0.32	Below Bpa[2], Above MSY-Btrigger[3]
Saithe (FP)	48,507	25,195	0.3	Above Bpa, Above MSY-Btriggger
Haddock (FP)	14,625	3,395	0.25	Below Bpa, Above MSY-Btriggger

Note: 1. According to ICES advice 2017 (ICES, 2017)
2 "Bpa"=The precautionary biomass level that triggers ICES to take action to raise the stock above this level.
3. "MSY-Btrigger"=The Biomass level that triggers ICES to recommend a fishing mortality below F-MSY.
4. SSB = Spawning Stock Biomass.

The advice from ICES for 2018 shows a very different picture than the advice from 2017 (ICES, 2018). ICES have become more optimistic of the cod and haddock stocks, while not so optimistic on the saithe stock. It has not been possible to include these results into the calculation below.

10.5 Results

The development in the demersal fishery is forecasted until 2025 using the method outlined in chapter 2 in four scenarios, of the Faroese demersal fishery around the Faroe Islands.[23]:

1. Current Faroese management: ITQs beginning in 2019, and constant effort 2015–2018. 4% limit on yearly adjustment in number of vessels in each segment after 2019;
2. ITQs from 2016. 4% limit on yearly adjustment in number of vessels in each segment in all years;

[23] Maximum catch per vessel per year restricted below a maximum of 2 times the catch per vessel in 2015.

3. Current FO management: ITQs beginning in 2019, and constant effort 2015–2018. No limit on yearly fleet adjustment after 2019;
4. Scenario 1 with taxes on 10% of prices.

Two forecasts are made for each scenario. First, the total socio-economic return is maximized over time with the results being presented in Table 39, while total profit of the fleet is maximized with the results in Table 40. The net present value of all future earnings is maximized through variation in number of vessels and days at sea per vessel. The forecast results are shown in the Tables for 2025 comparted to the initial situation in 2015. Where socio-economic return measures the extraordinary economic contribution of fisheries to the socio-economy, profit is the surplus for the private fishing companies. The biological foundation of the fishery in the initial situation is shown in Table 38.

Table 39 displays the model outcomes from the projection maximizing socio-economic return. The Table shows the socio-economic return together with the total number of vessels and the total fulltime employment. Table 40 displays the corresponding indicators from the projection maximizing profit.

Table 39: Forecast of socio-economic return, fleet and employment adjustment in 2025 by maximizing socio-economic return

Scenarios	Trawlers: Group 2	Longliners: Group 3	Total
Socio-Economic return (mill EUR)			
2015 initial situation	2	-11	-10
2025 scenarios:			
1. Current management	12	4	16
2. ITQ management free quota trade	15	4	19
3. Current management full adjustment	24	4	28
4. Current management 10% landing tax	12	4	16
Number of vessels			
2015 initial situation	31	14	45
2025 scenarios:			
1. Current management	23	11	34
2. ITQ management free quota trade	21	10	31
3. Current management full adjustment	12	10	22
4. Current management 10% landing tax	23	11	34
Employment (full-time)			
2015 initial situation	248	196	444
2025 scenarios:			
1. Current management	186	147	334
2. ITQ management free quota trade	165	144	309
3. Current management full adjustment	94	146	240
4. Current management 10% landing tax	186	147	334

Table 40: Forecast of profit, fleet and employment adjustment in 2025 by maximizing profit

Scenarios	Trawlers: Group 2	Longliners: Group 3	Total
Profit (mill EUR)			
2015 initial situation	-6	-5	-12
2025 scenarios:			
1. Current management	3	2	5
2. ITQ management free quota trade	5	2	7
3. Current management full adjustment	12	2	14
4. Current management 10% landing tax	0	1	1
Number of vessels			
2015 initial situation	31	14	45
2025 scenarios:			
1. Current management	23	11	35
2. ITQ management free quota trade	21	11	32
3. Current management full adjustment	12	11	23
4. Current management 10% landing tax	23	11	34
Employment (full-time)			
2015 initial situation	248	196	444
2025 scenarios:			
1. Current management	186	159	345
2. ITQ management free quota trade	165	157	322
3. Current management full adjustment	94	152	246
4. Current management 10% landing tax	186	147	334

Table 39 shows that the fleet will be much better off in all scenarios than in the initial situation. Scenario 1 shows the results in 2025 if the planned quota system is implemented in 2019. There is a 4% limit on how fast the adjustment can take place after 2019. We see that the socio-economic return goes from EUR -10 Million to EUR 16 Million. We also see that in scenario 2 where ITQs started in 2016 the socio-economic return is a bit higher at EUR 18 Million, this could be because the maximum adjustment of 4% has been taking place for three more years than in scenario 1. In scenario 3, when there is full adjustment, the total socio-economic return goes up to EUR 28 Million, in this case there is no restrictions on how fast the adjustment is taking place. In these three scenarios the longliners are not affected. This is probably due to the restriction that we made in the model that the maximum catch per vessel per year is 2 times the catch per vessel in 2015. Finally, scenario 4 shows the results if a 10% landing tax was set, which gives the same socio-economic return as scenario 1.

In Table 39 we also study the number of vessels that result from the model scenarios above. We see that the number of trawlers is reduced from 31 to 23 or 26% in scenario 1, while the numbers of longliners drop from 14 to 11 or 21%[24.] For scenario 3 where there is full adjustment, the number of trawlers goes from 31 to 12 vessels or 61%. In the other cases the number of vessel are reduced from 31 to 23 vessels (except scenario 2 where it is 21). The model only calculates based on the current situation, so these are vessels of the

[24] It is worth mentioning that these results are not so drastic as the last time similar calculations were made in 2014 for the project 'Reducing Climate Impact from Fisheries' (Waldo, et al., 2014). In that report the long liners should be reduced to 5 while the trawlers were to be 11. The reason for the lower reduction in this report is the restriction that in a given year the same vessel can at a maximum fish twice of what it is fishing in 2015, and that that the adjustment can only be 4% each year (except in scenario 3).

same size and capacity as today. The longliners were in 2014, 43 years old on average (Januar, 2016), so there could in the future come newer vessels that would fish more per vessel, so there would be fewer vessels than in the calculations above.

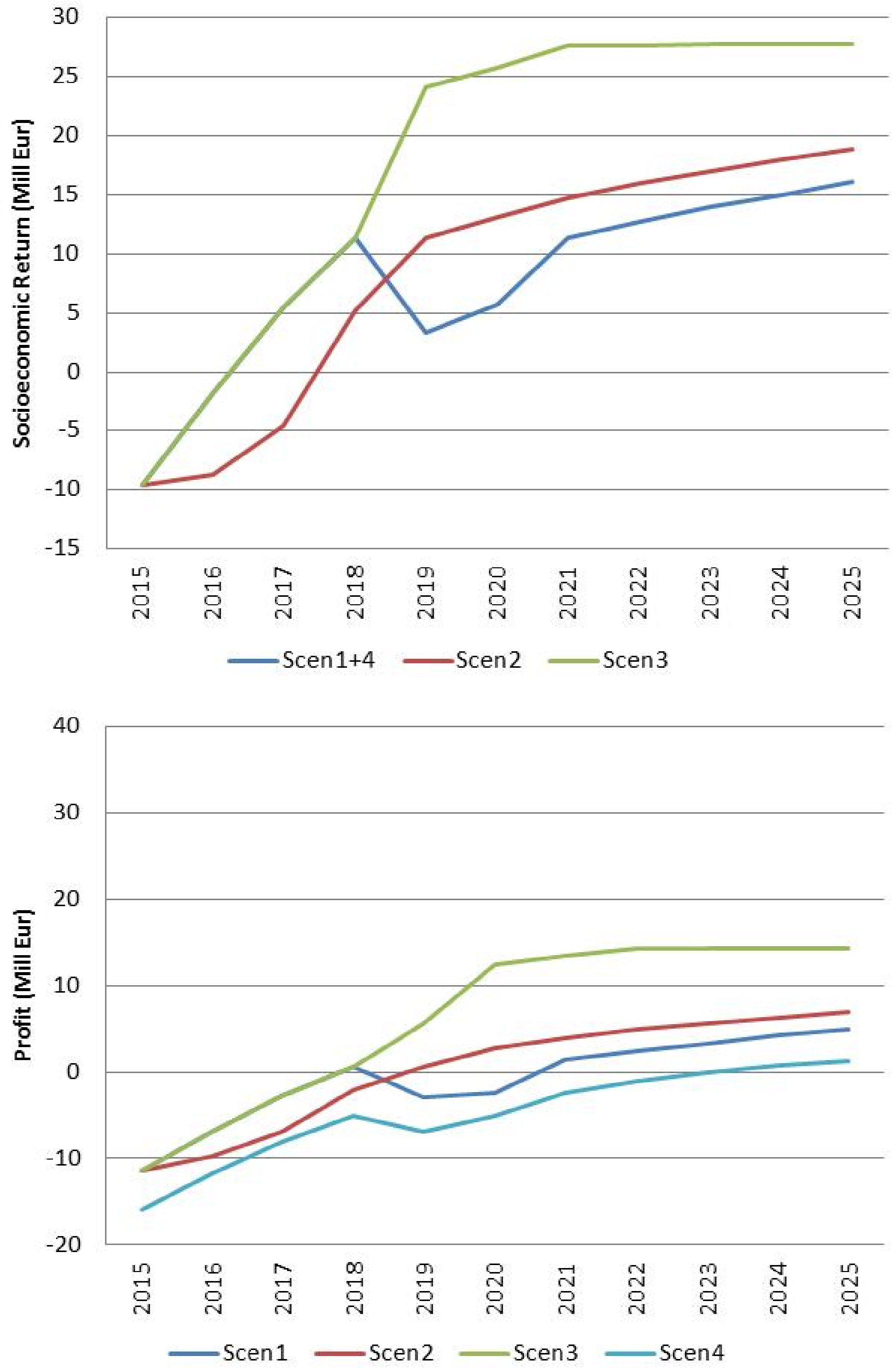
The number of full time employed is shown in the model scenarios above. In this case, it is assumed that there are 8 full time employed on a trawler while there are 14 on a longliner. The results here can be compared to the other results above. We see that the number of employed in the fleets are lowest in the full adjustment case, where the number of employed goes down from 444 to 249. This is quite a low number, but maybe this case (scenario 3) is not so realistic.

In Table 40 we maximize the profit of the fishery. In the initial situation the total profit is EUR -12 Million, but in the case that the current planned management is implemented the profit is EUR 5 Million. We see that the other scenarios are all much better than the current situation. The highest profit comes with the full adjustment. The profits for the fleet in scenario 4 are very low; this could indicate that this fishery is not profitable in any case; if a landing tax of 10% does not produce a higher profit for the fleet.

Table 40 shows the total number of vessels in each group. The results are very similar to the ones in Table 39. Still the most drastic is the full adjustment scenario 3, and the longliners do not show the same adjustment as the trawlers. Table 40 also shows the total number of full time employed. These are also similar to the results reported in Table 39.

Finally, while the results in previous Tables only show the numbers in 2025, Figure 30 shows the development of the results from 2015 to 2025. The left Figure is socio-economic return, while the right Figure shows the profit. We see that the results gradually move towards the results in 2025 reported in the Tables above. Scenario 1 and 4 are the same in the socio economic return maximization. In scenarios 1 and 3 the socio economic return and profit increases towards 2019 even though the effort is held constant in this period, because the stocks increase, thus increasing the catches. After 2019, when the ITQ system is implemented in scenarios 1, 3, and 4 it is seen that a shift occurs in the socio economic return and profit, given that the fishery now starts adjusting to the ITQ system. In scenario 2 the steady increase over the total period is caused by a combination of stock increase and fleet adjustment given the ITQ system.

Figure 30: Forecast of socio-economic return (top) and profit (bottom) 2015–2025, EUR Million



10.6 Policy considerations

As said in the introduction the Faroese demersal fleet has been regulated with a fishing days system since 1996. The economy of the fleet has not been a success and the biology of the stocks has not been favourable since 2002–2003. The results reported here are that the economy of the Faroese demersal fleet could be bettered significantly if the management system was changed from the current fishing days system to a quota system.

This is also been planned by the Faroese parliament to happen in 2019. The question whether this will actually happen is another question. The fishermen, and thereby some politicians, are not so keen for a quota system, and the official reason for their opposition has been that a quota system will induce considerable discards, even though these will be banned by law. The real reason might be that the fishing days system has so many excess days (cf. Figure 26) that the fishery is in reality almost open access, while the individual a quota system will restrict access to fish.

If we study the scenarios with the current management (1 and 4), and in this chapter this means that the quotas system is implemented in 2019. We see that in this case the socio-economic is much higher than in the current management i.e. with the fishing days system. The profit for the fishing industry is also much higher in the scenario 1 compared to the situation today.

There have been many discussions in the Faroes about the fisheries policy, especially the last three years, where the discussion concerned a new fisheries management system that was implemented in January 2018. One big part of this reform was a new allocation mechanism with auctions. There have been auctions in 2018 of around 15–25% of the rights for the pelagic fleet and the distant demersal fleet in the Barents Sea. In the case of the demersal fleet discussed in this chapter, the auctions of fishing rights are being initiated if the Total Allowable Catch is on a much higher level than they are today. For example, for the cod to be auctioned off, the Total Allowable Catch must be above 20 tons (cf. Figure 28). In the case that the Total Allowable Catch is increased to these levels, 25% of the stocks mentioned in this chapter are to be auctioned off. For the rest (i.e. the 75%) there are plans that there shall be a resource tax, but only if the fleets are profitable. There have been resource taxes on the very profitable pelagic fleet since 2011, and they still make a huge profit (cf. Figure 29). According to the model results presented in this chapter there is probably going to be a profit, if the planned implementation of the quota system goes ahead, in the demersal fleet, such that there is going to be a resource tax on the demersal around the Faroes. Scenario 4 presented above indicates what the outcomes of implementing such a tax will be.

There are of course uncertainties in the model, this chapter gives some indications what will happen if the current system was changed into an ITQ system in 2019 as planned, and there is a restriction on a 4% adjustment per year. There are also other scenarios in the chapter, for example, were the adjustment was unrestricted. One thing that is not modelled is that if the fishery becomes profitable again, we could see that the vessels were modernized and become more efficient. So there are of course other limitations in a model like this and it does not show what will actually happen but can only give some indications.

11. Nordic policy lessons on Market Based Fisheries Management

11.1 Introduction

Based on the country cases in the former chapters, the purpose of this chapter is to provide a cross-country comparison both of historical experiences with MBFM of Nordic fisheries and of forecasted future developments in the analysed fisheries under alternative hypothetical fishery policies. The cross-country comparison intends to serve as a basis for the political debate on the future of Nordic Fisheries.

In section 11.2, the prevailing MBFM systems are identified country-wise across the Nordic fisheries, while section 11.3 presents a cross-country comparison of the forecasted future developments in the selected cases under different fishery policies until 2025. Section 11.4 concludes with a list of Nordic policy lessons on MBFM.

11.2 The use of Market Based Management in Nordic fisheries to 2015

MBFM is founded on the direct use of the markets to allocate property rights of fishing. Transferability in the form of direct sale of fishing rights such as quotas is the core element. MBFM used in the Nordic countries today is shown in Table 41 including ITQ systems, but also Individual Quota systems with restriction on transferability, and a transferable effort system. Common for these systems is the transferability of fishing rights, one way or the other. It might be argued that for example the ration regulation existing earlier in the Nordic EU countries are market based, since the value of fishing quotas are capitalized in the assets of the vessels and with vessels sold with fishing rights included, the price of a vessels was often much higher than the physical value of the vessel. Indirectly this management is also founded in the use of markets. However, ration regulation is not considered a MBFM instrument given (i) that the market foundation is only indirect and (ii) that in all the countries where ration regulation have been replaced by ITQs, a substantial structural adjustment has followed with improved economy and reduced fleet size and employment

Table 41: Nordic fisheries subject to Based Management

Country	Fishery	Market Based Management	Introduced
Greenland	Offshore/coastal shrimp fisheryInshore halibut fishery	Individual Transferable Quotas Individual Transferable Quotas	1991/2000 2012
Iceland	Demersal fishery Pelagic fishery Vessels below 10 GRT.	Individual Transferable Quotas Individual Transferable Quotas Individual Transferable Quotas	1984–1988 1986 1990
Denmark	Pelagic fishery Demersal fishery	Individual Transferable Quotas Individual Transferable Quotas	2004–2007 2007
Finland	Pelagic fishery	Individual Transferable Quotas	2017
Sweden	Pelagic fishery Demersal fishery	Individual Transferable Quotas Individual Quotas with annual quota lease	2009 2017
Norway	Whole licensed fishery	Individual Quotas with transferability within vessel groups with vessels from the same region, but no transferability between vessel groups. Quota transfer claims removal of selling vessel from the fleet. The regulator keeps 20% of the quota sold and reallocates it to all vessels in the group.	1996
Faroe Islands	Pelagic fishery Demersal fishery Demersal fishery	Individual Quotas partly transferable at auctions Transferable days at sea Individual Quotas	2018 Until 2018 From 2019

Individual Transferable Quotas is the type of management most used in Nordic countries, as appearing from Table 41, with Iceland and Greenland having the longest record with the management system. Individual Quotas is in force in Norway, with transferability of quotas being possible, but only to vessel within the same vessel group and from the same region, further claiming removal of the vessel that sells quota and with the regulator keeping 20% of the quota for reallocation to all vessels within the group. In the Swedish demersal fishery, Individual Quotas also exists with annual allocation of quotas only to active fishermen, but with the annual quota being transferable. Transferable days at sea prevail until 2018 in the Faroese Demersal fishery, after which it is replaced by an Individual Quotas system. It is a possibility of sale of demersal quotas at auction in the system, but it is not likely yet, since the quotas still are historically low.

11.3 Cross-country comparison of forecasts until 2025

For selected vessel groups from each of the Nordic countries, forecasts are presented in chapter 4–10 for representative average vessels in each group. The vessel groups selected all include elements of MBFM. The vessel groups are:

1. Greenlandic shrimp fishery managed by ITQs;
2. Icelandic pelagic and Stern trawler fishery managed by ITQs;
3. Danish demersal fishery in the North Sea managed by ITQs;

4. Finnish large-scale pelagic fishery managed by ITQs;
5. Swedish large-scale pelagic fishery managed by ITQs;
6. Norwegian demersal fishery North of 62° managed by Individual limited Transferable Quotas;
7. Faroese demersal fishery managed by Individual Quotas sold at auctions.

National aggregated totals of physical and economic data for the selected fisheries are shown for the base period 2012–2014 in Table 42.

Table 42: National aggregated physical and economic data, annual average 2012–2014[1]

	Greenland SHRIMP	Iceland DEM/PEL	Denmark DEM NS	Finland PEL	Sweden PEL	Norway DEM>62°	Faroe Islands DEM
Physical data							
Fulltime employment/segment[2]	291	2,394	359	110	167	5,489	415
Number of vessels	30	79	147	63	30	1,192	45
Days at sea/vessel	206	170	97	91	110	163	250
Main species	PRA (~100%)	MAC (20%)	PLE (32%)	HER (91%)	HER (52%)	COD (61%)	SAI (30%)
	.	CAP (15%)	COD (26%)	SPR (9%)	SPR (25%)	HAD (20%)	COD (22%)
	.	COD (12%)	SAI (11%)	.	.	POL (16%)	.
Turnover/vessel (1,000 EUR)	6,233	7,633	701	460	1,733	750	1,778
Fishing tax revenue (EUR Mill)	14	35		.	.	.	.
Profit (EUR Million)[2]	39	98	7	2	12	152	-7
Profit (% land. value)	21%	16%	7%	7%	23%	17%	- 9%
Socio-econ. return (EUR Million)[2]	82	255	19	0	12	233	-9
Socio-econ. return (% land. value)	44%	42%	18%	- 1%	23%	26%	- 11%

Note: 1. For details on each country cases and for sources, see country chapters. "DEM" = demersal, "PEL" = pelagic, "NS" = North Sea, "BIG" = large-scale vessels, "PRA" = shrimp, "MAC" = mackerel, "CAP" = capelin, "COD" = cod, "HER" = herring, "SPR" = sprat, "HAD" = haddock and "POL" = Pollack.
2. Data for Greenland includes only the fleets and not activities at the factories, see chapter 4.

The considered Norwegian fishery is the largest both in terms of number of vessels (1,192) and employment (5,489 fulltime employed). Iceland is also well covered with 2,394 fulltime employed. Number of vessels and employment included in the analysed fisheries are substantially smaller in the remaining countries. The vessel groups reflect the different types of fisheries that exist in the Nordic countries. Demersal fisheries are analysed in Norway, Denmark and at the Faroe Islands, pelagic fisheries in Finland and Sweden and both in Iceland. In Greenland, the shrimp fishery is included. Large vessels are selected for Iceland and Greenland measured in turnover per vessel, while vessels from the Faroe Islands are also relative large. Measured in turnover and average employed per vessel, the Finnish, Danish and Norwegian vessels are smallest. The Swedish and Faroese vessels are of medium size.

With the large fleet size in the selected vessel groups from Norway and with the large vessel size of the selected groups from Iceland, total annual profit is largest in these countries (respectively EUR 152 Million and EUR 98 Million). Measured in percentage of the landing values, however, profit is largest in Sweden (23% of the landing value) and Greenland (21%). Deficit only appears at the Faroe Islands, which is due to the lack of ability of the current effort regulation system to limit fishing activities.

Total socio-economic return, i.e. what societies gain from the existence of the fisheries annually, are also largest in Iceland and Norway with EUR 255 Million and EUR 233 Million. However, measured as percentage of the landing values, socio-economic return is by far largest in Greenland (44%) and Iceland (42%).

The presence of ITQs in Greenland and Iceland for around thirty years is the main explanation for the economically well-performing fisheries in these two countries. Fishing taxes, on top of income taxes and corporation taxes, are in force in these two countries at a significant level, as opposed to the other countries where fishing taxes are not, or only to an insignificant degree, in force. For the Greenlandic shrimp fishery EUR 14 Million was collected, corresponding to 9% of the landing value, while for Iceland EUR 35 Million, 6% of the landing value, was collected. Such taxes are also in force in, for example Norway (0.2% of the landing value) and Denmark (per mille tax), but they are very small and serves other purposes.

It seems that management with ITQs for a long time period may aid fisheries in performing well economically. The increasing profits to the private fishing companies, which the remaining society automatically achieve a share of through income taxes and corporation taxes, seems to induce a pressure from the remaining society to receive their share. Arguments for introducing taxes are typically founded on, that the Nordic Fishery Laws indicate that fish stocks are the property of the societies. This pressure is behind the introduction of fishing taxes in Greenland and Iceland. The Faroe Islands also have experiences in collecting extra earning in the form of selling mackerel quotas on auctions. Hence, the three West Nordic countries where the socio-economy is severely dependent on the fisheries sector, all extraordinary collects profits from their fisheries, although the Faroe Islands in the analysed vessel group have not had much to collect with the deficits during 2012–2014.

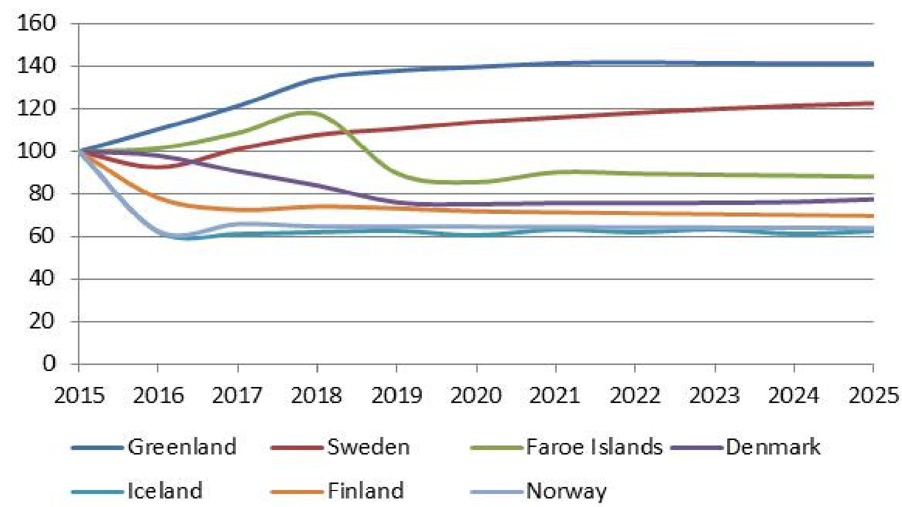
The report has focused on the forecasted economic development for the fisheries summarised in Table 42, until 2025 using the method described in chapter 3. The following four scenarios have been analysed:

1. Current management and a 4% limit on yearly adjustment in number of vessels in each group;
2. Free ITQ trade between all vessels and a 4% limit on yearly adjustment in number of vessels in each group;
3. Current management with no limit on yearly fleet adjustment;
4. Current management with a 4% limit on yearly fleet adjustment and 10% extra taxes on the landing value.

The discounted net present value of future socio-economic return and profit are maximized through variation in number of vessels and days at sea per vessel for each included vessel group in the four scenarios. While socio-economic return measures the extraordinary economic contribution of fisheries to the socio-economy, profit is the surplus for the private fishing companies.

The forecasts depend critically on the biological development of fish stocks. Future recruitment of fish is forecasted by estimating a function where recruitment increases with the size of the fish stocks until the MSY, after which it falls. This function is identified not to let the fish stocks coming above the maximum observed in the period 1995–2014. Total Allowable Catch is determined through a policy aiming at MSY, while individual fisheries will set their catches at a level that is as close as possible to MSY, while at the same time ensuring maximum economic outcome from the fishery. An index of the development in the forecasted catches is shown for each country case in Figure 31.

Figure 31: Index of predicted catches for 2015–2025, 2015 = 100



Note: 1. For each country, the index is calculated as average catches of the main species per year weighted with the share of the landing value of that species of the total turnover. The main species are those mentioned in Table 42. The countries are sorted after the size of the index in 2025.
2. The index is calculated on the basis of catches determined in the model that maximizes the net present value of future socio-economic returns. The corresponding index determined on the basis of profit does not deviation substantially from the above.

The index measures the average catch development for each country case until 2025 over the four scenarios. For each country case, the index is calculated as average catches of the main species per year weighted with the share of the landing value of that species of the total turnover. The larger index, the larger are the catches.

It appears that over the 2015–2025 forecast period catches increase most in the single species Greenlandic shrimp fishery, owing to that the shrimp stock were at a lower level in the base period 2012–2014 than over the period 1995–2014 on which the biological forecast is founded. Catches are also predicted to increase for the Swedish pelagic fleet. Catches in the remaining vessel groups are all predicted to fall. This is due to that stocks were at a higher level in 2012–2014 than over the entire 1995–2014 period and consequently due to that all these vessel groups perform multispecies fisheries giving rise to the "choke" species problem. The "choke" species problem indicates that if the quota on one stock is reduced, fishing effort on all stocks must be reduced correspondingly in the forecast model. The model does in such a situation forecast a substantially reduced activity in the vessel group, whilst in reality the vessels could have continued to fish on the remaining stocks, implying that the forecasted development is underestimated. Hence, since the biological forecasts might underestimate future catches in country cases where the index falls (Iceland, Norway, Finland, Denmark and the Faroe Islands) the economic forecasts are also underestimated. The relative difference of forecasts between scenarios, however, remains reliable, since all scenarios are subject to the same influence.

The forecast results are shown for 2025 in Table 43, displaying the results of the maximization of socio-economic return.

Table 43: Forecast of socio-economic return, fleet and employment adjustment in 2025 by maximizing socio-economic return

	Greenland SHRIMP	Iceland DEM/PEL[1]	Denmark DEM NS	Finland BIG PEL	Sweden BIG PEL	Norway DEM>62°	Faroe Islands DEM
Socio-economic return (EUR Million)							
2015 initial situation	69	225	22	-2	11	234	-10
2025 scenarios:							
1. Current management	127	203	28	2	22	198	16
2. ITQ management free quota trade[2]	135	211	29	.	.	218	19
3. Current management full adjustment	129	225	37	7	26	267	28
4. Current management 10% landing tax	127	203	28	2	22	198	16
Socio-economic return (% land. value)							
2015 initial situation	45	26	22	-7	21	27	-14
2025 scenarios:							
1. Current management	60	49	31	10	35	36	25
2. ITQ management free quota trade	52	51	32	.	.	37	30
3. Current management full adjustment	61	54	39	38	40	49	43
4. Current management 10% landing tax	60	49	31	10	35	36	25
Number of vessels/processing (tons)							
2015 initial situation	30	77	147	63	30	1,192	45
2025 scenarios:							
1. Current management	20	57	117	42	25	792	34
2. ITQ management free quota trade	24	53	118	.	.	792	31
3. Current management full adjustment	17	33	90	31	22	498	22
4. Current management 10% landing tax	20	57	117	42	25	792	34
Employment (full-time)							
2015 initial situation	291	2,331	352	110	168	5,471	444
2025 scenarios:							
1. Current management	201	1,764	272	73	141	3,637	334
2. ITQ management free quota trade	232	1,595	273	.	.	3,637	309
3. Current management full adjustment	167	1,066	192	37	120	2,232	240
4. Current management 10% landing tax	201	1,764	272	73	141	3,637	334

Note: 1. For Iceland, the initial year is 2016.
2. With the vessel groups included in the Finnish and Swedish cases, more quota trade than in scenario 1 is not possible in scenario 2. Therefore, scenario 1 and 2 are the same and only shown for scenario 1.

Source: Country cases in chapter 4–10.

It appears from Table 43 that the socio-economic return increase in 2025 compared to 2015 in all countries except in the Norwegian and Icelandic case. The socio-economic return in these two countries falls due to the forecasted catch reduction and to the "choking" problem, except for in the full adjustment scenario in the Norwegian case. The catches in 2025 are forecasted to decrease in both countries (cf. the discussion of Figure 31). Given that the Icelandic and Norwegian fisheries have been managed with market based instruments in many years, the predicted reduction in socio-economic return is surprising. Reasons might include that reduction in fish stocks and choking effects induces underestimation of the socio-economic return. But the reason in particular in Iceland may also be that vessels have high capital costs with expected future earnings capitalized in the quota values, affecting profit negatively when stocks dwindle. For the remaining countries, socio-economic return increases in all scenarios. In scenario 1, the largest increase appears in Sweden, Greenland, and the Faroe Islands. These three countries are, however, also the countries that perform best on catch development over the period. Hence, the positive economic development is not only due to structural adjustment following from MBFM, but also due to a predicted positive biological development in the fish stocks.

To clean for exogenous development in the fish stocks, whether positive or negative, the socio-economic return in percentages of the landing value must be compared.

In 2015, the socio-economic return is largest in Greenland forming 45% of the landing value, on a medium level in Norway, Iceland, Denmark and Sweden (21–27%), whilst negative at the Faroe Islands and in Finland. The high share of socio-economic return in the Greenlandic case is believed to reflect (i) that ITQs have been into force since 1991 for the large vessels and for all vessels since 2000 and (ii) that shrimp are caught by large vessels with increasing returns to scale. The low share in Finland reveals the earlier management with only Total Allowable Catches that are not followed by input regulation and, simultaneously, the negative socio-economic return at the Faroe Islands follows from the current days at sea management, with total days a sea not limiting the activity of the fleet. For the Danish and Norwegian cases the medium sized share might reflect that the demersal fleet consists of relative small vessels, while both the share and the vessels in the Swedish case are medium sized. Management is also important, with ITQs in Denmark since 2007 and only more recent in Sweden since 2009. The medium size of the share of the socio-economic return in the Norwegian case might reveal that the management with Individual Quotas have induced some medium level of structural adjustment in the fleet, despite the quotas only having limited transferability. The substantially reduced Icelandic share on 26% in 2015 compared to the 42% in base period (2012–2014) is surprising with the fleet consisting of large vessels, but might due to the forecasted catch reduction appearing in Figure 31. The sharp reduction, however, also induce uncertainty on the Icelandic forecast results.

The socio-economic return in percentage of landing value is predicted to increase from 2015 to 2025 in all country cases in all scenarios from 2015, except in the Norwegian case in scenario 4, with the introduction of a 10% landing tax.

Under the current management (scenario 1), the socio-economic return in percentage is predicted to increase most in relation to 2015 at the Faroe Islands from the current deficit on 14% to a surplus on 25% of the landing value. The percentage rises is also substantial in Iceland (23%-points), Finland (17%-points), Greenland (15%-points) and Sweden (14%-points), while smallest in Norway and Denmark (9%-points). Hence, in scenario 1 of unchanged management, the increases in socio-economic return in percentage of landing value at the Faroe Islands, Finland and Sweden are forecasted to follow the introduction of Individual Quotas (at the Faroe Islands in 2019) and ITQs (in Sweden in 2009 and in Finland in 2017). In the Icelandic case that has been managed with ITQs for many years, the sharp increase follows from catch fluctuations, while for Greenland a continued structural adjustment is forecasted leading to very high socio-economic return in percentage of the landing value. The increase for the Danish and Norwegian cases is relative small, which might be explained by this fishery being undertaken by relative small vessels.

The resulting situation in 2025 in scenario 1 reveals that the socio-economic return in percentage of landing values is highest in Greenland and Iceland (60% and 49%), which is believed to be due to the fisheries being performed with large vessels that have been managed with ITQs for many years, lowest in Finland (10%) and at the Faroe Islands (25%) due to earlier management where only a part of the expected structural adjustment comes before 2025. The share in the remaining cases in between on 31–36% reflects both the size of the vessels, the type management and for how long the regulations have been in force.

The number of vessels is in scenario 1 forecasted to have decreased in in 2025 compared to 2015 with 17–34% in all country cases when maximizing socio-economic return, while employment is predicted to fall with 16–34% except in Greenland where the reduced employment at the vessels are counterbalanced by increased employment at the land-based factories included in this country case only. Maximizing profit (Table 44 below) induce largely the same structural adjustment. Hence, with a continuation of the current management and without any policy changes, the structural adjustment is predicted to continue and lead to both a lower number of vessels and a reduced employment. Furthermore, since these forecasts are made assuming unchanged technology and since the technology normally improves over time, this structural adjustment might well be larger.

In scenario 2, assuming free quota trade with a 4% limit on annual fleet adjustment, the socio-economic return in percentage of landing values are larger than under continuation of the current management (scenario 1) in all cases except the Greenlandic. The increase in the share is, however, small in all cases with the largest increase seen at the Faroe Islands. The development in number of vessels and employment doesn’t differ more than 10% compared to continuation of the current management (scenario 1).

In the Greenlandic case, the socio-economic return in percentage of the landing value fall in scenario 2 compared to scenario 1, although the absolute socio-economic return increases. The reason for the reduction is that catches increases with free quota trade, since all quotas can be used.

In scenario 3 of continuing the current management unchanged without limiting annual fleet adjustment, the socio-economic return share increases, compared to scenario 1, in all cases. The increase in the share is largest in Finland with 28% (from 10% to 38%) and at the Faroe Islands (18%), where MBFM is first introduced in 2019. The increase in the Greenlandic and Icelandic case are very small, revealing that the structural adjustment has already lead to an approximately optimal fleet structure in these two countries, since they have had ITQs for many years. The Danish, Norwegian and Swedish cases are in between, revealing that some structural adjustment have already been seen, whilst some also remains.

The resulting situation in 2025 in scenario 3 is almost the same as in scenario 1 in Greenland and Iceland, while the share increase for the remaining countries 38–49% dependent on in particular management, size of vessels and returns to scale.

The number of vessels falls substantially with 12–42% and employment falls even more with 13–66% under scenario 3 compared to scenario 1. Fleet size and employment are reduced least in Greenland and Sweden, owing to the forecasted growth in catches. In the Icelandic and Faroese case, the fleet size is forecasted to fall the most, for the Icelandic case due to the uncertain predicted catch reduction, while for the Faroese case catches are predicted more stable and the reduction is mainly due to the shift from the current effort regulation to Individual Quotas in 2019.

Scenario 2 and 3 consider the same situation as in scenario 1 except for respectively replacing current management with free quota trade and afterwards removing the 4% fleet adjustment limit to full adjustment. But the situation where the two changes, i.e. free quota trade and full adjustment, are made simultaneously is not analysed. In such a situation, the effects of scenario 2 and 3 are expected to be combined, inducing larger socio-economic return than in scenario 2 and 3, as well as lower fleet size and lower employment.

In scenario 4 of continuing the current management with an added tax on 10% of the landing value the socio-economic return appears approximately the same as under the current management (scenario 1). The reason is that the tax transfer amounts from fishermen to the Government, but doesn't affect efficiency of fisheries substantially.

The forecast results where profit is maximized in the four scenarios are shown in Table 44. Profit differs from socio-economic return by being the economic surplus of fishermen where socio-economic return is the economics surplus of society.

Table 44: Forecast of profit, fleet and employment adjustment in 2025 by maximizing profit

	Greenland SHRIMP	Iceland DEM/PEL[1]	Denmark DEM NS	Finland BIG PEL	Sweden BIG PEL	Norway DEM>62°	Faroe Islands DEM
Profit (EUR Million)							
2015 initial situation	31	110	22	2	12	138	-12
2025 scenarios:							
1. Current management	70	77	28	4	20	101	5
2. ITQ management free quota trade[3]	72	84	29	.	.	113	7
3. Current management full adjustment	71	48	37	7	23	145	14
4. Current management 10% landing tax	58	60	28	2	16	75	1
Profit (% land. value)							
2015 initial situation	20	8	22	7	23	16	-16
2025 scenarios:							
1. Current management	33	18	31	19	32	18	8
2. ITQ management free quota trade	28	20	32	.	.	19	11
3. Current management full adjustment[2]	34	12	39	38	35	27	22
4. Current management 10% landing tax	27	16	34	10	29	14	2
Number of vessels/processing (tons)							
2015 initial situation	30	76	147	63	30	1,192	45
2025 scenarios:							
1. Current management	20	56	117	51	23	792	35
2. ITQ management free quota trade	22	53	118	.	.	792	32
3. Current management full adjustment	15	31	90	47	17	175	23
4. Current management 10% landing tax	20	54	117	47	23	792	34
Employment (full-time)							
2015 initial situation	291	2,331	352	110	168	5,471	444
2025 scenarios:							
1. Current management	201	1,725	267	80	137	3,637	345
2. ITQ management free quota trade	220	1,592	269	.	.	3,637	322
3. Current management full adjustment	152	814	209	51	110	1,760	246
4. Current management 10% landing tax	201	1,658	264	77	137	3,637	334

Note: 1. For Iceland, the initial year is 2016.
2. Profit in percentage of landing value before deduction of taxes is shown.
3. With the vessel groups included in the Finnish and Swedish cases, more quota trade than in scenario 1 is not possible in scenario 2. Therefore, scenario 1 and 2 are the same and only shown for scenario 1.

Source: Country cases in chapter 4–10.

The structural development when maximizing profits are to a large extent the same as maximizing socio-economic return. Some differences, however, remains. Profits are at a lower or the same level than socio-economic return in all countries in all scenarios due to (i) salary in fishing being higher than in other sectors, (ii) the rate of return on capital being higher in fishing than other sector, (iii) cost of quota purchase, and (iv) fishing taxes being paid by fishermen in some cases.

Profit in percentage of landing values are in 2015 all lower than or equal to the socio-economic share of landing values. The reasons are that remuneration of labour is larger in fisheries than in alternative sectors in which fishermen could work, that remuneration of capital is larger than in alternative industries assets could be invested and that profit over time is removed from the fishery through payment of permanent quotas to earlier fishermen. The profit share in 2015 confirms the result above that the Swedish, Danish and Greenlandic fisheries managed with ITQs are highest, while the Faroese and Finnish share are smallest.

In scenario 1, profit in percentage of landing values confirms the relative sizes achieved for socio-economic return except for Iceland. For the Icelandic case the low profit share (8%) indicates on top of reduced catches that ITQs have been in force for many years with expected future earnings therefore being capitalized in permanent quota values and removed from the fishery through quota trade. Forecasting profit also confirms the developments identified for socio-economic return in scenario 2 and 3.

In scenario 4, the tax introduced under an otherwise unchanged management affects, as opposed to socio-economic return, profit. Profits in scenario 4 falls or stays unchanged in 2025 in all country cases compared to scenario 1. Compared to 2015, however, profit increases despite of the tax in all cases except in Iceland and Norway. In these two countries, profit is reduced due to the forecasted catch reduction. For the remaining country cases, this calculation tells that even with a 10% tax on the landing value, profits will increase in 2015–2025 with unchanged continued management.

Hence, if taxes are introduced before structural adjustment is completed, the negative pressure on profits they induce, can often be more than meet by the positive pressure on profit from future structural adjustment. Thus, it may be free of charge for the fishing vessels that remain active to have taxes introduced in the long run, although taxes also affect fleet size and employment negatively.

The forecast results above are discussed only for the year 2025, while it should be kept in mind that the forecasts are made for the total period 2015–2025. In 2016, profits are forecasted either to decline or increase less than in the following years. After 2016 only increases are predicted. With company decisions on investment in quotas being based on profits, the speed of the structural adjustment is determined by profit.

In scenario 1 of current management, 75% of the development in profits in 2016–2025 is achieved after 3–8 years, with the fastest speed in the Greenlandic case and the slowest in Denmark. In scenario 2 of free quota trade, the adjustment is slowest in Denmark, Iceland and Norway (75% of the adjustment is achieved after 7 years), whilst fastest in Greenland (2 years). In scenario 3, adjustment is substantially faster with 75% of the effect obtained after 1–4 years in all cases. In scenario 4 the adjustment is a bit slower than in scenario 1 with 75% of the adjustment achieved one year later than in scenario 1 in most of the country cases.

The speed forecasted reveals that structural adjustment following MBFM reforms doesn't happens overnight, but on the contrary can take some time. Further, taking into account improvements in fishing technology over time, biological fluctuations and price fluctuations, it must be concluded that fisheries are often prone to some degree of continued never ending structural adjustment.

While the forecasts presented in this report identify lessons on MBFM at an early time where it remains possible to revise the fishery policies, they are also based on an "all other things equal" assumption. This is in particular relevant for prices that are assumed constant over the whole 2015–2025 period at the level in 2012–2014. While constant fish prices over time might be realistic given the relative constancy over the last decade of the FAO fish price index (Food and Agricultural Organization of the United Nations 2018), price fluctuations may arise from supply and demand chocks. Prices for largely all species are, however, formed on international integrated markets at which supply from Nordic fisheries are in competition with many other countries. Hence, fish supply from one Nordic fishery is in most cases not able to have noticeable effect on prices at the world market. That accounts for whitefish (cod, haddock, saithe, pollack and plaice), fish for reduction (sprat and capelin) and presumable also for shrimp, where the species supply internationally integrated world markets, respectively for whitefish, fishmeal and oil and shrimp (Asche and Tveteraas 2004; Nielsen *et al.* 2009; Bronmann *et al.* 2016; Ankamah-Yeboah *et al.* 2017).

On the other hand, Nordic fisheries are affected by supply and demand developments at the world markets. Here the long run trend is an upward pressure on prices following increased demand due to population growth, income growth and growing preferences for healthy food such as fish. This trend is met by a downward pressure on prices following an expected continued growth in global aquaculture, with supply of capture fisheries globally expected to stagnate. Aquaculture growth in pangasius, tilapia and warm water shrimp may in particular be important for Nordic fisheries, since these species compete at the European markets, respectively for whitefish and shrimp. Hence, demand seems to press fish prices upwards and aquaculture supply to press prices downwards, making constant prices a reasonable albeit uncertain assumption.

11.4 Nordic policy lessons on Market Based Fisheries Management

Fishery policies are heavily debated across the Nordic counties. Earlier the main subject focused on avoiding overexploitation and overcapacity, where it today is agreed by most that fishing must be sustainable and quotas set according to MSY. Today, therefore, the debate has a more direct focus on how to distribute the economic wealth fisheries create, following the earlier introduction of MBFM.

The debates on MBFM in the Nordic countries generally go in three different lines of arguments that feed into political decisions. One line of arguments emphasizes the socio-economic contribution of fisheries to fund national wealth. This line of arguments favours MBFM as an instrument to create societal wealth by having a viable and efficient fleet. Some finds that the current management with special arrangements for certain vessel groups, in some instances also for certain regions, ensure a reasonable balance between large/small vessels and regionally. Other finds that such special arrangements are not needed and may reduce socio-economic return and profits in fisheries.

Another line of arguments focuses on fisheries as a job creating sector, often by providing employment in small fishing communities spread along the coast where alternative jobs are difficult to find, and where reduction of the local fleet may decimate the harbour community and labour opportunities. Fishery reforms that at the expense of a larger GDP contribute to reducing local employment, induces a social risk when few alternative jobs are available. This line of arguments might be against ITQs. But it might also favour it if quotas are reallocated from offshore to small and local vessels.

A third line of arguments sees the extension of large vessels as a way to increase the maximum GDP contribution and societal welfare. However, since profits go to the private fishing companies, taxes or public sale of quotas are needed for society to obtain a fair share. This line of arguments is in favour of ITQs in combination with fishing taxes.

Nordic experiences and the forecasts provided in this report identify several lessons on the functioning of MBFM. These are relevant in debating the future Nordic fishery policies and enlighten the political trade-offs and dilemmas following from the three lines of arguments. The lessons are:

1. ITQs is a powerful instrument to increase earnings and remove overcapacity, but simultaneously fleet size and employment in fisheries is reduced;
2. All prevailing Nordic MBFM systems have special arrangements for some vessel groups;
3. The Market Based Management systems in the Nordic fisheries all have some variation of concentration rule in force;
4. It is not a universal rule that MBFM always removes the small vessels;
5. Fishing taxes may play a core role for wealth creation in the fishery dependent Nordic countries;
6. Expensive quotas makes it difficult to remove or drastically change an ITQ system;
7. Continued MBFM is forecasted to increase socio-economic return and profit towards 2025 substantially;
8. Free quota trade induces extra earning compared to current regulation in 2025;
9. An extra fishing tax on 10% of the landing value can in most of the country cases be collected without reducing profits in the long run.

Each lesson is explained in the following below.

1. ITQs is a powerful instrument to increase earnings and remove overcapacity, but simultaneously fleet size and employment in fisheries is reduced

ITQs have in all the Nordic countries been used as a powerful management instrument to eliminate overcapacity, thereby increasing profit and socio-economic return substantially, but have also reduced fleet size and employment in fisheries substantially. Although fleet reductions are also caused by other factors, such as technological development, ITQs have contributed substantially to solve the overcapacity problem. And, thereby, solve the basic fishery management problem "to avoid that there are many fishermen to fish too few fish" that other types of regulation have struggled with for many years. ITQs have also made vessel modernization and decommissioning subsidies redundant and have led to their elimination. For example, the ITQ system in the Swedish pelagic fisheries have increased earnings substantially and reduced the fleet with 55% in four years (2009–2013), while the Greenlandic coastal shrimp fishery is reduced 82% in 1992–2017 and today as opposed to earlier have surplus profit. While part of these effects may be due to other drivers than regulation, for example technological development, the Nordic experiences indicate that ITQs increase the speed of fleet adjustment. Other types of MBFM have had same effect as ITQs but to a lesser degree, except the Faroese effort regulation that is largely open access.

2. All prevailing Nordic Market Based Fisheries Management systems have special arrangements for some vessel groups

A fully liberal ITQ system with fully free quota trade does not exist in the Nordic countries. Examples of special arrangements include coastal fishery arrangements for smaller vessels in Iceland and Denmark and for Greenlandic shrimp fishing. The smaller vessels are protected by a quota sales ban to larger vessels and in Denmark combined with extra allocation of quotas. In Sweden small-scale herring fishery in The Sound is not part of the ITQ management, while in Norway quota transferability is limited to within each vessel group and further subject to geographical restrictions. The special arrangements reveal different purposes of the fishery policies that span from economic viability of the fleet and contribution to GDP, to regional priorities with the fleet spread in certain regions along the coast in many living fishing harbours. The broad use of special arrangement reveals that it is possible to control the structural adjustment in the Nordic Market Based Fisheries systems. Every time a special arrangement is introduced, however, profit and GDP contribution of fisheries is reduced.

3. The Market Based Management systems in the Nordic fisheries all have some variation of concentration rule in force

The Market Based Management of Nordic fisheries prevails only with concentration rules in force. MBFM has led to concentration of vessels and quotas on fewer hands, since such management is introduced when there are too many fishermen and too many vessels. The whole idea is to concentrate fishing on fewer fishermen and fewer vessels. However, to avoid concentration of ownership of vessels and quotas on very few hands and following the principle that "fishing must be performed by fishermen with boots on", Greenland, Iceland and Denmark, for example, all specify percentage of quotas that must be in the hand of a single company or person, while Norway uses quota roofs for each vessel for the same purpose. When concentration is restricted, profit and GDP contribution of fisheries are often reduced.

4. It is not a universal rule that Market Based Fisheries Management always removes the small vessels

The fleet structure with large and small vessels is determined both by technology, regulation and type of fishery. While Market Based Management of Nordic fisheries have reduced the number of vessels totally, it is an empirical question whether the number of small vessels is reduced more than the number of large vessels. Since pelagic fish are in most cases caught by large vessels and demersal fish often caught by small and medium sized vessels, small and medium sized vessels are not expected to disappear. Small and large vessels do not fish the same species. In Denmark, for example, even with free trade in permanent quota shares, the reduction in different vessel length groups is largely the same from the year 2000 until today. What is observed, however, is that within each vessel group the average vessel size increases. In Greenland, the coastal and off shore production trawler fleet have also been reduced largely by the same percentage since 2000. In Sweden, following the introduction of ITQs for pelagic fisheries, the number of vessel above 24 meter is reduced more than vessel below 24 meter in the period 2009–2013.

5. Fishing taxes play a core role for wealth creation in more of the fishery dependent Nordic countries

Taxes are applied and very important to fund public wealth in Greenland and Iceland, and have lesser extent also played a role at the Faroe Islands. Fishing taxes can potentially also play a role in the remaining Nordic countries, but with fishing sectors being a small activity nationally the pressure from tax payers is small. In these countries, prioritizing socio-economic return from a national perspective may not necessarily induce positive effects on socio-economic return in local fishing communities. Transfer of revenue from fishing taxes to local communities may then have a role to play in mitigating negative effects of MBFM.

6. Expensive quotas make it difficult to remove or drastically change an ITQ system

Capitalization makes larger revisions of Market Based Managed fisheries in the form of special arrangements and taxes expensive over time. The reason is that expected future earnings are capitalized in quota prices when permanent quota shares are traded. The current generation of quota owners has paid a price for their quotas founded on what they can expect to earn in the future. Hence, the expected future earning is removed from the fishery and ends at the fishermen that sell quotas. New special arrangements and taxes may induce economic problems for the current vessels that, due to the earlier paid quota prices, may not earn over-normal profit. Capitalization also makes it economically difficult to replace MBFM. Finally, capitalization makes it economic difficult to introduce the management, see what happens, learn by mistakes and then revise the system until it fits the political priorities. MBFM makes great demands to clear political priorities and to design the system in a long-lasting way already at the introduction. Reforming Market Based managed fisheries is thus economical easiest at times where unexpected price increases and unexpected fish stock increases can counterbalance negative economic effects. The only Nordic example of a removal of an ITQ system was at the Faroe Islands in 1996, where the management was abolished due to the unexpected return of demersal fish after being in force for only two years. At some point in time it may become so expensive to change the system that there is no point of return.

7. Continued Market Based Fisheries Management is forecasted to increase socio-economic return and profit to 2025 substantially

Socio-economic return and profit is forecasted to increase substantially over the period until 2025 in most of the country cases, while biological stock reductions are predicted to reduce socio-economic return and profit in other of the country cases. The fleet is forecasted to be reduced with 17–34% in 2015–2025, where the socio-economic return cleaned for biological developments by being in percentage of landing values is forecasted to increase 9–39%-points. Hence, despite MBFM has been in force for many years in some of the countries, structural adjustment is far from over. Further taking technological developments into account would lead to an even faster structural adjustment. Nordic fisheries faces over the coming decade continued growth in GDP contribution, continued fleet reduction and continued reduced employment in fisheries.

8. Free quota trade induces extra earning compared to unchanged management in 2025

MBFM and in particular ITQs is a powerful management instrument that increases the socio-economic return of the sector by letting the most efficient vessels buy quotas from other fishermen thereby from a society point of view taking advantage of fishermen skills, the best available fishing technologies, possible increasing returns to scale and clustering of the sector a few places instead of being spread. However, the effect of free quota trade on socio-economic return and fleet development is in this report predicted to be small, which might be due to that fishermen leaves fishing later than what is rational economically for them, for example following planned pension and time lags in their leave decisions.

9. An extra fishing tax on 10% of the landing value can in most of the country cases be collected without reducing profits in the long run

Introducing an extra tax on 10% of the landing value induce a downward pressure on profits, but otherwise unchanged management affect profits upwards over time. In most of the analysed cases, profits are forecasted to increase in 2025 compared to 2015, even with the 10% tax. Hence, the socio-economic return prevailing in fisheries with MBFM can still be collected to the Government to fund public wealth without inducing deficits in many of the Nordic fisheries.

Bibliography

Andersen, J. L., Frost, H., & Løkkegaard, J. (2005). Forvaltning af det danske konsumfiskeri. Fødevareøkonomisk Institut. Rapport / Fødevareøkonomisk Institut, Nr. 176.

Andersen P., Andersen J.L., Frost H. (2010). ITQs in Denmark and Resource Rent Gains. Marine Resource Economics, Vol 25., pp 11–22.

Ankamah-Yeboah, I., L. Staahl and M. Nielsen (2017), Market integration of cold- and warm-water shrimp in Europe, Marine Resource Economics 32(4):371–90.

Anon (2001) Economic performance of selected European fishing fleets: Annual Report 2001. Concerted Action FAIR CT-97-3541, Promotion of Common Methods for Economic Assessment of EU Fisheries.

Armstrong, C. W., & Sumaila, U. R. (2001). Optimal allocation of TAC and the implications of implementing an ITQ management system for the North-East Arctic cod. Land Economics, 77(3), 350–359.

Arnason, R. (1993). The Icelandic individual transferable quota system: Adescriptive account. Marine Resource Economics, 8(3), 201–218.

Arnason, R. (2002). A review of international experiences with ITQs: Annex to future options for UK fish quota management. Portsmouth: University of Portsmouth.

Arnason, R. (2005). Property rights in fisheries: Iceland's experience with ITQs. Reviews in Fish Biology and Fisheries, 15(3), 243–264.

Arnason, R. (2008). Iceland's ITQ system creates new wealth. The Electronic Journal of Sustainable Development, 1(2), 35–41. Retrieved from http://www.ejsd.co/docs/ICELANDS_ITQ_SYSTEM_CREATES_NEW_WEALTH.pdf

Arnason, R., Hannesson, R., & Schrank, W. E. (2000). Costs of fisheries management: the cases of Iceland, Norway and Newfoundland. Marine Policy, 24(3), 233–243.

Asche, F. and S. Tveteraas (2004), On the relationship between aquaculture and reduction fisheries, Journal of Agricultural Economics 55(2):245–265.

Asche, F., Bjørndal, T., & Gordon, D. V. (2009). Resource rent in individual quota fisheries. Land Economics, 85(2), 279–291.

Baldursson, E., & Gunnlaugsson, S. (2004). Sjávarútvegur í kauphöllinni: Saga og greining. Reykjavík: Kauphöll Íslands.

Baudron, A., Ulrich, C., Nielsen, R. J., & Boje, J. (2010). Comparative evaluation of a mixed-fisheries effort-management. ICES Journal of Marine Science(67), pp. 1036–1050. Retrieved from https://academic.oup.com/icesjms/article/67/5/1036/607659

Bjorndal, T., Child, A., & Lem, A. (2014). Value chain dynamics and the small-scale sector: Policy recommendations for small-scale fisheries and aquaculture trade (FAO Fisheries and Aquaculture Technical Paper no. 581). Retrieved from http://www.fao.org/fileadmin/user_upload/fisheries/docs/Value_chain_dynamics_and_the_small-scale_sector.pdf

Björk, L. 2017.Who do you know? Transaction relations in the Swedish pelagic ITQ system. In Essays on Behavioral Economics and Fisheries: Coordination and Cooperation. Ph.D. thesis, Economic studies No. 229. Department of Economics, University of Gothenburg.

Bronmann, J., I. Ankamah-Yeboah and M. Nielsen (2016), Market integration of pangasius and tilapia in relation to wild-caught whitefish in Germany, Marine Resource Economics. 31(4):421–432.

Christensen, A. S., Hegland, T. J., & Oddsson, G. (2009). The Icelandic ITQ system. In K. H. Hauge & D. C. Wilson (Eds.), Comparative evaluations of innovative fisheries management: Global experiences and European prospects (pp. 97–118). New York: Springer.

Chu, C., 2009. Thirty years later: the global growth of ITQs and their influence on stock status in marine fisheries. Fish Fish., 10 (2009), pp. 217–230.

Copenhagen Economics (2013), The Ecoonomic footprint of the fishery in Greenland, in Danish (Fiskeriets økonomiske fodaftryk i Grønland), report to the Greenland Business Association, October 2013, available at: https://www.copenhageneconomics.com/dyn/resources/Publication/publicationPDF/8/248/0/Fiskeriets%20økonomiske%20fodaftryk%20i%20Grønland.pdf

Danielsson, A. (1997). Fisheries management in Iceland. Ocean & Coastal Management, 35(2), 121–135.

Danish Agrifish Agency. Yearbook of fisheries statistics (2002, 2007, 2014).

Danish Ministry of Food, Agriculture and Fisheries, 2003. Regulation Directive no. 1028 of 11 December 2003.

Danish Ministry of Food, Agriculture and Fisheries, 2004. Directive on vessels used for commercial fishery in salt water, no. 124 of 27 February 2004.

Danish Ministry of Food, Agriculture and Fisheries, 2005. Parliamentary agreement on new regulation of Danish fisheries between the Government and Danish People's Party, 3rd November 2005 (In Danish).

Danish Ministry of Food, Agriculture and Fisheries, 2007. Strategy for the development of the Danish fishery and aquaculture sector 2007–2013 made for the European Fisheries Fund, 23 March 2007 (in Danish).

Danish Ministry of Food, Agriculture and Fisheries, 2008. Act on Fisheries and Aquaculture, Directive no. 978 of 26 September 2008.

Directorate of Fisheries, Hunting and Agriculture (1994), Modernization of the coastal and inshore fisheries, pp. 25–54, In Danish, review for the working group on structural adjustment under the Directorate of Fisheries, Hunting and Agriculture to the second spring meeting in the Greenland Parliament, Greenland Home Rule, Nuuk.

Directorate of Fisheries, Hunting and Agriculture (1995), Coastal shrimp fishery – capacity adjustment and regulation, in Danish, review made for the autumn meeting in the Greenland Parliament, Greenland Home Rule, Nuuk.

Directorate of Fisheries. (2014a). Fisheries management. Retrieved from http://www.fiskistofa.is/english/fisheries-management/

Directorate of Fisheries. (2014b). Strandveiðar (Quota to coastal fisheries). Retrieved from (Icelandic only) http://www.fiskistofa.is/fiskveidistjorn/umfiskveidistjornunarkerfid/strandveidar/

Directorate of Fisheries. (2014c). Línuívilnun (Quota to onshore bated longline). Retrieved from (Icelandic only) http://www.fiskistofa.is/fiskveidistjorn/linuivilnun/

Directorate of Fisheries. (2017a). Úthlutað aflamark fyrri ár (Annual catch quota previous years). Retrieved from (Icelandic only) http://www.fiskistofa.is/aflamarkheimildir/uthlutadaflamark/fyrriar/

Directorate of Fisheries. (2017b). Veiðigjöld (Fishing fees). Retrieved from (Icelandic only) http://www.fiskistofa.is/fiskveidistjorn/veidigjold/

Directorate of Fisheries. (2017c). Byggðakvóti (Quota to offset major disturbances within the system). Retrieved from (Icelandic only) http://www.fiskistofa.is/veidar/aflaheimildir/byggdakvoti/

Eggert, H., & Tveterås, R. (2013). Productivity development in Icelandic, Norwegian and Swedish fisheries. Applied Economics, 45(6), 709–720.

Einarsson, N. (2011). Fisheries governance and social discourse in post-crisis Iceland: Responses to the UN Human Rights Committee's views in case 1306/2004. In G. Alfredsson & T. Koivurova (Eds.), The Yearbook of Polar Law: Vol. 3 (pp. 479–515). Leiden: Martinus Nijhoff.

Eliasen, S., S. Sverdrup-Jensen, P. Holm and J. P. Johnsen. 2009. Nordic experience of fisheries management. Seen in relation to the reform of the EU Common Fisheries Policy. TemaNord 2009:579. Nordic Council of Ministers, Copenhagen.

EU 2013. Regulation No. 1380/2013 on the Common Fisheries Policy.

Eythórsson, E. (1996). Theory and practice of ITQs in Iceland: Privatization of common fishing rights. Marine Policy, 20(3), 269–281.

Eythórsson, E. (2000). A decade of ITQ-management in Icelandic fisheries: Consolidation without consensus. Marine Policy, 24(6), 483–492.

Fiskidaganevndin. (2017). Tilmæli um fiskidagar 2017/2018.

Fjársýsla Ríkisins (2017a). Ríkisreikningur 2014. Retrieved from http://www.fjs.is/media/rikisreikningur/Rikisreikningur-arid-2014-Heildaryfirlit-Rafraenundirritun.pdf

Fjársýsla Ríkisins (2017b). Ríkisreikningur 2013. Retrieved from http://www.fjs.is/media/rikisreikningur/Rikisreikningur-arid-2013,-Heildaryfirlit---Rafraen-undirritun.pdf

Food and Agricultural Organization of the United Nations (2018), FAO Fish Price Index – March 2018 update, includes September 2017, available at: http://www.fao.org/in-action/globefish/fishery-information/resource-detail/en/c/338601/

Frost, H., & Kjærsgaard, J. (2005). Overkapaciteten i den danske fiskerflåde. København: Fødevareøkonomisk Institut. Rapport / Fødevareøkonomisk Institut, Nr. 175

Frost, H. S., & Løkkegaard, J. (2001). Individuelle omsættelige kvoter: kort belysning af vigtige spørgsmål for dansk fiskeri. København: Statens Jordbrugs- og Fiskeriøkonomiske Institut. Rapport / Statens Jordbrugs- og Fiskeriøkonomiske Institut, Nr. 119Frost H., Hoff A. (2017). The Landings Obligation in view of different management regimes. Fisheries Research, 195, pp 202–213.

Frost H., Andersen P., Hoff A. (2013). Management of Complex Fisheries: Lessons Learned from a Simulation Model. Canadian Journal of Agricultural Economics, 61(2), pp. 283–307.

Gissurarson, H. H. (2000). Overfishing: The Icelandic solution. Retrieved from http://billhutten.s3.amazonaws.com/fw/docs/301.pdf

Gordon, D. V., & Hannesson, R. (2015). The Norwegian Winter Herring Fishery: A story of technological progress and stock collapse. Land Economics, 91(2), 362–385.

Guttormsen, A. G., & Roll, K. H. (2011). Technical efficiency in a heterogeneous fishery: the case of Norwegian groundfish fisheries. Marine Resource Economics, 26(4), 293–307.

Government of Greenland (2017), Comment to the Bill of the New Fishery Law, in Danish, 14 August 2017.

Greenland Home Rule (2009), Report of the Fishery Commission, February 2009, In Danish, available at http://naalakkersuisut.gl/~/media/Nanoq/Files/Publications/

Greenland Parliament (1990), The Act on Shrimp Taxes no. 20 of 25 October 1990, In Danish, available at http://lovgivning.gl/?sc_lang=da-DK

Greenland Parliament (1996), The Fishery Act no. 18 of 31 October 1996, In Danish, available at http://lovgivning.gl/?sc_lang=da-DK

Greenland Parliament (2017), The Act on Resource Taxes on Greenlandic Fishery no. 46 of 23 November 2017, In Danish, available at http://lovgivning.gl/?sc_lang=da-DK

Gunnlaugsson, S. (2014). Fisheries companies within the Icelandic stock exchange 2004–2013. Unpublished data.

Hagstovan. (2018). www.hagstova.fo

Havstovan. (2018). www.hav.fo

Hannesson, R. (2004). The privatization of the oceans. Cambridge: MIT Press.

Hannesson, R. (2013). Norway's experience with ITQs. Marine Policy, 37, 264–269.

Hannesson, R. (2014). Norway's experience with ITQs: A rejoinder.

Hannesson, R. (2016). Fish Quota Prices in Norway. Marine Resource Economics, 32(1), 109–117.

Hoff A., Frost H. (2018). Adjustment of a fishery given the discard ban: The Danish North Sea Case. Under review in Marine Resource Economics.

Holden, M., Garrod, D., 1996. The Common Fisheries Policy: Origin, Evaluation and Future. Oxford: Fishing News Books, Blackwell Scientific Publications Ltd.

http://px.hagstofa.is/pxen/pxweb/en/Atvinnuvegir/Atvinnuvegir__sjavarutvegur__aflatolur__londunartegundir/SJA09031.px

http://px.hagstofa.is/pxen/pxweb/en/Atvinnuvegir/Atvinnuvegir__sjavarutvegur__skip/SJA05002.px

ICES. The International Council for the Exploration of the Sea: Catch statistics. [Data set]. Retrieved from http://www.ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx

ICES. (2017). Report on the North Western Working group.

ICES. (2018). Report on the North Western Working group.

Jákupsstovu, H., Cruz, L., Maguire, J., & Reinert, J. (2007). Effort regulation of the demersal fisheries at the Faroe Islands:. ICES Journal of Marine Science(64), pp. 730–737. Retrieved from https://academic.oup.com/icesjms/article/64/4/730/642865

Januar. (2016). Report on accounts of Faroese fishing vessels.

Jónsson, G., & Magnússon, M. S. (1997). Hagskinna: Icelandic historical statistics. Reykjavık, Iceland.

Kroetz, K., Sanchirico, J. N., & Lew, D. K. (2015). Efficiency costs of social objectives in tradable permit programs. Journal of the Association of Environmental and Resource Economists, 2(3), 339–366.

Løkkegaard, J., Andersen, J. L., Frost, H. S., Jørgensen, M., & Lindebo, E. (2001). Udredning vedrørende anvendelse af individuelle kvoter (IOK) i det danske fiskeri. København: Statens Jordbrugs- og Fiskeriøkonomiske Institut. Rapport / Statens Jordbrugs- og Fiskeriøkonomiske Institut, Nr. 120.

Løkkegaard, J., Andersen, J. L., Boje, J., Frost, H. S., & Hovgård. (2007). Report on the Faroese fisheries regulation: the Faroe model. Department of Economics, University of Copenhagen. Retrieved from https://curis.ku.dk/ws/files/103804471/FOI_Report_193.pdf

Lög um stjórn fiskveiða nr. 38/1990. Retrieved from (Icelandic only) http://www.althingi.is/lagas/132a/1990038.html

Marko Lindroos, Sakari Kuikka ja Soile Kulmala (2007) Individual transferable quotas in the Baltic Sea herring fishery: A socio-bioeconomic analysis, Fisheries Research.

Matthiasson, T. (2003). Closing the open sea: Development of fishery management in four Icelandic fisheries. Natural Resources Forum, 27(1), 1–18.

Matthiasson, T. (2008). Rent collection, rent distribution, and cost recovery: An analysis of Iceland's ITQ catch fee experiment. Marine Resource Economics, 23(1), 105.

Maurstad, A. (2000). To fish or not to fish: small-scale fishing and changing regulations of the cod fishery in northern Norway. Human organization, 59(1), 37–47.

Merayo E., Nielsen M., Nielsen R., Hoff A. (2018). Are Individual Transferable Quotas an adequate solution to overfishing and overcapacity? Evidence from Danish Fisheries. Marine Policy 89, pp 167–176.

Ministry of Finance (2017), Report on the resource rent in the Greenlandic fishery and proposals for new models for resource rent taxation, In Danish, March 2017, available at: http://naalakkersuisut.gl/~/media/Nanoq/Files/Publications/Finanser/.

Ministry of Industries and Innovation. (2001). Niðurstöður nefndar um endurskoðun laga um stjórn fiskveiða ásamt fylgiskjölum. Retrieved from (Icelandic only) http://www.atvinnuvegaraduneyti.is/media/Skyrslur/Nidurst-nfd-um-endursk-l-um-stjorn-fiskveida-asamt-fylgiskjolum.pdf

Ministry of Industries and Innovation. (2010). Skýrsla starfshóps um endurskoðun á lögum um stjórn fiskveiða: Álitamál, greiningar, skýrslur og valkostir við breytingar á stjórn fiskveiða. Retrieved from (Icelandic only). http://www.atvinnuvegaraduneyti.is/media/Skyrslur/meginskyrsla_uppsett_lokaeintak.pdf

Ministry of Industries and Innovation. (2014). Act on fisheries management as subsequently amended: Act no. 116, 10 August 2006. Retrieved from http://eng.atvinnuvegaraduneyti.is/media/acts/Act-no-116-2006-on-Fisheirs-Management.pdf

Ministry of Industries and Innovation. (2014). Act no. 98, 8 April 1998. Retrieved from http://eng.atvinnuvegaraduneyti.is/media/acts/Act-no-22-1998-Fishing-and-Processing-by-Foreign-Vessels-in-Iceland.pdf

NAFO (2018), Map of fishing areas, available at https://www.nafo.int/, accessed July 2018.

NAFO/ICES Pandalus Assessment Group (2017), Report from the meeting, 27 September to 3 October 2017 at the Swedish University of Agricultural Sciences, Lysekil, Sweden, available at

http://www.ices.dk/sites/pub/

Nielsen, M., J. Smit and J. Guillen (2009), Market Integration of Fish in Europe, Journal of Agricultural Economics, 60(2), 367–385.

Nielsen M., Flaaten O., and Waldo S. 2012. Management of and Economic Returns from Selected Fisheries in the Nordic Countries. Marine Resource Economics 27(1):65–88.

Nielsen, M., Larsen, E., Egekvist, J., Abate, T.G., Nielsen, R., Frost, H., Kjaersgaard, J., 2013. Danish coastal fisheries: Structure and economy (in Danish) (IFRO Commissioned report No. 2013–01). University of Copenhagen.

Nielsen, M., L. Ståhl, R. Nielsen, I. Ankemah-Yeboah and D. Schütt (2017), Economic analysis of value chains for Greenlandic fish products, in Danish with English summary, report made for Statistics Greenland.

Nielsen, M., I. Ankamah-Yeboah, L. Staahl and R. Nielsen (2018), Price Transmission in the Trans-Atlantic Northern Shrimp Value Chain, Marine Policy 93:71–79.

Nielsen M., Hoff A., Nielsen R., Waldo S., Blomquist J., Asche F., Bergesen O., Viðarsson J., Sigurðardóttur S., Sveinþórsdóttir R. (2017). Employment and salary of Nordic coastal fishermen. TemaNord 2017:558.

Norwegian Directorate of Fisheries Website https://www.fiskeridir.no/English

NOU2014:16 Sjømatindustrien — Utredning av sjømatindustriens rammevilkår, Tromsø.

NOU2016:16 Strukturvirkemidler i fiskeflåten, Tromsø.

NOU2016:26 Et fremtidsrettet kvotesystem, Oslo.

OECD. (2011). Fisheries policy reform: National experiences. doi:10.1787/9789264096813-en.

Palsson, G., & Helgason, A. (1995). Figuring fish and measuring men: The individual transferable quota system in the Icelandic cod fishery. Ocean & Coastal Management, 28(1), 117–146.

Pincinato, R.B., Asche, F., Cojocaru, A.L. & Roll, K.H. (2018) The impact of transferable fishing quotas on cost, price and season length presented at The 40th Annual Meeting of the Norwegian Association of Economists 3–4 January 2018 at NHH, Bergen, Norway.

Proposition 2013/14:184 Ändringar i fiskelagen.

Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy.

Rigsrevisionen (2017). Rigsrevisionens beretning om kvotekoncentrationen i dansk fiskeri afgivet til Folketinget med Statsrevisorernes bemærkninger.

Runolfsson, B. (1997). Regional impact of the individual transferable quotas in Iceland. In L. Jones & M. Walker (Eds.), Fish or cut bait! The case for individual transferable quotas in the salmon fishery of British Columbia (pp. 65–89). Vancouver: Fraser Institute.

Runolfsson, B. (1999). On the management measures to reduce overcapacity in Icelandic fisheries. A short report for the Ministry of Fisheries. Retrieved from http://www.hi.is/~bthru/Capacity.pdf

Runolfsson, B. (2000). Aflahlutdeildir og eignarhald útgerða (Catch quotas shares and companies' ownership. Retrieved from (Icelandic only) https://notendur.hi.is/bthru/Audlindanefnd1.pdf

Runolfsson, B., & Arnason, R. (2001). Initial allocation of ITQs in the Icelandic fisheries (FAO Fisheries Technical Paper no. 411). Retrieved from http://www.fao.org/docrep/005/y2684e/y2684e05.htm

Runolfsson, B., & Arnason, R. (2001). The effects of introducing transferable property rights on fleet capacity and ownership of harvesting rights in Iceland's fisheries (FAO Fisheries Technical Paper nr. 412). Retrieved from http://www.fao.org/docrep/005/y2498e/y2498e04.htm

Saevaldsson, H. (2007). Áhrifaþættir á verð þorskaflaheimlda (B.Sc dissertation). Retrieved from (Icelandic only) http://skemman.is/handle/1946/815

Saevaldsson, H. (2014). Icelandic pelagic vessels carrying capacity & age & fishmeal factories total output 1991–2013. Unpublished data.

Salz P, Buisman E, Frost H, Accadia P, Prellezo R, Soma K. (2010). Study on the remuneration of spawning stock biomass. Final Report, Framian.

Schütt, D., F. Jensen and M. Nielsen (2014), Appendix C5 Greenland, pp 126–150 in Waldo, S., H. Ellefsen, O. Flaaten, J. Hallgrimsson, C. Hammarlund, Ø. Hermansen, J. R. Isaksen, F. Jensen, N. N. Duy, M. Nielsen, A. Paulrud, F. Salenius and D. Schütt (2014), Reducing Climate Impact from Fisheries: A Study of Fisheries Management and Fuel Tax Concessions in the Nordic Countries, pp. 126–150, Theme North report 2014:533.

Skaptadóttir, U. D. (2000). Women coping with change in an Icelandic fishing community: A case study. Women's Studies International Forum, 23(3), 311–321.

Squires, D., Maunder, M., Vestergaard, N., Restrepo, V., Metzner, R., & Herrick, S. (2012). Effort rights in fisheries: General principles and case studies. FAO. Retrieved from http://www.fao.org/3/a-i5744e.pdf

Stage, J., Christiernsson, A., and Söderholm, P. 2016. The economics of the Swedish individual transferable quota system: Experiences and policy implications. Marine Policy (66):15–20.

SSB (2016) Statistics Norway Website https://www.ssb.no/en

Standal, D., & Aarset, B. (2008). The IVQ regime in Norway: A stable alternative to an ITQ regime?. Marine Policy, 32(4), 663–668.

Standal, D., & Asche, F. (2018). Hesitant reforms: The Norwegian approach towards ITQ's. Marine Policy, 88, 58–63.

St. Meld 21 (2006–2007) Strukturpolitikk for fiskeflåten.

Statistics Denmark. Fishery account statistics (2002, 2007, 2014), http://www.statistikbanken.dk

Statistics Greenland (2018a), Foreign Trade Statistics, available at: http://bank.stat.gl/pxweb/en/Greenland/

Statistics Greenland (2018b), Account Data, available at: http://bank.stat.gl/pxweb/en/Greenland/

Statistics Greenland (2018c), Landing Statistics, available at: http://bank.stat.gl/pxweb/en/Greenland/, accessed June 2018.

Statistics Iceland. (2017). Decked vessels and trawlers 1999 [Data set]. Retrieved from https://www.statice.is/

Statistics Sweden. 2015a. Swedish sea-fisheries during 2014. Definitive data. Sveriges officiella statistic. Statistiska meddelanden: JO 55 SM 1501.

Statistics Sweden. 2015b. Fishing in inland waters by commercial fishermen in 2014. Preliminary data. Sveriges officiella statistic. Statistiska meddelanden: JO 56 SM 1501.

Swedish Agency for Marine and Water Management. 2014. Effekterna av systemet med överlåtbara fiskerättigheter inom pelagiskt fiske, [The effects of the individual transferable rights system in the pelagic fishery], Swedish Agency for Marine and Water Management, Gothenburg, 2014.

Swedish Agency for Marine and Water Management. 2016. Remiss om fördelningen av fiskemöjligheter för att underlätta genomförandet av landningsskyldigheten. Dnr 613–16, Havs- och vattenmyndigheten, Gothenburg.

Swedish government. 2017. Förslag till statens budget för 2018. Areella näringar, landsbygd och livsmedel. Proposition 2017/18:1, utgiftsområde 23. Stockholm, Sweden.

Swedish Parliament. 2017. Uppföljning av systemet med överlåtbara fiskerättigheter i det pelagiska fisket. Report 2016/17:RFR7. Riksdagstryckeriet, Stockholm.

United Nations (1982), United Nations Convention of Law of the Sea, available at: http://www.un.org/depts/los/

Yagi, N., Clark, M. L., Anderson, L. G., Arnason, R., & Metzner, R. (2012). Applicability of Individual Transferable Quotas (ITQs) in Japanese fisheries: A comparison of rights-based fisheries management in Iceland, Japan, and United States. Marine Policy, 36(1), 241–245.

Vørn. (2018). www.vorn.fo

Waldo, S., and Paulrud, A. 2013. ITQs in Swedish demersal fisheries. ICES Journal of Marine Science 70(1): 68–77.

Waldo, S., Berndt, K., Hammarlund, C., Lindegren, M., Nilsson, A., and Persson, A. 2013. Swedish coastal herring fisheries in the wake of and ITQ system. Marine Policy (38):321–324.

Waldo, S., and Wingård, C. 2010. Resursräntan i svenskt fiske. AgriFood Policy Brief 2010:3.

Waldo, S., Ellefsen, H., Flaaten, O., Hallgrimsson, J., Hammarlund, C., Hermansen, Ø., Salenius, F. (2014). Reducing Climate Impact from Fisheries (Tema Nord 533 ed.). Nordisk råd.

Sammendrag

Fiskeripolitik debatteres bredt i de nordiske lande med fokus på at afbalancere biologiske hensyn, bidrag til samfundsøkonomien og kystsamfundenes interesser. Markedsbaseret fiskeriforvaltning anvendes i dag i flere nordiske lande i dag og er central i debatten. Men hvor mange betragter markedsbaseret fiskeriforvaltning som et virkningsfuldt redskab som sikrer bedre økonomi i fiskeriet, betragtes det af andre som et kontroversielt reguleringsredskab.

I nærværende rapport *Strukturtilpasning og regulering af nordiske fiskerier frem mod 2025*: (i) dokumenteres effekterne af markedsbaseret forvaltning i udvalgte nordiske fiskerier historisk, (ii) analyseres og forudsiges strukturudviklingen af de udvalgte fiskeri indtil 2025 med uændret fiskeriforvaltning, iii) analyseres og forudsiges strukturudviklingen i disse fiskerier under alternativ forvaltning med andre politiske målsætninger, og (iv) oplistes erfaringer opnået med markedsbaseret forvaltning af nordiske fiskerier, som grundlag for politisk debat om fremtiden for nordisk fiskeri. Resultaterne præsenteres på konferencen *Fiskeri og samfund – udfordringer til 2025*, der afholdes i Stockholm 11-12. oktober 2018.

I *kapitel 2* præsenteres standard teori om fiskeriøkonomi og forvaltning. Det forklares, hvordan åben adgang til fiskeri fører til et "race for fish", som i sidste ende giver overfiskeri, små fiskebestande, for mange fiskerfartøjer og lav indtjening. Det forklares endvidere hvordan forskellige forvaltningsredskaber kan løse "fællesskabets tragedie", med fokus på hvordan markedsbaseret fiskeriforvaltning skaber effektivitet. Markedsbaseret fiskeriforvaltning kræver tildeling af ejendomsrettigheder, som kan handles på et marked. Valg af forvaltningsinstrument afhænger af målsætningerne i fiskeripolitikken.

Kapitel 3 introducerer den dynamiske bioøkonomiske Fishrent-model, der anvendes til forudsigelse af samfundsøkonomisk afkast og overskud fra basisperioden 2012-2014 frem til 2025. Følgende scenarier analyseres: (i) den nuværende forvaltning med en maksimumgrænse på 4 % for årlig ændring i antal fartøjer, ii) fri kvotehandel mellem alle fartøjer med samme maksimumsgrænse, iii) den nuværende forvaltning uden grænser for flådetilpasning og iv) den nuværende forvaltning med en maksimumsgrænse på 4 % for årlig ændring i antal fartøjer, samt en ekstra fiskeriafgift på 10% af omsætningen. Det samfundsøkonomiske afkast forstås som: *Det nettooverskud der er tilbage til aflønning af kapital og arbejdskraft ud over hvad der opnås i andre erhverv inkl. provenu af fiskeriafgifter*.

Syv landecases med markedsbaseret fiskeriforvaltning, en fra hvert af de nordiske lande, analyseres og resultaterne præsenteres separat for hver landecase i kapitel 4–10.

Kapitel 4 gennemgår grønlandsk rejefiskeri. Fiskeriet foregår med store fartøjer med forarbejdning ombord, samt med kystfartøjer der forsyner fabrikkerne på land. De store fartøjer har været reguleret med individuelt omsættelige kvoter siden 1991 og kystfiskeriet siden 2000. Det er ikke tilladt at sælge kvoter fra kystfiskeriet til de store fartøjer.

Det årlige samfundsøkonomiske afkast fra de 30 fartøjer er 82 mio. EUR (gennemsnit for 2012-2014), svarende til 44 % af omsætningen. Beskæftigelse i fiskeri udgør 291 fuldtidsansatte. Det samfundsøkonomiske afkast i forhold til omsætning er det højest observerede i denne undersøgelse og følger af 2/3-dels flådereduktion siden 2002. Det høje samfundsøkonomiske afkast skyldes den lange tilstedeværelse af individuelt omsættelige kvoter, de store fartøjers høje effektivitet, samt 5-6 år med prisstigninger.

Det forudsiges, at det samfundsøkonomiske afkast stiger til 60 % af omsætningen i 2025 med den nuværende forvaltning, som følge af fortsat strukturtilpasning og en antaget forbedring i rejebestanden. Dette er det højeste samfundsøkonomiske afkast forudsagt i denne undersøgelse. Fiskeflåden vil blive reduceret til 20 fartøjer og fulgt af faldende beskæftigelse i primært fiskeri, dog opvejet af stigende beskæftigelse på fabrikkerne på land. Fri kvotehandel kan forøge det samfundsøkonomiske afkast endnu mere.

Rejeafgifter, oven i indkomstskat og selskabsskat, er vigtige til at finansiere offentlige udgifter. Disse udgjorde 9 % af landingsværdien i 2012-2014. Det forudsiges, at en stigning i rejeafgiften på 10 % af omsætning ikke vil reducere overskuddet i 2025. Fortsat strukturtilpasning forøger overskuddet mere end afgiften reducerer.

Kapitel 5 analyserer islandsk pelagisk fiskeri og Stern-trawlerfiskeri. Demersale frisk fisk trawlere, demersale frysetrawlere, pelagiske frisk fisk fartøjer og pelagiske frysefartøjer undersøges. Der fokuseres på de store fartøjer, hvor de fleste Stern-trawlere er over 42 meter og de fleste pelagiske fartøjer er 60-80 meter. Island har den længste historie med individuelt omsættelige kvoter i Norden og en af de længste på verdensplan. Den begyndte i midten af 1980'erne.

Det årlige samfundsøkonomiske afkast for de 79 fartøjer er 255 mio. EUR, svarende til 42 % af omsætningen (2012-2014). Fuldtidsbeskæftigelsen er 2.394 personer. Som i den grønlandske case er det samfundsøkonomiske afkast stort. Dels som følge af den lange tilstedeværelse af individuelt omsættelige kvoter og den efterfølgende vedvarende strukturtilpasning. Dels som følge af tilstedeværelsen af store fartøjer som udnytter stordriftsfordele.

Det samfundsøkonomiske afkast med uændret forvaltning forudsiges at falde til 203 mio. EUR i 2025, svarende til 26 % af omsætningen. Flåden reduceres i dette scenarie til 57 fartøjer og beskæftigelsen til 1.764 fuldtidsansatte. Reduktionen følger af de forudsatte bestandsreduktioner og af "choking" problemet, som reducerer fiskeri på nogle arter urealistisk meget, og herigennem forårsager en undervurdering af det samfundsøkonomiske afkast. Fri kvotehandel forøger det samfundsøkonomiske afkast til 51% af omsætningen, mens fuld tilpasning giver mulighed for en stigning til 54 % af omsætningen. Under fuld tilpasning reduceres flåden til 33 skibe og beskæftigelse til 1.066 fuldtidsansatte. Strukturtilpasningen synes således at fortsætte.

Da fiskeriet har været reguleret med individuelt omsættelige kvoter i en lang årrække, er den forudsagte reduktion i det samfundsøkonomiske afkast overraskende, men kan skyldes, at reduktion af fiskebestande og choking problemet fører til undervurdering af det samfundsøkonomiske afkast. Årsagen kan dog også være, at fartøjer har høje kapitalomkostninger, fordi forventet fremtidig indtjening kapitaliseres i kvoteværdierne, hvilket påvirker overskuddet negativt, når fiskebestandene reduceres.

Fiskeriafgifter, ud over indkomstskat og selskabsskat, er vigtige for at finansiere de offentlige udgifter i Island. Disse udgjorde 6 % af landingsværdien i 2012-2014. Det forudsiges, at en fiskeriafgift på ekstra 10 % af omsætningen reducerer overskuddet i 2025. Årsagen er, at den forventede fremtidige indtjening er blevet kapitaliseret i kvoteværdierne. Hermed beskattes de nuværende kvoteejere, der allerede har betalt en del af deres forventede fortjeneste til tidligere kvoteejere.

I *kapitel 6* præsenteres den danske landecase for demersalt fiskeri i Nordsøen. Seks grupper af fartøjer af forskellig længde op til 40 meter som fisker med net, trawl og not er inkluderet. Disse små og mellemstore fartøjer er blevet forvaltet med individuelt omsættelige kvoter siden 2007.

De 147 fartøjers årlige samfundsøkonomiske afkast er 19 mio. EUR, svarende til 19 % af omsætningen (2012-2014). Heltidsbeskæftigelsen er 359 personer. Det samfundsøkonomiske afkast er af mellemstørrelse i dette studie og følger en kraftig flådereduktion siden 2007.

Det samfundsøkonomiske afkast forudsiges at vokse til 28 mio. EUR i 2025, svarende til 31 % af omsætningen, under den nuværende forvaltning. Fiskeflådens størrelse falder til 117 fartøjer og beskæftigelse til 272 fuldtidsansatte. Fuld tilpasning vil forøge det samfundsøkonomiske afkast til 39 % af omsætningen, yderligere reduceres flåden til 90 fartøjer og beskæftigelse til 192 fuldtidsansatte. Den kraftige strukturtilpasning, som startede i 2007, forudsiges således at fortsætte. Det forudsiges endvidere, at en fiskeriafgift på 10 % af omsætningen ikke vil reducere overskuddet i 2025 i forhold til 2012-2014, i det den fortsatte strukturtilpasning formodes at opveje denne effekt.

I *kapitel 7* analyseres den finske landecase for pelagisk fiskeri med fartøjer over og under 24 meter. Fiskeriet hqr4 været forvaltet med individuelt omsættelige kvoter siden 2017.

Det årlige samfundsøkonomiske afkast fra 63 fartøjer var nul i 2012-2014 med 110 fuldtidsbeskæftigede. Nulresultatet følger af fraværet af inputregulering, hvor alene totalkvoter var gældende indtil 2017.

Det årlige samfundsøkonomiske afkast i 2025 forudsiges til 2 mio. EUR med uændret forvaltning, svarende til 10 % af omsætningen. Dette forudsiges at stige til 38 % under fuld tilpasning. Reduktionen af flåden reduceres til henholdsvis 42 og 31 fartøjer, mens beskæftigelsen falder til 73 og 37 fuldtidsansatte. Det samfundsøkonomiske afkast og overskuddet forudsiges således at stige betydeligt. Det kan dog tage nogle år, da individuelt omsættelige kvoter først blev indført i 2017. En evt. fiskeriafgift på 10 % af omsætning med i øvrigt uændret forvaltning forudsiges ikke at ændre overskud i 2025 i forhold til 2012-2014. Dette skyldes at struktureltilpasningen modvirker effekten.

Kapitel 8 indeholder den svenske case for pelagisk fiskeri med fartøjer på 18-24 meter og større end 24 meter. Fiskeriet har været reguleret med individuelt omsættelige kvoter siden 2009. Kystfiskeri efter sild indgår ikke i denne undersøgelse, da det forvaltes separat.

Det årlige samfundsøkonomiske afkast for de 30 fartøjer udgør 12 mio. EUR, svarende til 23 % af omsætningen. Beskæftigelsen er 167 fuldtidspersoner. Det samfundsøkonomiske afkast er af mellemstørrelse i denne undersøgelse og følger af en flådeduktion på 55 % i 2009-2013.

Det årlige samfundsøkonomiske afkast er med uændret forvaltning forudsagt at stige til 22 mio. EUR i 2025 efter stigning i fiskebestandene. Dette svarer til 35 % af omsætningen, stigende til 40 % med fuld tilpasning. Flåden er reduceret til henholdsvis 25 og 22 fartøjer, mens beskæftigelsen falder til 141 og 120 fuldtidsansatte. Selvom individuelt omsættelige kvoter allerede har forbedret det samfundsøkonomiske afkast og overskuddet i fiskeriet, synes strukturtilpasningen at fortsætte. En fiskeriafgift på 10 % af omsætningen, under i øvrigt uændret forvaltning, forudsiges ikke at reducere overskuddet i forhold til 2012-2014, idet en vedvarende strukturtilpasning påvirker overskuddet i opadgående retning.

I *kapitel 9* analyseres det norske demersale fiskeri nord for 62°. Der indgår fem fartøjslængdegrupper på op til 28 meter som anvender konventionelle redskaber, samt en trawlergruppe. Individuelle kvoter har været gældende siden 1996. Disse kan overdrages inden for men ikke mellem fartøjsgrupper, med omsætteligheden yderligere begrænset regionalt og med 20 % af de solgte kvoter tilbageholdt og omfordelt til alle fartøjer i gruppen. Totalkvoter fordeles mellem fartøjsgrupper ved at holde de konventionelle fartøjers kvoter mere konstante end trawlernes kvotes kvoter.

Det årlige samfundsøkonomiske afkast for de 1.192 fartøjer er 233 mio. EUR og 26 % af omsætningen (2012–2014). Heltidsbeskæftigelsen er 5.489 personer. Det samfundsøkonomiske afkast er af mellemstørrelse i denne undersøgelse og opnås efter en halvering af flåden siden 1996. På trods af at fiskeriet udføres med gennemsnitligt set relativt små fartøjer, er det samfundsøkonomiske afkast af mellemstørrelse, hvilket indikerer at den nuværende forvaltning sikrer en vis strukturtilpasning.

Det samfundsøkonomiske afkast forudsiges reduceret til 198 mio. EUR i 2025 med uændret forvaltning, efter forudsatte reduktioner af bestanden, samt choking problemer. Choking problemet reducerer fiskeri på nogle arter urealistisk meget, hvilket fører til en vis undervurdering af det samfundsøkonomiske afkast. Det samfundsøkonomiske afkast i forhold til omsætning forudsiges dog at stige til 36 %. Flåden forudsiges reduceret til 792 fartøjer og beskæftigelsen til 3.637. Fri kvotehandel forøger det samfundsøkonomiske afkast, mens fuld tilpasning giver mulighed for en stigning til 49 % af omsætningen i 2025.

Den sidste landecase med færøsk demersalt fiskeri præsenteres i *kapitel 10* og inkluderer store trawlere og langlinefartøjer. Fiskeriet er blevet reguleret med omsættelige havdage siden 1996, men det er blevet besluttet at ændre reguleringen til individuelle kvoter fra 2019.

Det årlige samfundsøkonomiske afkast fra de 45 fartøjer er -7 mio. EUR, et underskud på 9 % af omsætningen. Underskuddet tyder på, at det færøske samfund er bedre stillet økonomisk ved at stoppe demersalt fiskeri og bruge kapital og arbejdskraft i andre sektorer. Underskuddet viser at den nuværende indsatsregulering ikke har været i stand til at begrænse fiskeriet tilstrækkeligt.

Med forvaltningsskiftet i 2019 forudsiges det samfundsøkonomiske afkast at stige til 16 mio. EUR i 2025 svarende til 25 % af omsætningen. Men tilpasningen tager tid, og med fuld tilpasning kan den stige til 43 %. Flåden er reduceret til 34 fartøjer med fuld tilpasning til 22. Fri kvotehandel forudses at resultere i et samfundsøkonomisk afkast på 30 % af omsætningen. En fiskeriafgift på 10 % af omsætningen, som også kan bestå i offentligt provenu fra salg af kvoter på auktion, kan indføres sammen med den nye 2019 forvaltning, hvor overskuddet stadig forudsiges at stige fra niveauet i 2012-2014.

I *kapitel 11* sammenlignes det årlige samfundsøkonomiske afkast i 2012-2014 på tværs af lande. Det er størst i Grønland (44 % af omsætningen) og Island (42 %), både som følge af den langvarige tilstedeværelse af individuelt omsættelige kvoter og som følge af at disse fiskerier gennemføres med store fartøjer som udnytter stordriftsfordele.

Det forudsagte samfundsøkonomiske afkast i 2025 sammenlignes også på tværs af lande. Igen er det med uændret forvaltning størst i Grønland (60 % af omsætningen) og Island (49 %), idet det dog stiger i alle landene. Den største stigning forudsiges på Færøerne (fra -14 % til +25 % af omsætningen) og i Finland (fra -7 % til +10 %). Disse forudsagte stigninger følger af forbedret forvaltning, i det Finland indførte individuelt omsættelige kvoter i 2017, og som følge af at Færøerne har besluttet at indføre individuelle kvoter fra 2019. I samtlige cases reduceres flåderne.

Baseret på landecases kan der læres flere forhold. Disse lærdomme er vigtige i debatten om den fremtidige fiskeripolitik i de nordiske lande. Debatten handler om at prioritere mellem fiskeriets bidrag til samfundsøkonomi og velstand, beskæftigelse i fiskerisamfund som ofte ligger spredt langs kysterne i tyndtbefolkede områder, samt at anvende fiskeriafgifter som en kilde til at finansiere offentlige udgifter. De forskellige prioriteringer udgør en ramme for de politiske beslutninger. Læringen fra Markedsbaseret fiskeriforvaltning i Norden ved denne undersøgelse er:

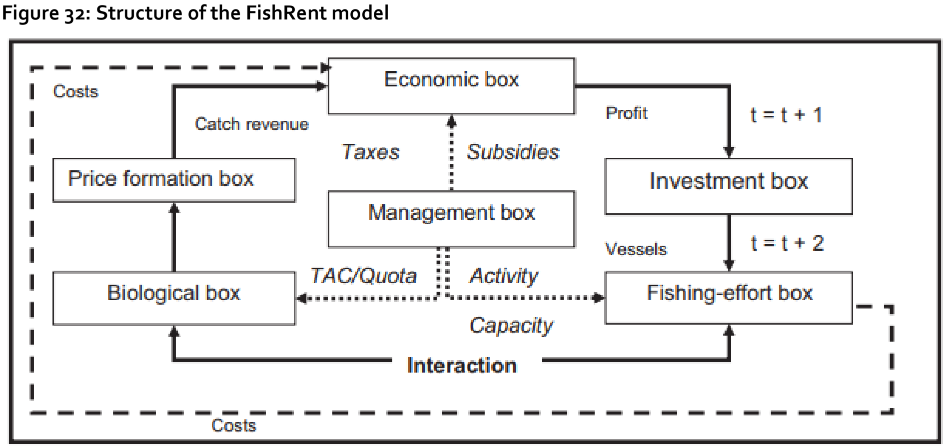
1. Individuelt omsættelige kvoter er et virkningsfuldt redskab til at forøge indtjening og fjerne overkapacitet, men samtidig reduceres flådestørrelse og beskæftigelse.
2. Alle eksisterende markedsbaserede fiskeriforvaltningssystemer i de nordiske lande har særordninger for visse fartøjsgrupper.
3. Alle eksisterende markedsbaserede fiskeriforvaltningssystemer i de Nordiske lande regulerer koncentrationen på den ene eller anden måde.
4. Det er ikke en universel regel, at markedsbaseret fiskeriforvaltning altid fjerner små fartøjer.
5. Fiskeafgifter kan spille en central rolle for fordelingen af velstand i de nordiske lande hvor fiskeriet fylder meget i samfundsøkonomien.
6. Dyre kvoter gør det vanskeligt at fjerne eller drastisk ændre individuelt omsættelige kvotesystemer.
7. Fortsat markedsbaseret fiskeriforvaltning forudsiges at forøge det samfundsøkonomiske afkast og overskud i 2025 betydeligt.
8. Frihandel med kvoter skaber ekstra indtjening i forhold til den nuværende regulering i 2025.
9. En ekstra fiskeriafgift på 10 % af landingsværdien kan i de fleste landecases opkræves uden på lang sigt at reducere overskuddet.

Appendix: The applied bio-economic model

FISHRENT is a dynamic bio-economic model with a long history of development (Salz *et al.* 2010, Frost *et al.* 2013). The structure of Fishrent is displayed in Figure 32. The model is implemented over time, meaning that the economic and biological conditions in year *t* depend on what happened in year *t-1*. As such the model applies dynamic feedback between fisheries and exploited fish stocks in the sense that year-on-year changes observed for total fish stock biomass are fed back into the model and hereby influence fishing opportunities and capacity, while on the other hand year-to-year changes in fishing capacity will feed back into the model and affect stock development.

The model assumes that all fishing activities are regulated within a given management system, represented by the *management box* in Figure 32. In the present context it is assumed that the fisheries manager restricts catches for a given year by imposing quotas. Catches are determined by stocks size and fishing effort (*fishing effort box*) and are restricted by the quota limits. Fishing effort is defined as fleet size (capacity measured as number of vessels) times days at sea per vessel. The fleet capacity is determined in the *investment box* and depends on previous year's profitability (*Economic box*). Increasing profits lead to investments while decreasing profits leads to disinvestment. The catches in a given year will influence stock changes (the *biological box*) and as such future catch possibilities. Market prices are set in the *price formation* box, and depend on the landings in the given year. The total economic outcome, i.e. the profit, is determined in the *economic* box, and depend on landings, prices and costs.

Figure 32: Structure of the FishRent model



Source: Frost *et al.* (2013).

The biological module is based on ICES published biomasses and catches (www.ices.dk) for the key stocks. Stock surplus production parameters are estimated externally, based on ICES data. The Economic module is based on national statistical databases, covering landings in weight and value, running and fixed costs, for the included fishing fleets.

Model equations

Individual Fishrent models have been constructed for each of the 7 country cases included in this study. Two economic maximisations have been performed for each case study:

1. Maximisation of the total profit, discounted to 2016 values, over the evaluation period (2016–2025);
2. Maximisation of the total socio-economic return over the evaluation period (2016–2025) discounted to 2016 values.

Thus, Fishrent maximizes the following two objective function for each country case:

$$max_{NV_{y,f},DAS_{y,f}}\Pi = max_{NV_{y,f},DAS_{y,f}}\left[\sum_{y,f}\pi_{y,f}\cdot(1+\rho)^{-y}\right] \text{ (a1)}$$

Where

$$\pi_{y,f} = \begin{cases} \tilde{P}_{y,f} \text{ ; Profit maximisation} \\ SER_{y,f} \text{ ; Socio-economic return maximisation} \end{cases} \text{ (a2)}$$

$\tilde{P}_{y,f}$ is the profit obtained by fleet f and $SER_{y,f}$ the socio-economic return produced by fleet f in year y. ρ is the discount rate, which is in the present context set to 3.5%. The independent variables in the maximization are the number of vessels $NV_{y,f}$ in vessel group f in year y and the number of days at sea per vessel $DAS_{y,f}$ exerted by vessel group f in year y. Thus, the actors in Fishrent are the fishers, or more specifically vessel groups, choosing to use their DAS per vessel, and invest/disinvest in number of vessels, in an economically optimal way over the simulation period. In scenarios 1, 2, and 4 it the yearly change in number of vessels in a given vessel group is constrained to be at the most ±4%. Thus, it is assumed in these scenarios that a fleet cannot "sell out" all vessels from one year to the next. In scenario 3 the yearly change in number of vessels is not constrained.

In the model maximisations, total country catches of each target species are restricted under the country quotas:

$$\frac{\sum_f L_{y,f,s}}{\sum_f Qsh_{f,s}} \leq Q_{y,s} \text{ (a4)}$$

Where $L_{y,f,s}$ is the landings of target species *s* taken by vessel group *f* in year, and $Q_{y,s}$ is the Country quota of species *s* in year *y* (cf. Table 45). $Qsh_{f,s}$ is the quota share of species *s* historically taken by vessel group *f*. The sum in the nominator on the left side of the equation is the landings of species *s* taken by the vessel groups included in the model, while the sum in the denominator is the historical fraction these segments takes of the national quota of species *s*, which is used to scale the catches determined by the model up to the full national catches of species *s* in year *y*.

When (a4) is the only landings constraint, landings are distributed between vessel groups in an economically optimal way, i.e. such that the overall profit/socio-economic return is maximised. This corresponds to free quota trade (ITQs). However, most of the national case studies have additional constraints on quota trade in their current management schemes, and thus additional constraints are included in the national models in scenarios 1,3, and 4 (where scenario 2 represents free ITQs for case studies). Table 45 outlines the additional constraints included in the national models.

Table 45: Individual maximisation constraints for each Country case study

Case	Management restrictions
Denmark	ITQ, but with quota trade restrictions between vessels above and below 15 meters: $$\sum_{\substack{f \\ (vesssel\ length<15m)}} L_{y,f,s} \leq Q_{y,s} \cdot \sum_{\substack{f \\ (vessel\ length<15m)}} Qsh_{f,s} \quad (a5)$$ $$\sum_{\substack{f \\ (vesssel\ length>15m)}} L_{y,f,s} \leq Q_{y,s} \cdot \sum_{\substack{f \\ (vessel\ length>15m)}} Qsh_{f,s} \quad (a6)$$
Sweden	Free ITQ, i.e. equation (a4) with no further restrictions
Iceland	ITQ but with no trade between stern trawlers and pelagic vessels, except mackerel that can be traded from stern trawlers to pelagic vessels: $$\sum_{\substack{f \\ (Stern\ trawlers)}} L_{y,f,s} \leq Q_{y,s} \cdot \sum_{\substack{f \\ (Stern\ trawlers)}} Qsh_{f,s}\ ; s \in all\ species \quad (a7)$$ $$\sum_{\substack{f \\ (Pelagic\ vessels)}} L_{y,f,s} \leq Q_{y,s} \cdot \sum_{\substack{f \\ (Pelagic\ vessels)}} Qsh_{f,s}\ ; s \in all\ species\ except\ macerel \quad a8)$$
Finland	Free ITQ, i.e. equation (a4) with no further restrictions.
Faroe Islands	ITQ from 2019 with no additional landings restrictions (i.e. equation a4 in force from 2019). Constant efforts 2015-2018, thus equation a4 not in force.
Greenland	$$\sum_{\substack{f \\ (Offshore\ Trawlers)}} L_{y,f,s} \leq Q_{y,s} \cdot \sum_{\substack{f \\ (Offshore\ Trawlers)}} Qsh_{f,s}$$

Regarding the maximisation of total socio-economic return (SER), the individual SER of fleet *f* in year *y* is given by:

$$SER_{y,f} = R_{y,f} - FuC_{y,f} - OCrC_{y,f} - VaC_{y,f} - FxC_{y,f} - OCaC_{y,f} \quad (a9)$$

Where $R_{y,f}$ is the revenue, $FuC_{y,f}$ the fuel costs, $OCrC_{y,f}$ the opportunity crew costs, $VaC_{y,f}$ the other variable costs, $FxC_{y,f}$ the fixed costs and $OCaC_{y,f}$ the opportunity capital costs of fleet f in year y.

The revenue is given by:

$$R_{y,f} = (\sum_s L_{y,f,s} \cdot p_{f,s}) \cdot (1 + OsFf_f) \text{ (a10)}$$

Where $p_{y,f,s}$ is the price obtained by fleet *f* for species *s* in all years (prices are in the present context assumed constant over the simulation period). $OsFf_f$ is a factor, based on historical revenue fractions, scaling the revenue of species included in the model up to the revenue of all species caught by vessel group *f*.

The fuel costs are given by:

$$FuC_{y,f} = E_{y,f} \cdot fc_f \text{ (a11)}$$

Where fc_f are the fuel costs per sea day, and $E_{y,f} = NV_{y,f} \cdot DAS_{y,f}$ is the total effort (number of sea days) exerted by vessel group *f* in year *y.*

The oppertunity crew costs are given by:

$$OCrC_{y,f} = E_{y,f} \cdot occ_f \text{ (a12)}$$

Where occ_f is opportunity crew costs per sea day for vessel group *f*.

The variable costs are given by:

$$VaC_{y,f} = R_{y,f} \cdot vc_f \text{ (a13)}$$

Where $vc_{y,f}$ is the fraction that the variable costs will constitute of the revenue.

The fixed costs are given by:

$$FxC_{y,f} = NV_{f,y} \cdot fc_f \text{ (a14)}$$

Where fc_f is the fixed cost per vessel in fleet *f*.

The opportunity capital costs are given by:

$$OCaC_{y,f} = NV_{y,f} \cdot oca_f \text{ (a15)}$$

Where oca_f is the opportunity capital costs per vessel in vessel group *f*.

Regarding the maximisation of total profit, the individual profit of fleet *f* in year *y* is given by:

$$\tilde{P}_{y,f} = R_{y,f} - FuC_{y,f} - CrC_{y,f} - VaC_{y,f} - FxC_{y,f} - CaC_{y,f} - QC_{y,f} \text{ (a16)}$$

Where $R_{y,f}$ is the revenue (equation a10), $FuC_{y,f}$ the fuel costs (equation a11), $CrC_{y,f}$ the crew costs, $VaC_{y,f}$ the other variable costs (equation a13), $FxC_{y,f}$ the fixed costs (equation a14), $CaC_{y,f}$ the capital costs of fleet f in year y and $QC_{y,f}$ the cost for quota trade and lease for vessel group f in year y.

The crew costs are given by:

$$CrC_{y,f} = R_{y,f} \cdot cc_f \text{ (a17)}$$

Where cc_f is fraction the crew costs constitute of the revenue for vessel group f.

The capital costs are given by:

$$CaC_{y,f} = NV_{y,f} \cdot ca_f \text{ (a18)}$$

Where ca_f is the capital costs per vessel in vessel group f.
Cost of quota trade $QC_{y,f}$ is treated below in a separate section.

The landings, less highgrading, of species *s* taken by fleet *f* in year *y* is given by the Cobb-Douglas form:

$$L_{y,f,s} = a0_{f,s} \cdot \left(E_{y,f}\right)^{a1_{f,s}} \cdot \left(B_{y,s}\right)^{a2_{f,s}} \text{ (a19)}$$

where $a0_{f,s}$, $a1_{f,s}$ and $a2_{f,s}$ are the parameters of the Cobb-Douglas function. $B_{y,s}$ is the total stock biomass of species *s* in year *y*, which is given by the mass balance equation:

$$B_{y,s} = B_{y-1,s} + R_{y-1,s} - \frac{\sum_f L_{y,f} \cdot (1+Disc_{y,f})}{\sum_f TACsh_{f,s}} \text{ (a20)}$$

Where $TACsh_{f,s}$ is the share that vessel group *f* has historically taken of the overall TAC of species *s*.

The recruitment $R_{y,s}$ is given by a second degree polynomium as a function of the stock:

$$R_{y,s} = \alpha_1 \cdot B_{y,s} - \alpha_2 \cdot B_{y,s}^2 \text{ (a21)}$$

I.e. a Schaefer like stock production function.

Given the stock in year y (assumed to be the stock in the beginning of year y) the total Total Allowable Catch for species s, $TAC_{y,s}$, is set according to the target fishing mortality F_s^0 (set according to MSY targets), which is constant over the simulation period:

$$TAC_{y,s}=\begin{cases}(1-\lim_{TAC})\cdot TAC_{y-1,s} & ;\ B_{y,s}\cdot(1-e^{-F_0^s-M_s})\cdot\dfrac{F_s^0}{F_s^0+M_s}<(1-\lim_{TAC})\cdot TAC_{y-1,s}\\ (1+\lim_{TAC})\cdot TAC_{y-1,s} & ;\ B_{y,s}\cdot(1-e^{-F_0^s-M_s})\cdot\dfrac{F_s^0}{F_s^0+M_s}>(1+\lim_{TAC})\cdot TAC_{y-1,s}\\ B_{y,s}\cdot(1-e^{-F_0^s-M_s})\cdot\dfrac{F_s^0}{F_s^0+M_s} & ;\ (1-\lim_{TAC})\cdot TAC_{y-1,s}<B_{y,s}\cdot(1-e^{-F_0^s-M_s})\cdot\dfrac{F_s^0}{F_s^0+M_s}<(1+\lim_{TAC})\cdot TAC_{y-1,s}\end{cases} \quad \text{(a22)}$$

The quota rent/purchase module

In the profit maximization (equations a1 and a2) the sum of discounted annual profits is maximized:

$max_{E_{y,f}} \sum_{y,f} \tilde{P}_{y,f} \cdot (1+\rho)^{-y}$ (a23)

Where $\tilde{P}_{y,f}$ is the profit after possible money transfers $QC_{y,f}$ has been subtracted (equation a16).

The long run socio-economic profit $P_{y,f}$ by fleet f in year y before subtraction of possible transfers for quotas is given by:

$P_{y,f} = R_{y,f} - FuC_{y,f} - CrC_{y,f} - VaC_{y,f} - FxC_{y,f} - CaC_{y,f}$ (a24)

Where $R_{y,f}$ is the revenue (equation a10), $FuC_{y,f}$ the fuel costs (equation a11), $CrC_{y,f}$ the crew costs (equation a17), $VaC_{y,f}$ the variable costs (equation a13), $FxC_{y,f}$ the fixed costs (equation a14) and $CaC_{y,f}$ the capital costs (equation a18) of fleet f in year y.
It is assumed that if $P_{y,f} \leq 0$ then no money transfer is taking place for the average vessel in fleet f in year y.

If $P_{y,f} > 0$ there is a possibility for money transfer in excess of the initial allocation. Whether this takes place depends on the profit per vessel in the previous year *y-1*. A distinction is made between the following cases:

1. $P_{y,f}/NV_{y,f} > P_{y-1,f}/NV_{y-1,f}$ and $NV_{y,f} \leq NV_{y-1,f}$, i.e. the profit per vessel in segment f increases while the number of vessels in segment f decreases from year y-1 to year y.
2. $P_{y,f}/NV_{y,f} > P_{y-1,f}/NV_{y-1,f}$ and $NV_{y,f} > NV_{y-1,f}$, i.e. the profit per vessel in segment f increases while the number of vessels in segment f also increases from year y-1 to year y.
3. $P_{y,f}/NV_{y,f} < P_{y-1,f}/NV_{y-1,f}$ and $NV_{y,f} > NV_{y-1,f}$ while $P_{y,f} > P_{y-1,f}$, i.e. the number of vessels and total profit in segment f increases from y-1 to y, while the profit per vessel decreases.
4. $P_{y,f}/NV_{y,f} < P_{y-1,f}/NV_{y-1,f}$ and $P_{y,f} < P_{y-1,f}$, i.e. the profit per vessel and the total profit in segment f decreases from year y-1 to year y.

In cases 1–3 it is assumed that quota transfer takes place. In case 4 it is assumed that the average vessel in vessel group *f* will not have had any quota transfer, given that both the total profit for the vessel group, and the profit per vessel decreases.

In cases 1–3 the price of quotas purchased per vessel is assumed to be given by the average of the sellers' willingness to accept and the buyers' willingness to pay. It is noted, that when the transfer (costs of the extra quota) is estimated, the profits before transfers are used for comparison. In this way it is assumed that the fishers know what the optimal quota allocation for the coming year is before any money transfer takes place. This assumption is necessary to compute future profit and compare it to historical profit in a consistent way.

Case 1: $P_{y,f}/NV_{y,f} > P_{y-1,f}/NV_{y-1,f}$ and $NV_{y,f} \leq NV_{y-1,f}$

In this case, where the profit per vessel increases while the number of vessels decreases from year *y-1* to year *y*, the segment's willingness to pay is assumed to be equal to the profit increase from year *y-1* to year *y* of the vessels remaining in the segment, i.e.:

$Willingness\ to\ pay|_{NV_{y,f} \leq NV_{y-1,f}} = NV_{y,f} \cdot (P_{y,f}/NV_{y,f} - P_{y-1,f}/NV_{y-1,f})$ (a25)

The willingness to accept is equal to the profit leaving the segment, i.e. the value of the transferred catches:

$Willingness\ to\ accept|_{NV_{y,f} \leq NV_{y-1,f}} = (NV_{y-1,f} - NV_{y,f}) \cdot (P_{y-1,f}/NV_{y-1,f})$ a26)

Thus, the total costs of quota transfer to the segment, given that $P_{y,f}/NV_{y,f} > P_{y-1,f}/NV_{y-1,f}$ and $NV_{y,f} \leq NV_{y-1,f}$ is given by:

$$Quota\ transfer\ costs|_{NV_{y,f} \leq NV_{y-1,f}}$$
$$= \left[(NV_{y-1,f} - NV_{y,f}) \cdot (\frac{P_{y-1,f}}{NV_{y-1,f}}) + NV_{y,f} \cdot (\frac{P_{y,f}}{NV_{y,f}} - \frac{P_{y-1,f}}{NV_{y-1,f}})\right]/2$$
………………………(a27)

<u>*Case 2:*</u> $P_{y,f}/NV_{y,f} > P_{y-1,f}/NV_{y-1,f}$ and $NV_{y,f} > NV_{y-1,f}$

In this case, where vessels have entered the vessel group and the profit per vessel increased from *y-1* to *y*, the willingness to pay is the total profit entering the segment from year *y-1* to year *y:*

$Willingness\ to\ pay|_{NV_{y,f} > NV_{y-1,f}} = P_{y,f} - P_{y-1,f}$ (a28)

The willingness to accept is estimated as the number of vessels entering the fishery times the average profit per vessel in the vessel group in year *y-1*, i.e. the lowest possible profit new vessels entering the fishery in year *y* can expect to obtain:

$$Willingness\ to\ accept|_{NV_{y,f}>NV_{y-1,f}} = (NV_{y,f} - NV_{y-1,f}) \cdot (P_{y-1,f}/NV_{y-1,f}) \text{ (a29)}$$

Thus, the total cost of quota transfer to the segment is given by:

$$Quota\ transfer\ costs|_{NV_{y,f}>NV_{y-1,f}} \cdots$$
$$= \left[(NV_{y,f} - NV_{y-1,f}) \cdot (P_{y-1,f}/NV_{y-1,f}) + (P_{y,f} - P_{y-1,f})\right]/2 \text{ ....(a30)}$$

Case 3: $P_{y,f}/NV_{y,f} < P_{y-1,f}/NV_{y-1,f}$ and $NV_{y,f} > NV_{y-1,f}$ while $P_{y,f} > P_{y-1,f}$

In this case, where vessels, and profit, has entered the segment, even though the profit per vessel has decreased, the same procedure is used as in Case 2. I.e. the willingness to pay is assumed to be the total profit entering the segment (equation 6), the willingness to accept is assumed to be equal to the lowest profit new vessels entering the fishery could obtain (equation a29) and the quota transfer cost thus equal to equation (a30).

List of abbreviations

- ITQ = Individual Transferable Quotas.
- MBFM = Market Based Fisheries Management.
- MSY = Maximum Sustainable Yield.

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Structural Adjustment and Regulation of Nordic Fisheries until 2025

Fishery policies are broadly debated in the Nordic countries, focusing on balancing biological concern of fish stocks, economic return to society and coastal communities' interests. Market Based Fisheries Management is used in several Nordic countries today and is the core of these debates. While it by many is considered a powerful tool that works towards ensuring improved economy of fisheries, it is also considered a controversial tool.

This report "Structural Adjustment and Regulation of Nordic Fisheries until 2025" document the effects of Marked Based Management of selected Nordic fisheries, forecast the structural development of these until 2025 under the current and alternative fishery management. Nordic lessons on Market Based Fisheries Management are also provided as a basis for the political debate on the future of Nordic Fisheries.

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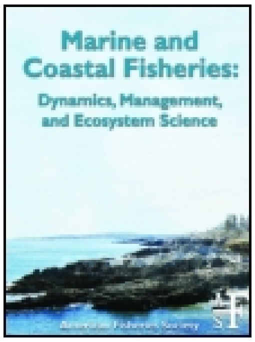

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ARTICLE

Understanding Social Resilience in the Maine Lobster Industry

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Abstract
The Maine lobster *Homarus americanus* fishery is considered one of the most successful fisheries in the world due in part to its unique comanagement system, the conservation ethic of the harvesters, and the ability of the industry to respond to crises and solve collective-action problems. However, recent threats raise the question whether the industry will be able to respond to future threats as successfully as it has to ones in the past or whether it is now less resilient and can no longer adequately respond to threats. Through ethnographic research and oral histories with fishermen, we examined the current level of social resilience in the lobster fishery. We concentrated on recent threats to the industry and the ways in which it has responded to them, focusing on three situations: a price drop beginning in 2008, a recovery in 2010–2011, and a second collapse of prices in 2012. In addition, we considered other environmental and regulatory concerns identified by fishermen. We found that the industry is not responding effectively to recent threats and identified factors that might explain the level of social resilience in the fishery.

The Maine lobster *Homarus americanus* fishery is heralded for its cultural status, the participatory nature of its regulatory scheme, the conservation ethic of its harvesters, and more recently, its seemingly infinite increase in landings and value (Acheson 2003; Acheson and Gardner 2010). Despite these characteristics, during the summer of 2012, this iconic fishery experienced the lowest prices in 30 years. The media reported examples of the way industry members described the 2012 season: "I don't see any winners in this, this year." (Seelye 2012); "It's down to a point now where it's not worth it to go out. It's ridiculous." (Wickenheiser 2012); and "There ain't no money right now to be made" (Lobstermen tying up their boats 2012).

This may seem to be a familiar narrative, as the historical booms and busts of the lobster fishery have been well documented (Acheson and Steneck 1997; Acheson 2003; Acheson and Gardner 2010). However, over the past three decades the lobster fishery has experienced much more boom than bust (Acheson 2003), as exemplified by a steady increase in landed weight and value since the mid-1990s (Figure 1). While this positive trend has been attributed to a combination of external factors, including the reduced abundance of predators and favorable environmental conditions (Acheson and Steneck 1997; Boudreau and Worm 2010; Steneck et al. 2011), the industry's success is often also attributed to its unique comanagement system and its ability to respond to crises and solve collective-action problems (Acheson 2003; Acheson and Gardner 2010; Wilson et al. 2013).

The 2012 crisis raises the question whether the industry will be able to respond to future threats as successfully as it has to ones in the past or whether it is less resilient now and thus no longer able to adequately respond to threats. We examined social resilience in the Maine lobster fishery in terms of the

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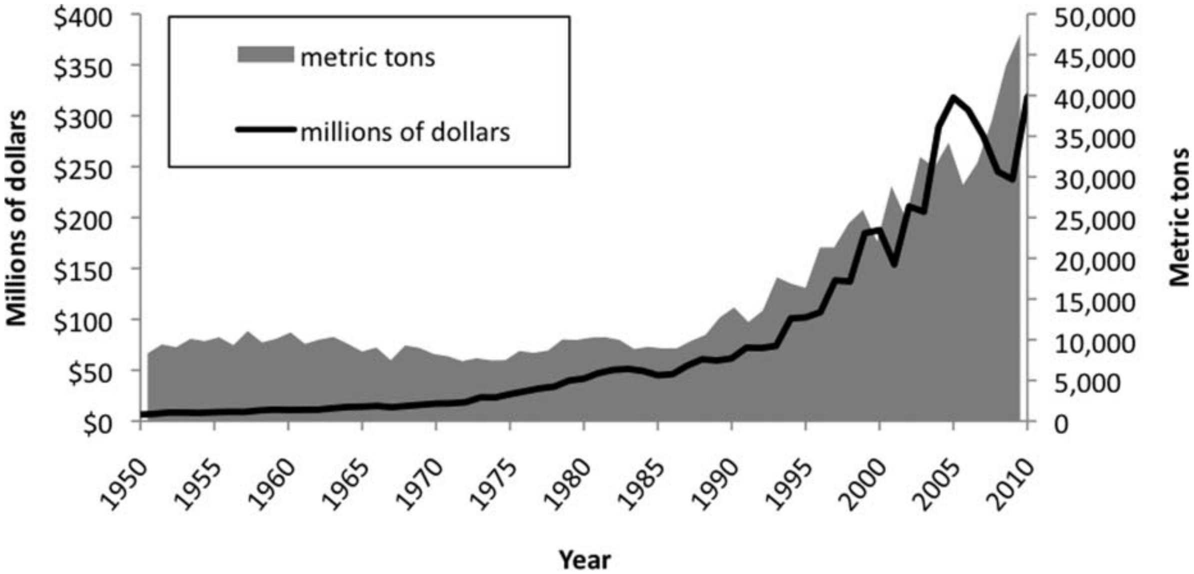

FIGURE 1. Maine lobster landings and value (Maine DMR 2012b).

specific threats facing fishermen and their ability to respond to these threats.

THEORETICAL PERSPECTIVE

Although the concept of resilience is pervasive in the ecological literature, we focus on social resilience or "the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change" (Adger 2000:347). It is difficult to discuss resilience without also addressing vulnerability, which we define as "the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt" (Adger 2006:281). Communities and individuals are more vulnerable if they are not able to adapt or if they are less resilient. Following a "people ecology" perspective, we sought to understand resilience by focusing on the differential threats faced by individuals and groups and their ability to respond to these threats (Vayda and McCay 1975; McCay 1978).

Threats can vary by frequency, intensity, and duration (Cutter 1996). Responses also vary in terms of the time that has to be invested and the magnitude of the adjustment necessary. We classify responses as *coping* (smaller, short-term reactions that can easily be reversed and modified as threats change) and *adaptations* (longer-term adjustments that require more investment and organization and are more difficult to alter in the future). The level of response is often determined by the condition of the threat. The theory of the "economics of flexibility" suggests that the likelihood and timing of these different response types relate to the depth of the threat (McCay 2002), i.e., that responses that require smaller investments (coping) will occur first, reserving some "flexibility" with which to respond to potential future threats or an intensification of the current threat. In this way responders ration their capacity for resilience, reserving *adaptation* responses for threats that are of larger magnitude or for use after lower-level *coping* responses have failed (McCay 2002:357).

METHODS

This paper is one component of a larger study assessing vulnerability and resilience in Maine fishing communities. As part of this project we conducted 18 semistructured (Bernard 2002) and 26 oral history interviews (Ritchie 2003) with fishermen, other community members, and government officials in four fishery-dependent communities in Maine from October 2010 to December 2011. These interviews lasted from 1 to 2 h and focused on the threats that fishermen have faced and the ways in which they have responded to these threats. We began our study with key-informant interviews and then relied on snowball sampling to broaden the representation until theoretical saturation (Bernard 2002). We selected respondents to represent the diverse marine fishery–related occupations in each community. The fishermen interviewed ranged in age from 34 to 80, with an average age of 54. While not all respondents were lobster fishermen, the majority of those interviewed held lobster licenses, representing zones A and D from the Canadian border to the midcoast region of Maine. All interviews were recorded, and all of the oral histories and a majority of the semistructured interviews were transcribed. Detailed notes were taken from other semistructured interviews. Three focus groups were held in June 2012 to gather more insight from fishermen and community members ($n = 13$) and to groundtruth some of the findings from the interviews; these sessions were recorded and detailed notes were taken from the audio files. We used QSR NVivo 9 to analyze data following a modified grounded theory approach that involved multiple

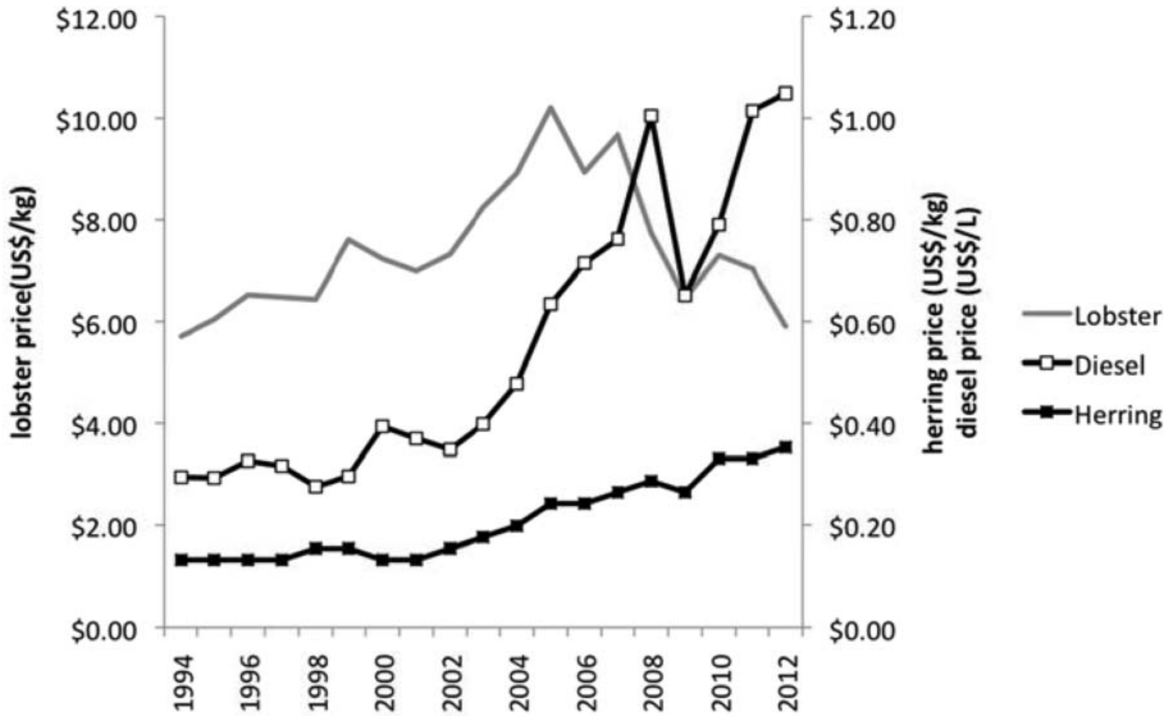

FIGURE 2. Lobster and herring prices are exvessel value (Maine DMR 2012b). While this accurately reflects the average price a lobster harvester receives at the boat, the price that he/she would pay for herring as bait would be much higher than the exvessel value and may increase at a more rapid rate. For example, it has been reported that a barrel of herring bait (approximately 91 kg) cost $25 in 2000 and $150 in 2010 (Acheson and Acheson 2010). The price of diesel fuel is taken from the U.S. Energy Information Administration and may not reflect the actual price paid by harvesters. Additionally, all of these prices may vary based on the quantity purchased or sold. However, the trend of increasing expenses and decreasing lobster prices is clear.

iterations of coding (Glaser and Strauss 1967; Strauss and Corbin 1998). In this paper we draw on themes that emerged from this analysis along with news articles and notes from public meetings that occurred after completion of the interviews.

In our analysis, we concentrated on recent threats to the industry and the ways in which it has responded to them, focusing on three situations: a drop in lobster prices beginning in 2008, a recovery of prices in 2010–2011, and a second collapse of prices in 2012. We also considered other environmental and regulatory concerns identified by fishermen. We discuss the current level of vulnerability in the lobster fishery and what we have learned about its resilience based on responses to recent threats. We also note factors that may explain the level of social resilience in this fishery and why it has not been able to respond effectively to recent threats.

MANAGEMENT OF THE MAINE LOBSTER FISHERY

Lobster management in Maine relies on a combination of informal and formal institutions (Acheson 2003). Historically, access to the lobster fishery has been restricted informally through "harbor gangs," small groups of fishermen who "maintain a fishing territory for the use of its members" (Acheson 2003:24). Membership in a harbor gang is restricted, and territory is defended from incursion by adjacent gangs through harassments ranging from verbal threats and abuse to the destruction of gear. Territoriality persists today, and reports of gear molestation from trap cutting to suspicious boat sinkings occur annually.

Formal management of lobster fishing has relied on effort controls (limited entry and trap limits). Enacted by the Maine state legislature in 1995, the Zone Management Law established a statewide trap limit, an apprenticeship program for new entrants, and a trap tag program that links traps to their owners. Additionally, the law created a formal comanagement system in the form of lobster management zones. Councils of fishermen elected by other license holders in the zone allow members to modify existing rules and propose new rules regarding trap limits and limited entry with a two-thirds majority vote. These proposals, if approved by the commissioner, are then transformed into state regulations by the Department of Marine Resources (DMR). As a result of this process, all zones have limits of 600–800 traps and six of the seven zones have restricted entry with varying entry-to-exit ratios.[1] This

[1] To remove effort from the fishery, most zones have created entry-to-exit ratios; a system where the number of new licenses issued in a year is dependent upon the number of licenses (more specifically trap tags) retired in the previous year. Licenses in the zone without entry-to-exit ratios have only increased by 2% from 1997 to 2011, while across all zones licenses have decreased 12% (Dayton and Sun 2012).

has helped to slow entry into the fishery and continue the sense of resource stewardship and empowerment of license holders. Lobster management also includes minimum and maximum size restrictions and a prohibition on the harvest of reproductive females. These measures, known as the double-gauge law and V-notch program, evolved through state legislation as a result of lobbying from the industry and are an example of successful collective action by this industry. Although these regulations were enacted by the legislature, they have long been supported by the industry because they follow fishermen's conservation logic, namely, to preserve lobsters during their most vulnerable stages of life (Acheson 2003:218).

2008 GLOBAL ECONOMIC CRISIS

In 2008, lobster fishermen faced a crisis with many of the same characteristics as the predicament faced in the summer of 2012. While the threats were similar—low prices, lack of market, and excess product—the mechanisms behind them were very different. In 2008, the dismal global economic climate created a chain of events resulting in a loss of market for Maine lobsters, which carried into much of the 2009 season.

As much as 70% of the lobsters landed in Maine are shipped to Canada for processing, reshipment, or export back to the United States (Steneck et al. 2011). Many of these processing plants were funded by Icelandic banks until October 2008, when the Icelandic banking system collapsed, pulling funding from the processors and forcing a majority to cease operations. The resulting reduction in demand forced Maine lobster prices down to record lows; as one lobsterman described the situation, "I made more money when I was 15 years old fishing out of a skiff" (Richardson 2010). Another described it as "an economic disaster the size of Katrina" (Lobster solutions hard to come by 2008).

Exacerbating the effect of these market pressures and low prices on lobster harvesters was the fact that bait and fuel prices were increasing simultaneously (Figure 2). One fisherman whom we interviewed put these price changes into historical perspective as follows:

> In 1994 . . . we got $2.60 a pound [$5.73/kg] for our product, fuel was 70 cents a gallon [$0.18/L], and our bait was $8 a bushel [$0.12/kg]. Last year [2009] we got $2.60 a pound [$5.73/kg], the bait was $21 a bushel [$0.32/kg], and fuel was $2.89 [$0.76/L].[2]

The cumulative impact of these threats led the lobster industry to adjust their strategies in creative ways to keep their businesses afloat.

The most common responses by lobster harvesters were changes in fishing behavior to increase profits. Some increased fishing effort to increase their landings and compensate for the low prices. Others limited the number of traps they hauled, hoping to reduce the glut in the market and drive the price up, or stopped hauling altogether because the prices they received were not enough to cover their expenses. These opposing strategies had little influence on overall landings and price, prompting some lobstermen to call for an industrywide tie-up to reduce production until prices recovered. However, due to a 1958 consent decree lobstermen are prohibited from refraining to harvest lobsters until a minimum price is reached and from compelling others to refrain from harvesting. Because Maine lobstermen are owner-operators, this type of organized tie-up violates U.S. antitrust laws related to collusion and price fixing. While an industry-led tie-up was prohibited, many fishermen hoped the state would intervene; however, the state has the authority to shut down the fishery only when it is required to protect the resource, not in response to economic conditions.

Unable to impact prices at the dock, many fishermen adopted strategies to reduce their expenses, such as dropping their sternmen and fishing alone. One fisherman describes his strategy to cut costs during 2008 as follows:

> We still kept fishing, but . . . you probably didn't haul as often, you know, and you didn't run your boat so hard. You didn't burn as much fuel. You know, you just kept going. You just tried to ride it out and stay with it.

According to our interviews, such responses are customary among fishermen who are having a particularly bad year or experience unexpected circumstances that increase their costs (such as a large repair or maintenance issue or other unforeseen personal expenses). Many fishermen refer to "belt tightening," i.e., reducing their expenses and living off as little as possible as their strategy to get through tough times. In 2008, the belt tightening was industrywide.

Due to the widespread nature of the crisis in 2008, there were additional responses that were practiced industrywide or that required organization from multiple facets of the industry. The Maine Lobster Promotion Council worked with local grocery chains to run lobster promotions in order to increase demand as well as publicizing the crisis with an ad campaign geared toward local consumers intended to increase demand in the fall when the tourist season is over. The public sector also offered support. U.S. Senator Olympia Snowe organized meetings between industry members and federal agencies to develop processing plants in Maine. The U.S. Department of Agriculture Trade Adjustment Assistance program was created to provide training and financial assistance to farmers or fishermen who have been negatively impacted by foreign imports[3] and is assisting over 4,000 fishermen in New England

[2]Unattributed quotes are from interviews or focus groups conducted for this project.

[3]While the specific threat to the lobster industry in 2008 was related to a lack of export markets, the TAA program was developed to increase domestic production of seafood overall, which suffers from a $9 billion deficit (TAA 2010).

(Northeast lobstermen begin to realize benefits from the USDA's Trade Adjustment Assistance (TAA) program 2012). In October 2008, Maine Governor Jon Baldacci signed an executive order creating a Task Force on the Economic Sustainability of Maine's Lobster Industry to examine possible long-term solutions to buffer the lobster fishery from global economic conditions. The task force drafted a strategic plan that included recommendations to increase markets within Maine, improve product quality and adjust the timing of landings to maximize price, and create promotional opportunities for Maine lobster (Mosely Group 2009). While the report identified strategies to promote Maine lobster, implementation of the plan required $7.50–8.25 million of funding per year, a majority of which would be provided by industry assessments. The Maine Lobstermen's Association voted against such assessments, and due to the lack of industry support no legislation was drafted to implement the recommendations of the strategic plan.

RECOVERY IN 2010–2011

Despite the "crisis of 2008," interviews conducted in 2010 and 2011 indicate that most fishermen characterized the Maine lobster fishery as resilient. Market demand had increased, and while prices had not rebounded to their pre-2008 levels, they were rising (Figure 2). The opinion that the lobster fishery was financially viable was almost unanimous, as described by one interview respondent: "Last year [2010] them guys made a fortune off that lobster." Fishermen without lobster licenses who were interviewed during this period commonly expressed regret that they had not gotten licenses when they were available or had let their licenses lapse in favor of participating in other fisheries. These attitudes signify the perceived health of the industry and the importance of lobster as part of a diversified, resilient harvesting strategy. As one fisherman put it, "the only thing I'm missing is my lobster license, which is a big one. I'd like to have that card in my deck." Similarly, another fisherman stated, "it seems to me like in the last few years they've done pretty good. I mean they must be doing alright because they're all trading in their boats every year for bigger, newer boats."

While the overall perception was that the resource was doing well, anxiety about the future status of the fishery remained. Concerns during this period focused on both potential stock declines and market volatility. One fisherman explained his concern as follows: "In my opinion, lobster fishing has never been better than it has been in the last 15–20 years. How long is it gonna last? That's the big question. Nobody knows the answer." Even absent any reductions in stock abundance, the instability in prices gave rise to market concerns for the future:

> The stocks have been pretty much increasing. There were a couple lull years, oh, I would say around 2008, 2009 were down years a little bit, but since then the stocks have been increasing again. The stocks look really, really good for the future . . . . Now if the market doesn't adjust to it, it doesn't mean it's a good thing. I'd rather catch 1,000 lb [454 kg] at $5.00 a pound [$11/kg] than catch 3,000 lb [1,360 kg] at $2.00 a pound [$4.41/kg].

TABLE 1. Comments illustrating lobster harvesters' perceptions of market-related problems in the industry.

"Lobster price has rebound some, but if that goes to the shit again at $2 a pound, which it can, you're screwed."
"We need to do a better job marketing our product."
"Our financial business plan is based on a $4 boat price. If we get below $4, it doesn't work." (Lobstering in 2010, 2010)
". . . if they'll do that and start processing all the Maine lobsters, don't let Canada have our lobsters for nothing, keep the lobsters in the United States, the price would go up."
". . . another thing that we should be doing is instead of lugging our lobsters to here and there, we should be buying them and processing them here. Take the meats. I mean we can now dissect our lobsters and take the meat and freeze it and can it, do this and that with it. It's something we could be doing in this community right here."

This uncertainty, combined with increased dependence on a single species, is frequently cited as a source of vulnerability for the industry's future (Steneck et al. 2011; Wahle et al. 2013).

There are approximately 7,000 license holders on the coast of Maine, many living in towns with limited alternative economic opportunities. One fisherman described the dependence on lobster in his town this way:

> So your lobster stocks collapse . . . this town's screwed because we're not diverse enough to handle something like that and probably in the '90s when it was diverse, it was scallopers, draggers, lobstermen, all of the above, and everybody made a living doing a little bit of everything, but now it's basically all their eggs are in lobstering except for a scattering few.

It is generally established that diversity leads to increased resilience in social–ecological systems (Folke et al. 2002). This increase in resilience occurs both during disturbances (when diversity reduces the impact of threats by spreading the risk) and after disturbances (because a diverse system has a greater capacity to respond to change) (Folke et al. 2002; Turner et al. 2003). The strategy of diversification is also utilized specifically by fishermen. Much like maintaining a stock portfolio with high- and low-risk investments, fishermen who harvest multiple species can buffer the effects of a price collapse or reduced catch of a particular species by shifting to other fisheries. This strategy is particularly important in an environment with high uncertainty, such as fishing, as it is difficult to predict future hazards (Berkes 2007). However, given increasingly restrictive regulatory environments, a diverse harvesting strategy is more difficult to employ, reducing resilience in many fisheries (Tuler et al. 2008; Murray et al. 2010). Historically, many fishermen in Maine utilized this strategy and targeted a diverse mix of species, harvesting what was abundant and in season. As many species such as groundfish began to decline and regulatory restrictions were strengthened, many fishermen transitioned to harvesting lobster or intensified their lobster harvesting efforts. This dependence on lobster has led some scholars to describe the Gulf of Maine as a lobster monoculture (Wilson et al. 2007; Steneck et al. 2011). Such a shift may have been a successful response to threats at the time, but the increased dependence on a single fishery has also reduced the current level of resilience in the fishing industry.

Despite the responses and adjustments made by the industry in 2008, many fishermen continued to refer to the vulnerabilities that had been identified that year and spoke to the need to increase the economic sustainability of the fishery (Table 1). Looking back, it appears that their concerns about market stability and lobster prices were extremely prescient, as these vulnerabilities were exposed again just 2 years later.

2012 ENVIRONMENTAL CRISIS

The summer lobster season of 2012 materialized in many ways as a déjà vu of 2008, with lobster prices falling dramatically. While the external price shock experienced by the fishermen was much the same, the mechanism creating the threat was very different, however. Unseasonably warm water temperatures caused a glut of soft-shell lobsters in the late spring and early summer—too early for the Maine tourist season and its associated markets and overlapping the period when Canadian processors are at full capacity processing domestic lobster. Because soft-shell lobsters do not package well, they cannot be shipped live, further reducing the available market. Additionally, soft-shell lobsters fetch lower prices, as they contain less meat than comparable hard-shell ones. These factors combined in the summer of 2012 to produce the lowest lobster prices in 30 years, down to an exvessel value of $1.35 per pound ($2.98/kg) in some ports (Seelye 2012).

Confronting threats similar to those faced in 2008, the industry unsurprisingly reacted with almost identical responses. Many lobstermen started to increase their fishing effort to make up for the lower prices. One fisherman stated, "I didn't used to need to come in with a huge haul to make a living . . . . Now I do" (Seelye 2012). Other lobstermen took the opposite approach and began tying up their boats, hoping that a reduction in supply would increase prices. Again, there were calls for an organized tie-up but the commissioner of the DMR said that the state could not shut down the fishery for economic reasons and would not tolerate any type of peer pressure, including cutting traps to encourage other boats to tie up (Lobstermen tying up their boats 2012).

While the DMR did not have the authority to intervene, the state government reiterated its support for the industry, creating a committee of Lobster Advisory Council members, processors, dealers, exporters, and industry representatives to "consider whether there are changes that could be made in the lobster fishery to improve the quality of the product landed and the profitability of the industry" (Maine DMR 2012a). The governor also announced that the state would investigate ways to encourage additional processing capacity in Maine. One new Maine processing plant shipped its first load of lobsters in August 2012 and is anticipating processing 4.8 million pounds (2.2 kg) per year when running at full capacity (Hall 2012). Additional plants opened in 2013, increasing Maine's overall processing capacity to 10–12 million pounds; approximately 60–70% of Maine lobster landings are still shipped to Canada for processing, however (Canfield 2013).

Although this new processing capacity will undoubtedly help reduce the dependence on Canadian processors, some say that it is putting the cart before the horse: "If you don't focus on marketing, [having] more processors in Maine is just going to force the price down" (Trotter 2012). Echoing the sentiment expressed in 2008 as well as the conclusions of the governor's task force of that year, many lobstermen feel that the focus needs to be on increased marketing and branding of Maine lobster as a product: "What we have that (Canadians) don't have is a great brand. . . . We just need to be innovative. In the U.S., the Maine brand is strong, there are huge untapped markets right here in this country" (Trotter 2012). The recent increase in processing capacity in Maine may facilitate this branding, as more product will be available that can be labeled "Maine made" because it will not have traveled to Canada for processing. The federal government has supported this marketing strategy, and Maine congresswoman Chellie Pingree was able to negotiate with two major cruise lines to commit to purchasing 8,800 lb (3,991 kg) of Maine lobster to be served to passengers on ships that visit Maine (McCracken 2012). While this is an important step that will help increase domestic markets and create demand for the product, it may be no more than a symbolic effort, as the order accounts for less than one one-hundredth of a percent of total lobster landings in Maine.

OTHER THREATS FACING FISHERMEN

In addition to the drop in prices in 2008 and 2012, our research identified other factors that threaten the resilience of the lobster fishery in Maine. First, the limited-entry system has made it difficult for many young people to obtain lobster licenses. One fisherman explained the situation as follows: "You gotta jump through hoops and breathe fire to get in the fishery now . . . you have to apprentice and log days and hours to get on a waitlist and will be dead and gone before (you) ever gets into lobstering." This has many fishermen concerned about the future of the lobster industry as current fishermen begin to age and retire without a matching influx of young fishermen:

> I think we'll see a drastic dip in the number of people in the fishing business, because we've limited entry drastically. You take a town like this one that has 60 or 80 fishermen in it, half of those guys probably won't be in the business 20 years from now, and I don't see 20 or 30 [new entrants into the fishery] coming along.

Members of the industry are not the only ones concerned about the rising age structure of harvesters and the restrictions of the current limited-entry system. During the 125th legislative session, the Maine legislature directed the DMR to commission an independent evaluation of the costs and benefits of the limited-entry licensing system. The resulting report suggested that one deficiency of the system is the long waiting period for receiving a new license and that the current average tenure on the waiting list is 6 years (Dayton and Sun 2012).[4]

Additionally, fishermen are concerned about future environmental conditions that may threaten the industry. The sea surface temperatures of the northeastern continental shelf were higher in the first 6 months of 2012 than they have been in the last 70 years, and preliminary data suggest that this has affected temperatures throughout the water column, including bottom temperatures (Dawicki 2012). This has many fishermen worried that the Gulf of Maine could experience stock declines similar to those seen in southern New England in the late 1990s. One fisherman explained his concern about future environmental conditions this way:

> One of the things that I worry about more than anything else is environmental conditions because we've seen in Long Island Sound and places south of Cape Cod where the fishery can be wiped out almost overnight because of environmental factors—pollution, warm water . . . . I think Maine has always been protected because of its cold water . . . . I worry that if it warms up just a little bit, we're gonna have major problems.

The combination of warm water temperatures and an increased density of lobsters has led to concern that shell disease will be a threat in the future; although the prevalence of the disease has increased since 2010, it is still seen in less than 1% of the lobsters sampled in Maine.

DISCUSSION

The parallels between the 2008 and 2012 crises are difficult to ignore. Both were characterized by external threats that affected lobster prices and markets. While the drivers behind these threats differed—global economic and environmental conditions, respectively—the results were very much the same. So what does all this mean in terms of the resilience of the Maine lobster fishery?

One would think that having experienced the crisis of 2008, the industry would have been better prepared to respond to the threats faced in 2012, but as Patrice McCarron, executive director of the Maine Lobsterman's Association stated, "Unfortunately, this summer's crisis revealed that little progress has been made since 2008" (MacPherson 2012). The fact that the industry was not more prepared to respond to a similar crisis 4 years later indicates that the lobster industry is not as resilient as we think.

We classify many of the responses to the crises of the past 4 years as *coping* strategies (short-term changes in behavior designed to withstand a perturbation) rather than *adaptation* (longer-term strategies that require larger investments and that are more difficult to reverse) (Tuler et al. 2008). In the past the lobster industry has been remarkably successful in responding to threats, enacting institutional changes from trap limits to V-notching, size gauges, and the zone council system (Acheson 2003). So why has it not adapted similarly to the new market pressures and historically low prices? We offer five possible explanations: (1) adaptation and institutional change take time, and because the current threats are relatively new the industry has not had adequate time to adapt to them; (2) the crisis is not perceived as extreme or imminent enough to require long-term adaptation; (3) the current management scheme is unable to adapt to these types of challenges; (4) the new economic threats are external and on a broader scale, requiring larger market-based responses that are outside the scope of the harvesting operation; and (5) the unpredictable timing and nature of these new threats has led to coping responses.

Adaptation Takes Time

The process followed by Maine lobster fishermen throughout the 20th century to devise the rules and institutions that currently regulate the Maine lobster fishery illustrates that institutional change and adaptation is a slow, complex process (North 1990). First, the lobstermen had to agree that changes were necessary and would have a positive impact on the fishery. Obtaining agreement in a fishery often characterized as fiercely individual can be an arduous task. One fisherman describes the difficulty in organizing lobster fishermen as follows: "You could have 3,000 guys agreeing on doing something and you have one guy saying, 'No, I'm not going. I'm gonna do it my way,' and the 3,000 will rapidly join him." Once consensus was achieved, the lobstermen had to convince the state legislature to enact legislation to create the institutions necessary to implement reform. This has not been a quick, easy process; it has required 70 years of evolving biological, social, and political conditions to create the current lobster management scheme (Acheson 2003).

The recent crisis in the lobster fishery has spanned just 5 years, and with the rebound in prices from 2010 to 2011 the

[4]While the report made numerous recommendations to remedy this, none have been implemented as of the publication of this article.

actual period in which the threats were experienced is even shorter. Therefore, it may be premature to expect the lobster industry to have devised new institutions that increase their resilience to these price shocks. Some fishermen are aware of the time required for this process. As one explained, "There is no quick fix to this. We do not need to overreact and act fast by putting in some regulation that just won't work in the long run" (Lobster solutions hard to come by 2008). The historical ability of the industry to devise institutions to adapt to variability in stock abundance generates confidence in its capacity, given adequate time, to adapt to the new threats and to create new institutions that will address the issues.

Level of Crisis

The level of a threat can be determined by its intensity, frequency, and duration (Cutter 1996), which in turn affect the magnitude of the response to the threat (Kasperson et al. 1995; Dow 1999). While the crises of 2008 and 2012 created difficult economic times for many in the lobster industry, the effects have been relatively short-lived. We recognize that the crises were catastrophic for lobstermen who lost their boats or who were forced out of the industry, but for those who were able to continue fishing our interviews showed that during the years 2010 and 2011 many still perceived the fishery to be doing well. Just 2 years after experiencing the crisis of 2008, fishermen spoke of threats to the lobster industry in vague, futuristic terms.

The perception that threats to the lobster fishery are not imminent or of high enough degree to require substantial adaptation is supported by the widespread success of the lobster fishery for the past 30–40 years. With increases in landings and relatively stable markets since the mid-1980s, many in the industry have not experienced significant misfortune. As one fisherman explained,

> The fishermen who are 40 and under have never known struggle. They really haven't. . . . All they've ever known for the last 20–25 years is ever-increasing catches, ever-increasing wallets, and they may think they have, okay, but they've never known struggle. . . . To me, struggling is no matter what you have for bills you can't catch enough lobsters to pay for 'em. And they've never known that.

The recent success of the fishery has left younger members of the industry without the "social memory" of strategies that have been successful in responding to threats in the past. Social memory is a key aspect of resilience, as it provides a wealth of information regarding the diversity of responses available to different threats and their likely outcomes (Folke et al. 2005). This lack of social memory reduces the resilience of the lobster industry, as it cannot utilize the "head start" in responding to threats that social memory provides.

This lack of experience with previous threats may also lead the industry to underestimate the level of current threats. Due to the recent positive trend in landings, there is little perception that there is any current threat to the abundance of Maine lobster stocks. One fisherman in 2011 described the status of the resource as follows:

> The ocean is full of lobsters, it's full of them. There's nothing to get 50 lobsters in a pair of traps; it's not keepers, you understand, but lobsters overall. . . . I've never seen that in any of my lifetime, so things look good in the lobster industry for a while if they all live.

Because of this, many fishermen believe that they will be able to compensate for lower prices by fishing harder and are therefore less likely to make long-term adaptive changes. Some fishermen recognize the futility of this strategy, however:

> Well, see, lobstermen have a bad business plan. When the price drops they go harder to try to make up for price difference, which you start to use more bait; so when you start to use more bait it increases the bait price and, as you go harder, you burn more fuel and then you start catching even more lobsters that even drives the price of lobsters even further down, so it's not a really good business plan.

Intensifying pressure on the resource may not be a good business plan, but the fact that it is seen as a viable strategy when times get tough may be one factor impeding the institutional change necessary for long-term sustainability in the market.

Previous institutional changes in the lobster fishery have followed crises that were perceived as significant, imminent threats. The transition of the industry from one in which harvesters had a "pirate ethic" and violated laws for personal gain to one with a "conservation ethic" that promoted sustainable regulations and compliance has been attributed to the catastrophic stock collapse in the 1930s, which caused 30% of lobstermen to leave the industry (Acheson and Gardner 2010). After years of division, this crisis shocked the industry, catalyzing the transition to more sustainable regulations and industrywide understanding of the importance of complying with those regulations. Perhaps the price drops of 2008 and 2012 have not been catastrophic enough for the industry to realize institutional change.

Noneconomic threats are also perceived as future threats, but they do not appear urgent to a majority of the industry. Environmental changes, such as shell disease and consistent changes in water temperature have yet to substantially impact harvest levels and are therefore deemed to be less urgent. A shock to the system of the same magnitude as the stock collapse of the 1930s may be necessary before real institutional change will occur.

Adaptability of the Current Management Scheme

The level of vulnerability of the lobster industry after the shocks of the last 4 years remains to be seen. Some of this will hinge on future market and environmental conditions that are unknowable, but it will also be determined by the flexibility of the institutions that regulate the industry. At a recent meeting at which lobstermen were asked to list elements of the current management system that are working, many fishermen found it difficult to think of a bright spot. One fisherman summarized it as "the whole thing's broke." The comanagement system of the lobster fishery relies heavily on harvester participation, which has declined in recent years. Fishermen who have attended meetings say that as a whole the industry is "apathetic until after the fact" and that opinions are not voiced until after policy decisions have been made. This may be due to fatigue, as lobstermen have attempted to change regulations in the past only to meet interference from the state. One fisherman described the process as "good intentions go in and garbage comes out."

One of Elinor Ostrom's[5] design principles for long-enduring institutions is that "external authorities do not challenge the rights of appropriators to devise their own institutions" (Ostrom 1990:101). The state has ultimate authority over which industry proposals are adopted in the form of regulations, and while this provision lends organization and authority to the process, in its current form it may not prove responsive enough to industry needs. If the institutions stay rigid and change does not occur, the industry could be at a precipice, where threats that were previously absorbed become catastrophic (Holling 1986). However, if the system remains flexible, the lobster industry may increase its resilience and ability to adapt to recent and future threats.

Perhaps the zone council system is "not adaptive to industry," as some fishermen have stated. This alone does not preclude the ability of the industry to respond to current threats. One aspect of resilient systems is that a disturbance or threat "has the potential to create opportunity for doing new things, for innovation, and for development" (Folke et al. 2005:253). The lobster industry could demonstrate its resilience by devising new ways of responding outside of the zone council or legislative system. This type of response may require additional leadership or political entrepreneurs to initiate reform. Political entrepreneurs are people who "do more than work for the public good; they also offer information, expertise, and public resources" and "are the means by which [the rules] are negotiated" (Acheson 2003:72, 79). They can be the catalyst required to generate new rules and institutions to respond to threats. As the fishing community ages, there seems to be less interest in spending the time required to make the connections and persuade the right people to make regulatory changes. This lack of leadership reduces social resilience and the ability to initiate new responses to change. Without a new generation of political entrepreneurs to take the reins, it may be difficult for any new system of management, or increased flexibility of current management schemes, to come to fruition.

[5]Nobel Prize winner and noted researcher of common pool resource institutions.

Broad-Scale Threats Require Response at a Matching Scale

The current threats facing the industry exhibited by the price drops of 2008 and 2012 are large-scale, external threats; therefore, any successful response must be at an appropriately broad scale. When the global economy falls into a recession that affects lobster prices or water temperature changes the temporal distribution of landings, there are few response options available to the individual harvester. As one lobsterman stated, "The only thing you can do is tighten your belt up and keep on fishing." Individual or collective action from harvesters cannot respond adequately to an external threat of this scale.

Collective action in the lobster fishery is akin to a prisoner's dilemma, and although the industry has collectively devised institutions to respond to threats in the past these threats were largely internal and related to taking collective action for conservation (Acheson and Gardner 2010). Threats of this nature are at a scale to which individual fishermen can respond, as their behavior has a direct effect on stock abundance, resulting in an effective, tight feedback loop that links their response to its effect on the threat. This feedback loop is a key factor in stimulating responses (Berkes 2002). As a threat broadens in scale, the feedback loop becomes less coupled, decreasing the motivation for response. Because the price threats in the lobster fishery are at a broad scale, this feedback loop is less tightly related to the harvesters' responses; therefore, a larger-scale response is required, such as one by the state. However, while the state allows for collective action with respect to conservation (e.g., the double-gauge law and V-notching), it prohibits it with respect to economic objectives (i.e., coordinated tie-ups), further impeding the ability of lobster fishermen to respond to economic changes such as those experienced in 2008 and 2012.

Nested scales of management increase resilience in complex social–ecological systems (Ostrom and Janssen 2004). When multiple scales of management exist, there is a variety of responses available to address threats within the system. The current management institutions in the lobster fishery are appropriate to respond to threats to the resource, but in order to respond to broader, market-based threats new, larger-scale institutions are required. There is evidence that toward the end of the 2012 season the industry acknowledged the need for large-scale market-based responses. In the fall of 2012, the industry was exploring license surcharges of $3 million annually that would fund promotional efforts aimed at expanding local, regional, and global markets (Schreiber 2012). This support for a larger-scale response is an encouraging sign for future resilience in the lobster industry.

Unpredictable Threats Lead to Coping Responses

One reason coping responses have been the main ones thus far is the unpredictable nature of these new threats. Collective action and new institutions were successful in responding to past threats because those threats were predictable and consistent. It was much easier to foresee the threats of increased effort in the fishery and the harvesting of short lobsters than it is to anticipate when market prices will drop. The source, extent, and timing of the more recent threats to the lobster industry are unpredictable. Environmental changes may be easier to respond to if there are gradual changes such as consistent, incremental shifts in the species' distribution or a slow, linear increase in the prevalence of shell disease. But if these changes occur in an abrupt, unpredictable manner with no evidence of changing future conditions, the responses will be equally abrupt and unplanned.

There is a general recognition that the good times cannot last forever. This is exemplified by the ways in which lobstermen describe the future: "There's going to be a huge, huge catch of lobsters for a few years now. But that can be reversed real quick." "No one says lobsters have to stay alive; they could die just as quick as they come." "It's good right now, but it's not going to stay that way." While the uncertainty of the future is almost universally acknowledged, there is no general recognition of what the specific threats will be or when they will occur. Because the threats are unpredictable, reliance on coping responses may be the most logical strategy.

The current resilience in the lobster industry may be best described by (1) the attitude among harvesters that they need to be prepared for future threats, whatever they may be, and (2) the coping responses they are implementing to deal with a less predictable future. This attitude is reflected by a reduction in purchases of new boats. As one lobsterman described the situation, "There's not many boat builders making lobster boats right now because . . . people aren't buying." Another fisherman described the way he is changing his behavior due to this unpredictability as follows: "The way the fishing is now, I can't see myself doing the tricks I used to do, trade trucks every year, I mean. I think I'm gonna have to keep what I've got." While large-scale, institutional responses will help increase the resilience to future market threats, smaller coping strategies appear to be the best option now available to increase the resilience to other unpredictable, external threats in the future. It remains to be seen whether the resilience created by these coping responses will be adequate to withstand future threats.

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REFERENCES

Acheson, J. M. 2003. Capturing the commons: devising institutions to manage the Maine lobster industry. University Press of New England, Lebanon, New Hampshire.

Acheson, J. M., and A. W. Acheson. 2010. Factions, models, and resource regulation: prospects for lowering the Maine lobster trap limit. Human Ecology 38:587–598.

Acheson, J. M., and R. Gardner. 2010. The evolution of conservation rules and norms in the Maine lobster industry. Ocean and Coastal Management 53:524–534.

Acheson, J. M., and R. S. Steneck. 1997. Bust and then boom in the Maine lobster industry: perspectives of fishers and biologists. North American Journal of Fisheries Management 17:826–847.

Adger, W. N. 2000. Social and ecological resilience: are they related? Progress in Human Geography 24:347–364.

Adger, W. N. 2006. Vulnerability. Global Environmental Change 16:268–281.

Berkes, F. 2002. Cross-scale institutional linkages: perspectives from the bottom up. Pages 293–321 *in* E. Ostrom, T. Dietz, N. Dolsak, P. C. Stern, S. Stonich, and E. U. Weber, editors. Drama of the commons. National Academies Press, Washington, D.C.

Berkes, F. 2007. Understanding uncertainty and reducing vulnerability: lessons from resilience thinking. Natural Hazards 41:283–295.

Bernard, H. R. 2002. Research methods in anthropology: qualitative and quantitative approaches, 3rd edition. Altamira Press, Walnut Creek, California.

Boudreau, S. A., and B. Worm. 2010. Top-down control of lobster in the Gulf of Maine: insights from local ecological knowledge and research surveys. Marine Ecology Progress Series 403:181–191.

Canfield, C. 2013. Maine moves to capture lobster-processing market. Associated Press (July 5). Available: http://bigstory.ap.org/article/maine-moves-capture-lobster-processing-market. (January 2014).

Cutter, S. L. 1996. Vulnerability to environmental hazards. Progress in Human Geography 20:529–539.

Dawicki, S. 2012. Sea surface temperatures reach record highs on northeast continental shelf. National Oceanic and Atmospheric Administration Ecosystem Advisory 2. (18 September 2012).

Dayton, A., and J. Sun. 2012. An independent evaluation of the Maine limited-entry licensing system for lobster and crab. Report of Gulf of Maine Research Institute to Maine Department of Marine Resources, Boothbay Harbor.

Dow, K. 1999. The extraordinary and the everyday in explanations of vulnerability to an oil spill. Geographical Review 89:74–93.

Folke, C., J. Colding, and F. Berkes. 2002. Synthesis: building resilience and adaptive capacity in social–ecological systems. Pages 352–387 *in* F. Berkes, J. Colding, and C. Folke, editors. Navigating social–ecological systems: building resilience for complexity and change. Cambridge University Press, New York.

Folke, C., T. Hahn, P. Olsson, and J. Norberg. 2005. Adaptive governance of social–ecological systems. Annual Review of Environment and Resources 30:441–473.

Glaser, B., and A. Strauss. 1967. The discovery of grounded theory: strategies for qualitative research. Aldine, Chicago.

Hall, J. 2012. Lobster processing: young Mainer to open seafood plant. Portland Press Herald (August 13). Available: http://www.pressherald.com/news/getting-lobsters-from-trap-to-table_2012-08-14.html. (August 2012).

Holling, C. S. 1986. The resilience of terrestrial ecosystems: local surprise and global change. Pages 292–317 *in* W. Clark and R. Munn, editors. Sustainable development of the biosphere. Cambridge University Press, Cambridge, UK.

Kasperson, R. E., J. X. Kasperson, B. L. I. Turner, K. Dow, and W. B. Meyer. 1995. Critical environmental regions: concepts, distinctions, and issues. Pages 1–41 *in* J. X. Kasperson, R. E. Kasperson, and B. L. Turner, editors. Regions at risk: comparisons of threatened environments. United Nations University Press, Tokyo.

Lobster solutions hard to come by. 2008. Commercial Fisheries News. Available: http://www.fish-news.com/cfn/editorial/editorial_11_08/Lobster_crisis-Solutions_will_come_hard.html. (February 2015).

Lobstering in 2010. 2010. Free Press (January 7). Available: http://freepressonline.com/main.asp?Section ID=52&SubSectionID=78&ArticleID=4574. (February 2015).

Lobstermen tying up their boats. 2012. WMTW-TV, Portland, Maine (July 12). Available: http://www.wmtw.com/news/money/Lobstermen-tying-up-their-boats/-/8791814/15499618/-/oskfp7z/-/index.html?absolute=true. (August 2012).

MacPherson, I. 2012. A road map for the future. Landings: News and Views from Maine's Lobstering Community (October 15). Available: http://mainelandings.org/tag/lobster-council-of-canada/. (October 2012).

Maine DMR (Maine Department of Marine Resources). 2012a. Lobster Advisory Council's profitability and lobster quality committee meeting. Maine DMR, Augusta.

Maine DMR (Maine Department of Marine Resources). 2012b. Historical Maine landings data. Available: http://www.maine.gov/dmr/commercialfishing/historicaldata.htm. (August 2012).

McCay, B. J. 1978. Systems ecology, people ecology, and the anthropology of fishing communities. Human Ecology 6:397–422.

McCay, B. J. 2002. Emergence of institutions for the commons: contexts, situations, and events. Pages 361–401 *in* E. Ostrom, T. Dietz, N. Dolsak, P. C. Stern, S. Stonich, and E. U. Weber, editors. Drama of the commons. National Academies Press, Washington, D.C.

McCracken, C. 2012. Cruise ship buys local lobsters on waterfront: congresswoman Pingree thanked for new business opportunity. Bangor Daily News (September 12). Available: http://bangordailynews.com/community/cruise-ship-buys-local-lobsters-on-waterfront-congresswoman-pingree-thanked-for-new-business-opportunity/. (October 2012.)

Mosely Group. 2009. Maine lobster industry strategic plan. Report for Governor's Task Force on the Economic Sustainability of Maine's Lobster Industry, Augusta.

Murray, G., T. Johnson, B. J. McCay, M. Danko, K. St. Martin, and S. Takahashi. 2010. Creeping enclosure, cumulative effects, and the marine commons of New Jersey. International Journal of the Commons 4:367–389.

North, D. C. 1990. Institutions, institutional change, and economic performance. Cambridge University Press, New York.

Northeast lobstermen begin to realize benefits from the USDA's Trade Adjustment Assistance (TAA) program. 2012. Fishermen's Voice 17:11–12.

Ostrom, E. 1990. Governing the commons. Cambridge University Press, New York.

Ostrom, E., and M. A. Janssen. 2004. Multilevel governance and resilience of social–ecological systems. Pages 239–259 *in* M. Spoor, editor. Globalisation, poverty, and conflict. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Richardson, J. 2010. Mainers gobbling lobster to keep industry afloat. Portland Press Herald (March 13). Available: http://www.pressherald.com/archive/mainers-gobbling-lobster-to-keep-industry-afloat_2008-10-28.html. (October 2012).

Ritchie, D. A. 2003. Doing oral history: a practical guide. Oxford University Press, New York.

Schreiber, L. 2012. Lobster industry aims bigger on marketing. Working Waterfront (November 14). Available: http://www.workingwaterfront.com/articles/Lobster-Industry-Aims-Bigger-on-Marketing/15081. (December 2012).

Seelye, K. Q. 2012. In Maine, more lobsters than they know what to do with. New York Times (July 28). Available: http://www.nytimes.com/2012/07/29/us/in-maine-fishermen-struggle-with-glut-of-lobsters.html?_r=1&hp. (October 2012).

Steneck, R. S., T. P. Hughes, J. E. Cinner, W. N. Adger, S. N. Arnold, F. Berkes, S. A. Boudreau, K. Brown, C. Folke, L. Gunderson, P. Olsson, M. Scheffer, E. Stephenson, B. Walker, J. Wilson, and B. Worm. 2011. Creation of a gilded trap by the high economic value of the Maine lobster fishery. Conservation Biology 25:904–912.

Strauss, A., and J. Corbin. 1998. Basics of qualitative research: techniques and procedures for developing grounded theory. Sage, Thousand Oaks, California.

TAA (Trade Adjustment Assistance for Farmers). 2010. U.S. lobster exports & the U.S.–Canada relationship. Available: http://taatrain.cffm.umn.edu/LobsterMrktOV/Default.aspx?SectionID=194. (October 2012).

Trotter, B. 2012. Maine ponders industry strategy as lobster protests continue in Canada. Bangor Daily News (August 8). Available: http://bangordailynews.com/2012/08/08/business/maine-ponders-industry-strategy-as-lobster-protests-continue-in-canada/. (February 2015).

Tuler, S., J. Agyeman, P. P. da Silva, K. R. LoRusso, and R. Kay. 2008. Assessing vulnerabilities: integrating information about driving forces that affect risks and resilience. Human Ecology Review 15:171–184.

Turner, B. L., R. E. Kasperson, P. A. Matson, J. J. McCarthy, R. W. Corell, L. Christensen, N. Eckley, J. X. Kasperson, A. Luers, M. L. Martello, C. Polsky, A. Pulsipher, and A. Schiller. 2003. A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences of the USA 100:8074–8079.

Vayda, A. P., and B. J. McCay. 1975. New directions in ecology and ecological anthropology. Annual Review of Anthropology 4:293–306.

Wahle, R. A., A. Battison, L. Bernatchez, S. Boudreau, K. Castro, J. H. Grabowski, S. J. Greenwood, C. Guenther, R. Rochette, and J. Wilson. 2013. The American lobster in a changing ecosystem: a U.S.–Canada science symposium, 27–30 November 2012, Portland, Maine. Canadian Journal of Fisheries and Aquatic Resources 70:1571–1575.

Wickenheiser, M. 2012. Maine lobstermen reeling from low prices, seeking cooperation from dealers. Bangor Daily News (July 5). Available: http://bangordailynews.com/2012/07/05/business/maine-lobstermen-reeling-from-low-prices-seeking-cooperation-from-dealers/. (December 2012).

Wilson, J. A., J. M. Acheson, and T. R. Johnson. 2013. The cost of useful knowledge and collective action in three fisheries. Ecological Economics 96:165–172.

Wilson, J., L. Yan, and C. Wilson. 2007. The precursors of governance in the Maine lobster fishery. Proceedings of the National Academy of Sciences of the USA 104:15212–15217.

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Ecoviability for ecosystem-based fisheries management

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Abstract :

Reconciling food security, economic development and biodiversity conservation is a key challenge, especially in the face of the demographic transition characterizing many countries in the world. Fisheries and marine ecosystems constitute a difficult application of this bio-economic challenge. Many experts and scientists advocate an ecosystem approach to manage marine socio-ecosystems for their sustainability and resilience. However, the ways by which to operationalize ecosystem-based fisheries management (EBFM) remain poorly specified. We propose a specific methodological framework-viability modelling-to do so. We show how viability modelling can be applied using four contrasted case-studies: two small-scale fisheries in South America and Pacific and two larger-scale fisheries in Europe and Australia. The four fisheries are analysed using the same modelling framework, structured around a set of common methods, indicators and scenarios. The calibrated models are dynamic, multispecies and multifleet and account for various sources of uncertainty. A multicriteria evaluation is used to assess the scenarios' outcomes over a long time horizon with different constraints based on ecological, social and economic reference points. Results show to what extent the bio-economic and ecosystem risks associated with the adoption of status quo strategies are relatively high and challenge the implementation of EBFM. In contrast, strategies called ecoviability or co-viability strategies, that aim at satisfying the viability constraints, reduce significantly these ecological and economic risks and promote EBFM. The gains associated with those ecoviability strategies, however, decrease with the intensity of regulations imposed on these fisheries.

Keywords : biodiversity, ecological economics, ecosystem approach, fisheries, scenario, viability

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1 Introduction and motivations

Reconciling food security with biodiversity conservation is among the greatest challenges of the century, especially in the face of the world demographic transition (Godfray *et al.*, 2010; Rice & Garcia, 2011). The creation of the IPBES (International Panel for Biodiversity and Ecosystem Services) at the interface between decision support and scientific knowledge is in direct line with these concerns. Implementing this bio-economic perspective is especially challenging in the case of fisheries and marine ecosystems. Marine and coastal ecosystems are experiencing accelerating changes affecting species and communities at different biotic scales, sometimes with alarming trends and largely unknown consequences (Butchart *et al.*, 2010; MEA, 2005). These changes are partially due to past and current fishing pressure, thus questioning the sustainability of current fishing activities and food production systems, and raise key questions in terms of food security, especially for developing countries with high demographic growth. Climate change complicates and exacerbates the issues by inducing new, or intensifying existing, risks, uncertainties and vulnerabilities.

As a consequence, ensuring the long-term ecological-economic sustainability of marine fisheries systems, and preserving the marine biodiversity and ecosystems that support them, have become a major issue for national and international agencies (FAO, 2013). In response, an increasing number of marine scientists and experts advocate the use of ecosystem-based fishery management (EBFM) accounting for the various ecological and economic complexities at play. Pikitch *et al.* (2004) for instance claim that EBFM is a new direction for fishery management, essentially reversing the order of management priorities so that management starts with the ecosystem rather than a target species, while FAO (2003) proposes the following definition:

> "An ecosystem approach to fisheries strives to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries."

The way to operationalize this EBFM approach, however, remains challenging (Sanchirico *et al.*, 2008; Doyen *et al.*, 2013), along with the identification of methods, approaches and tools to support its implementation. Hence, there is a need to develop new models, indicators and scenarios in this domain (Plagányi *et al.*, 2007). In particular, the effectiveness of current regulatory instruments including fishing quotas or financial incentives needs to be reconsidered in light of this new multi-functional, cross-sectoral and interdisciplinary context, accounting for the multiple commodities and services provided by marine biodiversity and ecosystems. The aim of this paper is to contribute to this discussion through the use of viability modelling.

Viability modeling is now recognized by a growing number of researchers (Jennings, 2005; Cury *et al.*, 2005; Thébaud *et al.*, 2013; Krawczyk *et al.*, 2013) as a relevant framework for EBFM. In the context of dynamic systems, the aim of the viability approach is to explore states and controls that ensure the 'good health' and safety of the system (Aubin, 1990; De Lara & Doyen, 2008). By identifying the viability conditions that allow constraints to be fulfilled over time, considering both present and future states of a dynamic system, the viability approach conveys information on sustainability (Baumgartner & Quaas, 2009). It accounts for dynamic complexities, uncertainties, risks and multiple sustainability objectives. Resilience and recovery goals can also be addressed through viability modeling using the notion of minimal time of crisis (Béné *et al.*, 2001; Deffuant & Gilbert, 2011). As reviewed recently by Schuhbauer & Sumaila (2016), the approach has already been successfully applied to fisheries management in several contexts (Eisenack *et al.*, 2006; Martinet *et al.*, 2007; Sanogo *et al.*, 2013; Krawczyk *et al.*, 2013) including (eco)-system or biodiversity dynamics (Mullon *et al.*, 2004; Doyen *et al.*, 2007; DeLara *et al.*, 2012; Gourguet *et al.*, 2013; Maynou, 2014). In relation to food security, Cissé *et al.* (2013, 2015); Hardy *et al.* (2013) provide useful bio-economic insights in the context of developing countries under important demographic pressure.

The main objective of this paper is to show through modeling and scenario analyses how this viability approach can provide a relevant methodological framework to implement EBFM. The work relies especially on four contrasted case studies: the small-scale fishery of French Guiana (South America), the small-scale fishery of Solomon Islands (Pacific), the Bay of Biscay multi-species demersal fishery (Europe) and the Northern prawn fishery of the Gulf of Carpenteria (Australia). All four fisheries are represented as systems of intermediary complexity (Plagányi *et al.*, 2014) and analyzed using the same modeling framework, common methods, indicators and scenarios. The calibrated models are dynamic, multi-species and multi-fleet and account for various sources of uncertainty. A multi-criteria analysis of alternative effort strategies is implemented, with the objective to assess the fulfillment of different constraints and objectives at the 2030-2050 horizon, based on ecological, social and economic reference points. We name such an approach ecoviability as in Cissé *et al.* (2015) to highlight the ecological, economic and ecosystemic ingredients of this viability modeling.

The scientific contribution of the paper is twofold. First it demonstrates the advantages of using the ecoviability approach to operationalize EBFM through a series of contrasted case studies. In particular it shows how implementing a viability strategy can lead to 'win-win' situations in terms of reduction of ecological and economical vulnerabilities and risks. Second, the paper highlights some potentially important differences between more heavily regulated and less regulated fisheries when comparing a viability strategy to the current state (status quo). Ecoviavility indeed leads to 'win-win' outcomes in terms of both economic expectation and bio-economic risk for less regulated fisheries while, in contrast, heavily regulated fisheries face trade-offs because they perform well in terms of economic expectation and scores.

The paper is organized as follows. Section 2 presents the generic ecoviability modeling approach including the controlled uncertain dynamics, viability metrics and scenarios. Section 3 is devoted to the application of the general framework to the contrasted case studies and especially to the comparison of scenarios including the viability scenario. Section 4 discusses the results in particular with respect to EBFM while Section 5 concludes. Mathematical details on the models and methods are described in the Appendix.

2 Ecoviability approach, models and scenarios

The viability approach relies on mathematical models derived from the theory of dynamic systems control under constraints. Within this generic framework, the ecoviability framework (also termed co-viability) specifically focuses on the ecological-economic viability of exploited ecosystems including fisheries and marine resources. In this section, the generic framework that underlies ecoviability modeling in the four case studies is presented. The common mathematical framework allows us to consider the problem of integrating multi-species, multi-fleet, dynamic and uncertain socio-ecological systems while taking into account ecological and economic viability goals or constraints which all constitute major ingredients for EBFM.

2.1 A multi-species multi-feet dynamic model

Marine social ecological systems are described by a set of n marine stocks exploited by m distinct fleets. A state space formulation (Clark & Mangel, 2000) in discrete time is used to represent the evolution of the ecosystem. Thus the n stocks whose states at time t are denoted by $x_i(t)$ are governed by the following controlled and uncertain dynamic equations

$$x_i(t + \Delta t) = g_i\big(x(t), e(t), \omega(t)\big), \tag{1}$$

from initial time $t = t_0$ to temporal horizon $t = T$ with time step Δt. The states $x_i(t)$ can potentially be vectors of abundance or biomass at different ages or sizes or by sex. The global state $x(t)$ representing the community or ecosystem state is the vector of states $x(t) = (x_1(t), \dots, x_n(t))$. The vector $e(t) = (e_1(t), \dots, e_m(t))$ is the control of the system through the effort (duration or number of vessels) of the different fleets at time t. Alternatively, output controls through catches could be used based on production functions as described below in equation (2). The variables $\omega(t) = (\omega_1(t), \dots, \omega_p(t))$ represent the uncertainties affecting the dynamics of the system through random fluctuations on species growth or recruitment, species interactions and catchabilities. The growth functions g_i for each species (or groups of species) may account for inter-specific competition and/or trophic interactions.

The catches $h_{ij}(t)$ of stocks $x_i(t)$ by fleet j depend on fishing effort $e_j(t)$ through the production function

$$h_{ij}(t) = h_j\big(x_i(t), e_j(t), \omega(t)\big). \tag{2}$$

The harvest function $h_j = (h_{1j}, \dots, h_{ij}, \dots, h_{nj})$ of every fleet j accounts for the technical interactions and bycatch which may occur and complexify the control of the system. Catches can also be uncertain (depending on $\omega(t)$) because of random catchability for instance. See appendix, sections A.3, A.4, A.5 and A.6 for more details for each case study.

2.2 The ecoviability objectives

The viability approach focuses on the safety and feasibility of controlled dynamics of the system with respect to constraints or targets representing the good health, safety or sustainability of the socio-ecosystem. These constraints can involve ecological thresholds as in the case of an extinction threshold in population viability analysis (PVA) (Morris & Doak, 2003). Economics constraints (guaranteed rent, food security, ...) can also be integrated as recently reviewed in Schuhbauer & Sumaila (2016), thus allowing for multi-criteria and bio-economic analyses. Such integrated viability objectives generally refer to a mix of the following ecological and economic constraints.

First, an ecological requirement is considered through biological or ecological indicators $\mathrm{Bio}(x(t), \omega(t))$ as follows:

$$\mathrm{Bio}\big(x(t), \omega(t)\big) \geq \mathrm{Bio}_{\mathrm{lim}}. \tag{3}$$

The ecological indicators $\mathrm{Bio}(x(t), \omega(t))$ correspond to biodiversity or biological metrics which may typically encompass species richness, trophic index or measure of spawning biomass for structured populations. They can also be uncertain because of stock measurement errors or because of uncertainty with regard to ecological thresholds in fish population viability or in fish communities. In that context, the threshold $\mathrm{Bio}_{\mathrm{lim}}$ can stand for an ecological tipping point.

Second a food security objective is taken into account through the aggregated catch $H\big(t\big) = \sum_{i,j} h_{i,j}(t)$ which plays the role of food supply. Maintaining the food supply high enough with respect to the demand reads

$$H\big(t\big) \quad \geq \quad H_{\mathrm{lim}}(t), \tag{4}$$

where $H_{\mathrm{lim}}(t)$ refers to some basic need threshold which may be time-dependent typically because of demographic growth.

Third, economic viability is captured through profitability of the fleets as follows

$$\mathrm{Profit}_j(t) \geq 0. \tag{5}$$

Here the economic value $\text{Profit}_j(t) = \text{Profit}_j(x(t), e(t), \omega(t))$ relates to the profit of each fleet j computed as the difference between the revenues $\text{Inc}_j(t)$ derived from catches $h_j(t)$ and operating costs $c_j(t)$ associated with the fishing effort $e_j(t)$; namely

$$\text{Profit}_j(t) = \text{Inc}\Big(h_j(t), \omega(t)\Big) - c_j\big(e_j(t), \omega(t)\big).$$

Note that these income and cost values are also potentially affected by random uncertainties $\omega(t)$ because of market price and cost (e.g. fuel) fluctuations.

Such an ecoviability framework integrating biodiversity, productive and profitability requirements helps overcome the apparent antagonism between ecology, often concerned with survival and conservation issues, and economic considerations, usually centered around the pursuit of optimality and profitablity (see below). In the bio-economic context, strong links have been shown to exist between viability approaches and notable steady states such as Maximum Sustainable Yield (MSY) or Maximum Economic Yield (MEY) (Béné *et al.*, 2001), the Rawlsian 'maximin' approach (Doyen & Martinet, 2012) or precautionary approaches (DeLara *et al.*, 2007). A key mathematical tool for the analysis of viability is provided by the so-called viability kernel as illustrated by figure A.4 in the Appendix. The viability kernel corresponds to a safe space within the initial set of constraints where the system needs to remain to be viable and to remain so in the future. It exemplifies the need for anticipating viability crisis.

In contexts where uncertainties have a probabilistic nature, bio-economic viability can be defined as the fulfillment of constraints with a high enough probability (Doyen & De Lara, 2010); namely

$$\mathbb{P}\big(\text{Constraints } (3), (4), (5) \text{ are fulfilled for } t = t_0, .., T\big) > \beta \qquad (6)$$

where β corresponds to some prescribed confidence rate (99%, 90%, ...) and where the probability $\mathbb{P}$ is computed with respect to the uncertainty ω which summarizes stochasticities on communities dynamics (growth, species interactions), catchabilities or technical interactions, costs or prices.

2.3 Fishing scenarios

We assume that the historical trajectories of the system are given by a sequence of states $x(t)$ and controls $e(t)$ until a current time denoted by t_0. By contrast, effort scenarios consist in sequences $e(t_0), \ldots, e(T)$ from current time t_0 to horizon T (typically $T = 2050$).
The first scenario of interest for the analysis is the 'baseline' (or status quo) scenario (SQS), where the control remains fixed at the level it is at t_0:

$$\textbf{SQS:} \qquad e(t) = e(t_0) \text{ for } t = t_0, .., T \tag{7}$$

The second scenario considered is the scenario that aims at maximizing the expected net present value of fishery returns. This scenario, denoted by NPVS is defined as follows:

$$\textbf{NPVS:} \qquad \max_{e(t_0),\ldots,e(T)} \textsc{npv}(e) \tag{8}$$

where net present value $\textsc{npv}(e)$ of a scenario of efforts $e = e(t_0), \ldots, e(T)$ is defined by

$$\textsc{npv}(e) = \mathbb{E}\left(\sum_{t=t_0}^{T} \rho^t \sum_{\text{fleets } j} \text{Profit}_j(t)\right). \tag{9}$$

Here $\mathbb{E}$ refers to the expected value of returns with respect to uncertainty ω and ρ stands for the discount factor. The numerical method to compute this expected value and the optimal controls are detailed in the following section 2.4 devoted to metrics and in the Appendix A.1. Such a strategy turns out to be close to a dynamic MEY (maximum economic yield) strategy in the long run (Clark, 1990).

The third scenario, denoted hereafter by EVS, is the ecoviability scenario which corresponds to the strategy that maximizes the probability that the system remains viable from t_0 to horizon T with respect to the control (the fishing effort $e(t)$); namely

$$\textbf{EVS:} \qquad \max_{e(t_0),\ldots,e(T)} \mathbb{P}\big(\text{Constraints } (3), (4), (5) \text{ are fulfilled for } t = t_0, .., T\big). \tag{10}$$

Such a formulation points to the fact that the viability approach, in a stochastic context, consists in minimizing bio-economic risk or vulnerability. The appropriate effort strategies which ensure the viability of the system as solutions of the maximal viability problem (10) are given by feedback controls in the form of $e(t, x)$. This is due to the dynamic programming structure underlying the probabilistic viability problem, as stressed in Doyen & De Lara (2010). Such strategies enable adaptive management, accounting for uncertainties affecting the entire social-ecological system. The numerical method to compute this ecoviability probability value and the viable controls are detailed in the following section 2.4 devoted to metrics and in Appendix A.2. The scientific software SCILAB (`http://www.scilab.org/en`) has been used for both probabilistic simulations and optimization computations.

2.4 Ecological and economic metrics

This subsection introduces the metrics that will be used for the analysis and the comparison of the scenarios. The scores especially focus on ecological or economic viability probabilities and net present values ratio.

Net present value: The normative scenario NPVS defined in (8) is based on the expected net present value defined by

$$\mathrm{NPV}(e, \omega) = \sum_{t=t_0}^{T} \rho^t \sum_{\text{fleets } j} \mathrm{Profit}_j(t).$$

The numerical approximation of the expected value first relies on the mean over a finite number of replicates of the random variables $\omega(.)$ underlying the uncertainties. In other words, we consider the following K replicates $\omega_k(.)$ of random variables $\omega(.)$ over time $t_0, \ldots, T$

$$\begin{cases} \omega_1(t_0), \ldots, \omega_1(T) \\ \quad\quad\vdots \\ \omega_K(t_0), \ldots, \omega_K(T), \end{cases}$$

and we approximate the expected value by its mean over the K replicates as follows

$$\mathbb{E}_\omega \left(\mathrm{NPV}(e,\omega)\right) \approx \frac{1}{K}\sum_{k=1}^{K}\mathrm{NPV}(e,\omega_k).$$

In order to compare the different case studies, the net present values are homogenized in the sense that the ratio between the net present value of every scenario and the maximal net present value (related to the NPVS) is computed as follows:

$$\textsc{Inpv}(e) = \frac{\textsc{npv}(e)}{\textsc{npv}\left(e^{NPVS}\right)} \tag{11}$$

where net present value is defined in equation (9) and e^{NPVS} stands for the optimal effort of the net present value scenario NPVS. Thus this ratio Inpv is smaller than 1 in every case study. It takes the value 1 for the NPVS effort strategy.

Viability probability scores: The ecoviability probability underlying scenario EVS defined in (10) is computed in a similar way using the fact that the probability is the expected value of an indicator (boolean) function. More specifically, we rewrite the viability probability as follows

$$\mathbb{P}\big(\text{Constraints } (3), (4), (5) \text{ are fulfilled for } t = t_0, .., T\big) = \mathbb{E}\left[\prod_{t=t_0}^{T}\mathbf{1}_C(x(t), e(t), \omega(t))\right] \tag{12}$$

with the indicator function

$$\mathbf{1}_C(x, e, \omega) = \begin{cases} 1 & \text{if constraints } (3), (4), (5) \text{ are satisfied} \\ 0 & \text{otherwise.} \end{cases}$$

Ecological viability probability $\mathbb{P}\big(\text{Constraint (3) are fulfilled for } t = t_0, .., T\big)$ and economic viability probability $\mathbb{P}\big(\text{Constraints (5) are fulfilled for } t = t_0, .., T\big)$ that will be used in the comparison of scenarios are particular instances of the general viability probability computed in (12).

Biodiversity metrics The ecological viability probability relies on biological, ecological or biodiversity indicators. The choice of biodiversity metrics remains the subject of numerous debates, with indicators ranging from structural indices, taxonomic or functional indicators to emblematic species. Regarding ecoviability studies for stylized models involving global biomass or abundances of species, the species richness index, the marine trophic index and the Simpson indicator have been used. The species richness denoted by SR is computed as follows:

$$\mathrm{SR}(t) = \sum_i \mathbf{1}_i(x_i(t)), \tag{13}$$

with the boolean function

$$\mathbf{1}_i(x) = \begin{cases} 1 & \text{if} \quad x \geq B_{\lim,i} \\ 0 & \text{otherwise.} \end{cases}$$

The marine trophic index MTI(t) of an ecosystem is computed as follows

$$\mathrm{MTI}(t) = \frac{1}{N(t)} \sum_{i=1} T_i N_i(t) \quad \text{with abundances } N_i(t) = \frac{x_i(t)}{\upsilon_i} \tag{14}$$

where υ_i is a fixed average weight by species and T_i is the trophic level of species i. The Simpson index SI complements the SR index by estimating the probability that two individuals belong to the same family or species.

For structured models, the use of indicators associated with the ICES precautionary approach and thresholds for the spawning biomass of fish populations gave important insights into the risks of stock collapse.

3 Results as a synthesis of different case studies

Ecoviability approach, models and scenarios constitute the original contribution of the paper. This section shows in particular the interest of such ecoviability modeling to operationalize EBFM by bringing together and comparing the bio-economic models and viability scenarios of four contrasted case studies including the small-scale fishery of French Guiana (South America), the small-scale fishery of Solomon Islands (Pacific), the Bay of Biscay multi-species demersal fishery (Europe) and the Northern prawn fishery of the Gulf of Carpenteria (Australia). In this section, the different case studies and EBFM contexts are first presented. Then the formalization of the viability modeling approach for all case studies is described. The specific features of the systemic and mechanistic models as well as the specific viability constraints related to the four case studies are then listed. Bio-economic performances of viability scenarios for two case studies are then compared graphically. Then it is shown how implementing a viability strategy can lead for the four case studies to 'win-win' situations in terms of reduction of ecological and economical risks. The paper also highlights some important differences of ecoviability scenarios between more heavily regulated and less regulated fisheries in terms of economic risk as well as effort reallocation. The viability models, scenarios and performances of these examples are detailed in Doyen *et al.* (2012); Gourguet *et al.* (2013, 2014, 2015); Cissé *et al.* (2013, 2015); Hardy *et al.* (2013).

3.1 Case studies

The geographical diversity of the four case studies involved in the analysis, ranging from South America, Pacific, Europe to Australia, is useful to obtain generic findings. The following paragraphs briefly describe the major features of these fisheries. Particular emphasis is put on ecosystem challenges for these fisheries following Pitcher *et al.* (2009). While achieving EBFM is a major objective for fisheries worldwide, these case studies exemplify the extent to which the degree of EBFM implementation can significantly vary across countries. In that regard, the description of the main differences and common features between these four case studies is informative (Table 1). In particular, two groups can be distinguished: small scale (and coastal) fisheries in Solomon islands and French Guiana; large scale (and more industrial) fisheries for the Bay of Biscay and the Northern Prawn Fisheries.

French Guiana Fishery: The small-scale fishery operating along the coast of French Guiana in South America is a multi-species and multi-fleet fishery landing about 3 000 tonnes per year worth €9 million (≈ US$ 9.78 million). Daily bio-economic data have been recorded by IFREMER since 2006 (Cissé *et al.*, 2013). The fishery, which is highly diverse with about 30 exploited species such as weakfish species (*Cynoscion acoupa, C. virescens, C. steindachneri*, Sciaenidae), sea catfish species (*Sciades proops, S. parkeri, Notarius grandicassis*, Ariidae), grunts (*Anisotremus surinamensis, Genyatremus luteus*, Haemulidae), snooks (*Centropomus undecimalis, C. parallelus*, Centropomidae), Giant grouper (*Epinephelus itajara*, Serranidae) and shark plays a key socio-economic role for the local population, both in terms of livelihood and food security. Recent demographic projections however indicate a likely doubling of the local human population by 2030. Demand for local fish is therefore expected to increase substantially, with some potential risk for the sustainability of the fishery and the local ecosystem's biodiversity. The evaluation based on the Rapfish method proposed in Cissé *et al.* (2014) of the status of this coastal fishery in terms of EBFM rates it a medium score and points to areas of potential improvement among which discarding and capacity building of the supply chain are important.

Bay of Biscay Mixed Fishery: The Bay of Biscay demersal fishery is a multi-fleet, multi-gear fishery targeting several species including Norway lobster (*Nephrops norvegicus*, Nephropidae), European hake (*Merluccius merluccius*, Merlucciidae), Anglerfish and Blackbellied anglerfish (*Lophius piscatorius* and *L. budegassa*, Lophiidae) and Common sole (*Solea solea*, Soleidae) with high commercial values (Gourguet *et al.*, 2013). Its turnover amounted to € 200 million (≈ US$ 217 million) in 2009. The fishery, however, is under strong pressure, with several stocks already fully exploited. The fishery also operates within a context of high uncertainty with regard to economic costs and biological dynamics. Additional management complexities are induced by the many technical interactions associated with the multi-fleet nature of the activities (trawlers, gillnets). Maintaining the bio-economic sustainability of these different components is thus difficult. A multi-annual management plan based on the recent European Common Fisheries Policy (CFP) reform aims to achieve Maximum Sustainable Yield for all stocks before 2020 subject to economic and social viability constraints. In addition, implementing the recently adopted landing obligation (decided at the European scale) is a major challenge for this mixed fishery. The fishery is managed by technical measures, access and quota regulations. Pitcher *et al.* (2009) globally scored France a ' fail grade' in their evaluation of progress in implementing EBFM.

The Australian Northern prawn fishery: The Northern prawn fishery is one of Australia's most valuable fisheries in terms of total landed value with AU\$ 91.6 million ($\approx$ US\$ 71 million) in 2009-2010 involving 52 trawlers since 2007 (Punt *et al.*, 2010). This multi-species and multi-fishing strategies trawl fishery targets several high-value species of tropical prawns, each with different dynamics and levels of biological variability. The bulk of revenue is obtained from high-valued but rather unpredictable white banana prawns (*Fenneropenaeus merguiensis*, Penaeidae) and two species of tiger prawns (Grooved tiger prawn, *Penaeus semisulcatus*, and Brown tiger prawn, *Penaeus esculentus*, Penaeidae). The fishery's management objective is to maximize economic yield, while accounting for biodiversity impacts. According to Pitcher *et al.* (2009), Australian fisheries are well advanced in achieving EBFM. Furthermore, in certifying the Northern prawn fishery in November 2012, the MSC (Marine Stewardship Council) acknowledged efforts to limit fishing impacts on the ecosystem, although some concerns remain. Indeed, while the mandatory introduction of Turtle Excluder Devices (TEDs) and By-catch Reduction Devices (BRDs) played a major role in the MSC accreditation by significantly reducing by-catch species such as turtle, syngnathid and sawfish, it only reduced the catches of sea snakes by 5%.

Solomon Islands Fishery: Solomon Islands are located at the extreme east of the coral triangle in the Pacific. This region shelters the highest level of marine biodiversity in the world (Burke *et al.*, 2012). The most recent Solomon Islands biodiversity assessment for instance accounted for more than one thousand fish species for these islands (Green *et al.*, 2006). While nearly all coastal dwellers fish for subsistence and self-consumption, an increasing number of them now also engage in income-generating fishing activities. The most recent value of Solomon catches (Brewer, 2011) estimates it at US\$ 21 million. This dual function (subsistence and cash-generation) makes small-scale coastal fisheries a crucial element of the local socio-economic system. Yet, the population of Solomon Islands has doubled in the last 20 years. This demographic trend and the subsequent increase in demand for fish, along with the increased marketing of the output impose a growing pressure on marine resources and on the local ecosystem. The pressure is especially strong on some key species such as groupers (*Serranidae*), parrotfish (*Scaridae*) and particularly on sea-cucumbers' species (*Holothuroidea*). To deal with such issues, a community-based approach (Govan *et al.*, 2009) in line with the implementation of EBFM has been promoted for the last 30 years. In that respect, WorldFish Center (2010) shows several lessons of successful applications of EBFM in the main islands of the country.

3.2 Formalization and calibration of models for the case studies

The formalization of the four different bio-economic models used for the viability analyses has been carried out following the generic modeling framework described in Section 2 and especially the multi-species multi-fleet stochastic dynamics (1). However, beyond this common mathematical framework, two different approaches have been used regarding this formalization: For the case studies of demersal mixed fishery of the Bay of Biscay and the Northern prawn fishery in Australia, models were derived from available structured models (in class or age). In Solomon Islands and French Guiana case studies for which no assessments were available, stylized bio-economic models based on the global biomass of species (or groups of species) were developed. The specific features of the systemic and mechanistic models related to the four case studies are detailed in the four paragraphs below. They are also listed and compared in Table 2. More mathematical details on the models are also provided in Appendices A.3, A.4, A.5 and A.6.

The parameterization of the four different models has also been achieved following two distinct approaches. For the case studies of demersal mixed fishery of the Bay of Biscay and the Northern prawn fishery in Australia, calibrations were derived from available stock assessments and economic data. In Solomon Islands and French Guiana case studies for which no assessments were available, specific stock and bio-economic models were developed and fitted to the available data. To validate the models and to show to what extent the estimated trajectories fit the observed trajectories, graphs are displayed in the Appendix sections A.3, A.4, A.5 along with figures A.1, A.2, A.3. A comparison of the estimated parameters, their number and underlying data is provided at the bottom of Table 2.

French Guiana: The fishery population dynamics model used in this case is a multi-species, multi-fleet dynamic model in discrete time (Cissé *et al.*, 2013, 2015). The model accounts for trophic interactions between 13 exploited species and a fourteenth stock aggregating other marine resources. The biomass of the species are assumed to be governed by a complex dynamic system based on Lotka-Volterra trophic relationships and fishing effort of the different fleets. Daily observations of catches and fishing efforts from the landing points all along French Guiana's coast, available from January 2006 to December 2009, were used to calibrate the model. Estimations of the parameters were carried out using a least-square method minimizing the distance between observed and estimated catches. Data from the literature (Leopold, 2004) and Fishbase (`http://www.fishbase.ca/`) were used to provide qualitative trophic information concerning the sign of the relationship between species and intrinsic growth rates, and to initiate parameter estimations.

Demersal mixed fishery of Bay of Biscay: As detailed in Doyen *et al.* (2012) and Gourguet *et al.* (2013), population dynamics of the three species included in the analysis (hake, nephrops and sole) were modeled using an age-structured population model. Parameters were derived from stock assessments carried out by ICES (2009) using a virtual population model (Darby & Flatman, 1994; Shepherd, 1999). The dynamic model was then fitted for each species separately, using data on catch and abundance from surveys or derived from commercial CPUEs.

Northern prawn fishery of Australia: As described in Gourguet *et al.* (2014) and Gourguet *et al.* (2015), three species of prawns were modeled using a size-structured population model that operates on a weekly time-step. The parameters of this multispecies population model were estimated using data on catches and effort, catch rates, as well as length frequency data from both surveys and commercial landings (Punt *et al.*, 2010).

Solomon Islands: As in the French Guiana case study, the states of the stock are defined in terms of the global biomass of different groups of species. The model is a multi-group, multi-fleet dynamic model (Hardy *et al.*, 2013) which accounts for trophic interactions between exploited species. The dynamics of the 8 groups included in the model is described through a Lotka-Volterra trophic model accounting for fishing mortality from the several fleets involved in the fishery. Different sources of information were used to parameterize the model. For the sea cucumber and coral fish groups, parameters were calibrated based on data extracted from the literature including Green *et al.* (2006) and FishBase. The parameterization of the model for skipjack was carried out in two steps. First, a Western Pacific assessment (Langley & Hampton, 2008) was used to estimate the industrial fishery's parameters. Then, the model including all fleets (industrial and artisanal) was fitted to data on catches from 1982 to 2006.

3.3 Viability constraints of the case studies

The different types of constraints applied to the four case studies presented in section 3.1 are also compared (Table 3). Some of the viability constraints such as profitability constraints are common to the four case studies, while others such as food security are specific to French Guiana and Solomon Islands. The ecological constraints also differ between structured models in Bay of Biscay or Northern prawn fishery where viability relies on precautionary thresholds for stock biomass while more stylized models in French Guiana or Solomon Islands are based on biodiversity metrics. Mathematical details regarding these viability constraints are also provided in Appendices A.3, A.4, A.5 and A.6.

3.4 Ecoviability scenarios

As illustrated in figure 1 for the example of the Bay of Biscay and in figure 2 for French Guiana case, eco-viable strategies satisfying dynamics in equation (1) and objectives specified in equation (10) were identified for the four case studies. The blue diamond lines represent the estimated historical paths while the viability thresholds are indicated in red triangle lines. The envelop of all possible simulated trajectories accounting for the uncertainties is represented by the dark dotted lines and the grey areas include 95% of the trajectories. The green (full) line within the grey zone is one particular trajectory associated with one specific random selection. The shocks underlying figures 1 and 2 are due to the change of fishing efforts induced by ecoviability strategies: for the Bay of Biscay, the change occurs at the beginning of the scenario namely 2009 while, in French Guiana, the efforts are modified in 2011 and then in 2026 as a revision of decisions is applied after 15 years. The figures illustrate how every ecological-economic constraint is satisfied with a very high probability over time despite the complexities and uncertainties affecting the social-ecological system.

3.5 Viability performances of scenarios

The ecological and economic viability probabilities of the status quo (SQS), net present value (NPVS) and ecoviability (EVS) scenarios are displayed and compared for the four case studies in figure 3. The graph shows that the status quo strategies SQS (grey granite dots) as defined in equation (7) do not adequately cope with bio-economic risks in general in the sense that these SQS offer only a low probability of meeting either the socio-economic viability constraint for Bay of Biscay and French Guiana or both ecological and economic constraints for Solomon Islands. The Northern prawn fishery is the only case displaying good scores from the viewpoint of both ecological and economic risks since viability probabilities are close to 100%.

We also note that, in all case studies, ecoviability strategies EVS (blue degraded dots) reduce ecological and economic risks, as compared to the SQS. The mitigation of ecological and economic risks through ecoviability strategies EVS is not surprising since this EVS relies on the maximization of the ecoviability probability. However, the magnitude of the viability gains between EVS and SQS is not straightforward and varies according to the case study. In the example of the Bay of Biscay fishery, the EVS leads to a strong increase in the probability that socio-economic constraints will be complied with. This improvement is slightly smaller for the French Guiana fishery. In Solomon Islands, the EVS leads to the strongest gain in the management of both ecological and socio-economic risks. In the Northern prawn fishery, the viability benefits are limited because the SQS already performs well as already pointed out. The viability probability metrics thus provide informative and synthetic multi-attribute criteria to grade the case studies in terms of EBFM. Moreover, the improvement associated with lowering bio-economic and ecosystem risks decreases with the level of regulations already in place in these fisheries: the Northern Prawn and the Bay of Biscay fisheries which are characterized by higher levels of regulation than the French Guiana and Solomons Islands fisheries show lower bio-economic and ecosystem risk reductions than those two other fisheries. This finding is likely due to the fact that the regulatory frameworks already in place have been successful at reducing some elements of these economic and/or ecological risks. For instance, fisheries in the Bay of Biscay are managed by targeting MSY (Maximum Sustainable Yield) (ICES, 2009), while the Gulf of Carpenteria prawn fishery is managed with a MEY (Maximum Economic Yield) goal

(Gourguet *et al.*, 2014).

3.6 Synergy or tradeoff between risk and economic expectations

The trade-offs between ecoviability and expected economic scores are investigated in figure 4. More specifically, the figure compares the scenarios according to both their ecoviavility probability and their mean economic performance in terms of net present values. From its very definition, the ecoviability strategies EVS provide the largest probability for the fisheries to be eco-viable. More interestingly, we note in figure 4 a) focusing on the two cases of small-scale fisheries (French Guiana and Solomon Islands) that these EVS strategies also involve an increase in mean annual economic performance of the fishery as compared to the status quo SQS. French Guiana and Solomon Islands therefore appear to offer potential win-win strategies compared to the current situations. In contrast, as displayed in figure 4 b) focusing on large scale fisheries, the pursuit of ecoviability strategies in the Northern prawn fishery entails a trade-off between co-viability and expected economic performance: meeting the inter-annual economic constraint of positive profits in the Northern prawn fishery can only be achieved through a reduction in the net present value. The case of Bay of Biscay is intermediary in the sense that adopting an EVS strategy is a 'win-noloss' situation as compared to the SQS because enhancing the bio-economic viability is not detrimental to net present value. The global trade-off is even more apparent when comparing the ecoviability strategies with the strategy aimed at maximizing the Net Present Value of profits in the fishery (NPVS, red circle): in all four case studies, the pursuit of ecoviability objectives entails lower mean returns than those which would be achieved by NPVS strategies. Such a trade-off strongly relates to the mean-variance analysis, intensively used in portfolio theory and finance, stressing the antagonism between mitigating risks and promoting the mean (or expected) performances. Such a result exemplifies the idea that an EBFM relying on viability probability criteria and on the mitigation of ecological-economical risks significantly differs from bio-economic maximizing strategies underlying the net present value (NPVS), or economic yield (MEY).

3.7 Viable effort or vessels reallocation

Ecoviability conditions were achieved in each case by adjusting the fleet fishing effort. The control in the Bay of Biscay and the Australian case studies correspond to capacity adjustments in the number of vessels, assuming that the fishing time per vessel remains constant. In both the Solomon and the Guiana case studies, the adjustment takes place at the level of fishing time per vessel or per fisher, assuming that the numbers of vessels/fishers in the fisheries remain stable.

Results differ according to the case studies and constraints. The efforts associated with the ecoviability scenarios for the four case studies are detailed in Doyen *et al.* (2012); Gourguet *et al.* (2013, 2014, 2015); Cissé *et al.* (2013, 2015); Hardy *et al.* (2013) and summarized in Table 4. It turns out that, in the Bay of Biscay and the Australian cases, ecoviability was achieved by decreasing the capacity of the fleets (decrease in the number of vessels) while in both the Guiana and Solomon examples, bio-economic viability was obtained by both increasing global fishing effort and reallocating it between the different metiers. For instance, in Solomon islands, the viability scenario relies on an important increase of the small-scale (inshore) tuna fishery combined with reductions in sea-cucumber and reef fish fisheries. The global growth of efforts obtained for the ecoviability of the two small-scale fisheries is mainly due to the food security constraint implying increased global fishing intensities in the future. In Solomon Islands, the use of FADs (fish aggregating devices) for skipjack tuna is also favorable to sustainability, stressing the importance of technological innovation in enabling a re-allocation of effort towards more sustainable levels per fish stock (Hardy *et al.*, 2013). More globally, ecoviability induces global reallocations of fishing efforts due to an integrated, multi-species multi-fleet framework well aligned with the holistic objectives of EBFM.

4 Discussion

4.1 Ecoviability is globally well suited to EBFM.

The central contribution of the paper is to synthesize the potential of the ecoviability modeling approach to operationalize EBFM through different and contrasted case studies. We discuss this assertion with respect to the three items proposed in Pitcher *et al.* (2009); Ward *et al.* (2002), namely EBFM principles, EBFM criteria and EBFM implementation, to assess the performances of fisheries with respect to the ecosystem approach.

In terms of EBFM principles, the ecoviability approach globally performs very well. A central feature of the approach is indeed to suppose that ecosystems are complex, dynamic, that their attributes and boundaries are constantly changing, in particular as they relate to the interactions with human uses. Consequently a central aim of ecoviability is to maintain the structure and function of ecosystems, including the biodiversity and productivity of natural systems. Thus it clearly reverses the order of management priorities so that management starts with the ecosystem rather than one target species. We discuss these EBFM principles and issues in a more detailed way in the following subsection 4.2 devoted to models of intermediate complexity. Another principle for EBFM requires human use and values of ecosystems to be central to establishing objectives for the use and management of natural resources. In that respect, the ecoviability approach considers that natural resources are best managed within a system based on a shared vision and a set of ecological and socio-economic targets or constraints developed amongst stakeholders. These multi-attribute and bio-economic principles of EBFM are examined in more detail in the following subsection 4.3 dedicated to sustainability and the triple bottom line. Furthermore, viability management is adaptive through feedback controls especially accounting for uncertainties. This EBFM principle is discussed in the subsection below 4.4 focusing on adaptive management.

In terms of EBFM criteria, the ecoviability approach also performs well. First viability scenarios account for the policy and societal framework at play in every case studies in the sense that management reflects national and international goals, objectives and constraints relating to both conservation and sustainable use. Second, the social, economic and cultural context of the fishery is incorporated by relying on acceptable bio-economic thresholds, tipping points and precautionary boundaries. These dimensions are investigated in the following subsection 4.6 devoted to decision making for fisheries management. In particular ecological values are incorporated through biodiversity or biological viability constraints. This last issue is examined in subsection below 4.5 related to the choice of biodiversity metrics. Furthermore, viable management relies on the knowledge of utilized species through calibrated and dynamic models. Thus the resource management system is comprehensive and inclusive, based on reliable data and scientific knowledge. Again this is explained in 4.2 dealing with models and complexity. Finally environmental and economic externalities are incorporated especially through stochasticities as elaborated in the subsection 4.4.

Lastly, regarding EBFM implementation, we cannot assess this meaningfully in the case studies as ecoviability management strategies are not currently in place. French Guiana could provide however a good test-case in that regard in the future, as the implementation of such a strategy is in progress with stakeholders. In the Bay of Biscay, ingredients of ecoviability are also integrated in current management since socio-economic viability constraints are indeed balanced with MSY targets in practical management decision-making (Gourguet *et al.*, 2013). More globally, we discuss possible improvements of the approach in terms of implementation in subsection 4.7 regarding the need to integrate more clearly technical change within the models and scenarios. In subsection 4.8, we highlight the need to account for other management tools such as quotas or protected areas.

4.2 Ecoviability allows models of intermediate complexity adapted to EBFM

The need to take into account the complexity of fisheries management problems especially in the context of EBFM is now broadly recognized (Pahl-Wostl, 2007). Research and the case studies presented here show that this can be done using an integrated, systemic modeling approach that seeks to capture realistic features of marine social-ecological systems, but including only the strictly necessary level of complexity. Such an approach based on multi-species, multi-fleets dynamic models is in line with 'models of intermediate complexity' (MICE) as discussed in Plagányi *et al.* (2014). MICE models such as those examined here make it possible to address the ecosystem approach at intermediate scales between analytically tractable models used to identify MEY-MSY approaches for single stocks, and higher dimensional and numerical models attempting to capture the 'end-to-end' complexity of the social-ecological system at play. The latter models are usually characterized by a more limited ability to derive the mathematical properties of the system under consideration and may appear as 'black boxes'. MICE being 'question-driven', these models will tend to limit the complexity to only account for those components of the social-ecological system required to address specific management issues. The viability approach applied has hitherto largely been focused on stylized/simplified models, to allow for analytical solutions. The applied work presented here demonstrates however the applicability of the viability approach to more realistic representations of fisheries systems, taking account of their complexities and dynamics, notably via numerical simulations.

4.3 Ecoviability directly deals with sustainability

The ecoviability modeling framework used here involves an integrated, multi-functional and multi-criteria approach in line with EBFM as in Béné *et al.* (2001); Doyen *et al.* (2012); Pereau *et al.* (2012); Thébaud *et al.* (2014); Krawczyk *et al.* (2013); Maynou (2014). A wide range of stakeholders are involved in fisheries and their management, including industrial, artisanal, subsistence and recreational operators, suppliers and workers in related industries, managers, environmentalists, biologists, economists, public decision makers and the general public. Each of these groups has an interest in particular outcomes from fisheries and marine ecosystems, and the performances that are considered desirable by one stakeholder may sound less desirable for another (Hilborn, 2007). Considering this multi-attribute nature of marine fisheries management is a way to guarantee a feasible and acceptable exploitation of aquatic resources, enabling the conditions for sustainability from economic, environmental and social viewpoints as stressed by Pope (1983). The present work is fully aligned with these considerations and the triple bottom line nature (Brooks *et al.*, 2015) of sustainable development, as well as the multi-objective principles stressed in EBFM. Moreover the use of thresholds, precautionary limits, reference or tipping points underlying viability goals results in a simple and operational way to characterize the safety and sustainability of marine ecosystems and fisheries.

Furthermore, by focusing on viability, the models presented in this paper exhibit management strategies and scenarios that account for intergenerational equity. This is another important ingredient of sustainability and sustainable uses of ecosystems underpinning EBFM. As emphasized in Doyen & Martinet (2012), viability is closely related to the maximin (Rawlsian) approach which gives key insights into intergenerational equity (Heal, 1998). In this respect, the ecoviability strategies and scenarios link present and future performances, the various bio-economic constraints being equally binding through time. This offers a substantial progress compared to purely economic-oriented strategies such as the NPVS approach, which involves discount factors and generally favor present or short-term performances. This result is particularly illustrated in Gourguet *et al.* (2013); Cissé *et al.* (2013); Hardy *et al.* (2013) related to the case studies examined in this paper.

4.4 Ecoviability provides an adaptive management with respect to uncertainties

Accounting for uncertainties is a major challenge in ecosystem management. Uncertainties may concern data measurements, ecological dynamics (climate variability, environmental stochasticities) and anthropogenic dynamics (price variability, compliance, etc.). The use of stochastic or probabilistic viability (Doyen & De Lara, 2010) as detailed in equation (10) provides a solid and rigorous framework for detailed analyses of bio-economic risks, vulnerabilities and ecosystem sustainability. In that vein, Gourguet *et al.* (2013); Mouysset *et al.* (2014) stand as important illustrations. In addition, as stochastic viability is based on dynamic programming, it provides closed loop (feedback) controls which enable adaptive strategies and scenarios with respect to possible future states. Adaptability is also possible due to the multi-valued nature of viable management strategies that focus on sets of possible strategies in contrast to optimal control or equilibrium approaches which are usually unique or deterministic, and therefore less flexible.

4.5 Ecoviability can capture the dynamics of biodiversity

The ecosystem approach requires the use of biodiversity indicators to assess the ecological states of communities and ecosystems, to track their temporal or spatial changes and finally to identify drivers of changes. Unfortunately the choice of biodiversity metrics remains the subject of numerous debates, with indicators ranging from structural indices, taxonomic or functional indicators to emblematic species. For instance, analyzing the ecological state of lakes, Allen *et al.* (1999) concluded that the taxonomic diversity index was an ambiguous indicator of biological integrity when used alone. This conclusion may be broadened to structural indicators in the case of marine fish communities (Blanchard *et al.*, 2001). In the case of marine fisheries, the relevance of functional indicators such as the marine trophic level index and the average maximal size in the community to detect some ecosystem effects of fishing can also be questioned (Blanchard *et al.*, 2005).

Regarding ecoviability studies, the species richness index, the marine trophic index and the Simpson indicator have been used, especially in the Guiana (Cissé *et al.*, 2013) and Solomon Islands (Hardy *et al.*, 2013) case studies. For the Bay of Biscay and the Gulf of Carpenteria, the use of indicators associated with the ICES precautionary approach and thresholds for the spawning biomass of fish populations gave important insights into the risks of stock collapse. More generally, it turns out that it is the combination of several ecological indicators, structural and functional, instead of one unique universal biodiversity criterion that seems relevant to evaluate the state of fish megafauna. In this respect, the multi-attribute nature underlying the ecoviability approach has led to major advances strongly connected with criteria requirements for EBFM. Indeed, this multi-criteria approach has been shown to facilitate the comparison of alternative management options in cases where there may be uncertainty, and even disagreement, regarding the selection of not only the indicators of system viability, but also of the thresholds that define the viability space (Thébaud *et al.*, 2014).

4.6 Ecoviability can represent the short term vs. long term choices

As demonstrated on figures 1 and 2, the viability approach has allowed the identification of strategies, through reallocation of fishing effort, that create or increase the social-ecological systems viability over a certain period of time. French Guiana and Solomon Islands case studies however also suggest that this viability can be maintained only for a limited number of years: 25 years in French Guiana (Cissé *et al.*, 2015), 35 years in Solomon Islands (Hardy *et al.*, 2013). The two case studies therefore underline the long-term serious problem faced by these territories which are already under intense demographic pressure. Based on the results of these analyses, it appears that the mid-century population will be too high for the resource available, and that even the options/innovations envisaged (e.g. the reallocation of a greater share of the fishing effort toward the tuna resource through the introduction of FADs in Solomon Islands) will eventually reach their limits. The 2050 decade is therefore likely to constitute a tipping point for these islands under the assumption of constant demographic growth and current consumption habits.

Solomon Islands and French Guiana will therefore face important challenges -for which (even) the viability approach seems challenged to find endogenous solutions. The marine resources of these territories have a natural productivity limit which will eventually be reached unless an overall dynamics shift occurs toward another regime. In our case, one possible shift is related to demographics. In Solomon Islands, the hypothesis that such a shift might occur is not totally unrealistic as data indicates that the local demography seems to decrease by 15% every decade. In French Guiana, however, the recent Census suggests that such a change is not yet happening (Cissé *et al.*, 2013). Such structural constraints, including demographic or technological, stress the need for the ecoviability approach to adopt a more adaptive framework in line with MSE (management strategy evaluation) accounting.

4.7 Ecoviability can allow underlining the role of technical change

As noted in Squires & Vestergaard (2013a,b), technical change in fisheries is a major driver of the sustainability and viability of both fisheries and marine ecosystems and has to be integrated into models aiming at operationalizing EBFM. Technological innovation in the long term will affect not only the dynamics of the system but also alter and modify the ecoviability constraints. These changes will possibly create more viability space in the way it has occurred with the introduction of FADs in Solomon Islands (Hardy *et al.*, 2013). In other cases, however, economic and technological changes may restrict this viability space. Gourguet *et al.* (2013) for instance show how in the case of the Bay of Biscay, the projected increase in fuel price leads to a decrease in the general viability of the fisheries.

More generally, the very general systemic, mechanistic and dynamic framework underlying equation (1) potentially allows for the introduction of capital dynamics and accounting for technological changes. In that respect, viability works proposed in Doyen & Martinet (2012) already stress the role played by technical change and substitution between capital and natural resources through the analysis of the Dasgupta-Heal-Solow model. One can also argue that the stochasticity introduced in the models for the economic parameters (prices, costs) is a way to partially capture the technical uncertainties.

4.8 Ecoviability can rely on many fisheries management tools

At this stage, it is worth stressing that other management controls should be investigated to address and operationalize EBFM. To keep models simple, the emphasis in this paper has been on fishing effort controls. However, the disadvantages of regulations relying on effort and especially situations of technological creep on fishing effort and fishing mortality are well-known (Wilen, 1979). Consequently, alternative managements based for instance on catch quotas, transferable quotas (Chu, 2009) or marine reserve should be taken into account and examined in the viability, co-viability or ecoviability framework. This has been done in others papers and for other case studies showing that the viability modeling framework is flexible enough to cope with such important management issues for the ecosystem approach. For instance DeLara *et al.* (2012) deal with harvesting quotas while Pereau *et al.* (2012) address ITQ management systems. Marine Protected Areas are investigated in Doyen *et al.* (2007). A simple change enabling the movement from effort and input controls to catch and output controls consists of using Schaeffer or Cobb-Douglas production functions. But this can be more complicated in multi-species and multi-fleet contexts and in situations with non-compliance. In Pereau *et al.* (2012), the modeling principle is that the effort of agents (fishers or fleets) is adjusted in a rational way (through optimization of rents) to comply with the level of harvesting quotas supply. For the Bay of Biscay and French Guiana case studies, the implementation of such ecoviability goals and approach associated with catch quota regulation strategies is an ongoing work.

5 Conclusions

This paper has shown the extent to which the operationalization of EBFM via ecoviability modeling of management strategies and scenarios can be relevant. From a methodological point of view, major advances have recently been made regarding the use of this approach to sustainability issues, in the contexts of multiple dimensional states (multi-species), controls (multi-fleet fishing) and criteria (ecological, social and economic scores). The use of stochastic viability modeling has also promoted a more realistic analysis of ecological-economic risks, vulnerabilities and social-ecological system sustainability. From the decision support viewpoint, identification of eco-viable scenarios in each case study provides important insights in terms of redistribution of fishing effort and conservation measures.

The paper especially highlights that adopting an ecoviability strategy can lead to 'win-win' situations in terms of mitigation of ecological and economical vulnerabilities as compared to the current situation. The paper also stresses some significant differences between more regulated and less regulated fisheries when comparing a viability strategy to the current state (status quo) in terms of economic expectation (mean) and risk (variance). For small scale fisheries, ecoviability turns out also to be a 'win-win' option as compared to the current situation. By contrast, a trade-off between economic expected value and risks is identified for large scale and regulated fisheries. In other words, implementing an ecoviability strategy for large scale and already regulated fisheries could be more difficult because some stakeholders could be reluctant to adopt such a strategy based on bio-economic risk mitigation.

Many stimulating challenges remain. The study of social-ecological system resilience using the tools of viability analysis appears particularly fruitful (Béné *et al.*, 2001; Deffuant & Gilbert, 2011) due to the insights it brings into recovery and restoration issues, and the ability of fisheries to cope with shocks. Moreover, a refined account of governance (Gutierrez *et al.*, 2011) and EBFM implementation issues through game theory in the context of multi-agent viability also appears very promising. Doyen & Pereau (2012); Pereau *et al.* (2012); Hardy *et al.* (2016) for instance show that coordination strategies or structures (cooperative, community-based management or transferable quota market for large scale fisheries) between agents may improve the bio-economic viability by inducing relevant changes in fishing efforts of different fleets. Although the models in the current examples focus on ecological and economic objectives, the viability models can also accommodate more social indicators as for instance in Pereau *et al.* (2012) where a participation goal for the agents is imposed. Moving from modeling and management based on input control (effort) to a management based on output control (catch) seems appropriate given the current issues in fisheries governance. At this stage, the comparison of ecoviability strategies with the MSY- MEY strategies that are commonly put forward at the international level should be strengthened. The development of spatially explicit models, as initiated in Thébaud *et al.* (2014), which integrate spatial controls of fishing pressure, including e.g. protected areas, is also an important goal for ecoviability modelers with respect to the operationalization of EBFM.

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References

Allen, A.P., Whittier, T.R., Kaufmann, P.R., Larsen, D.P., O'Connor, R.J., Hughes, R.M., Stemberger, R.S., Dixit, S.S., Brinkhurst, R.O., Herlihy, A.T., Paulsen, S.G. (1999) Concordance of taxonomic richness patterns across multiple assemblages in lakes of the northeastern United States. *Canadian Journal of Fisheries and Aquatic Sciences*, 56(5), 739-747.

Aubin, J-P. (1990) A survey of viability theory. *SIAM Journal on Control and Optimization*, 28(4), 749-788.

Baumgartner, S., Quaas, M.F. (2009) Ecological-economic viability as a criterion of strong sustainability under uncertainty. *Ecological Economics*, 68 (7), 2008-2020.

Banks, R., Clarke, S., Staples, D., Souter, D. (2012) *Australia Northern prawn fishery: Public Comment Draft Report.* MRAG Americas Inc, p. 397.

Béné, C., Doyen, L., and Gabay D. (2001) A viability analysis for a bio-economic model. *Ecological Economics*, 36, 385-396.

Blanchard, F. (2001) Dynamics of harvested demersal fish communities: analysis of the species diversity in the Bay of Biscay (Atlantic Ocean) and in the Gulf of Lions (Mediterranean Sea). *Aquatic Living Resources*, 14(1), 29-40.

Blanchard, J.L., Dulvy, N.K., Jennings, S., Ellis, J.E., Pinnegar, J.K., Tidd, A., Kell, L.T. (2005) Do climate and fishing influence size-based indicators of Celtic Sea fish community structure? *ICES Journal of Marine Science: Journal du Conseil*, 62(3), 405-411.

Brewer, T. D. (2011) Coral reef fish value chains in Solomon Islands: Market opportunities and market effects on fish stocks. ARC Centre of Excellence for Coral Reef Studies, James Cook University.

Brooks, K., Schirmer, J., Pascoe, S., Triantafillos, L., Jebreen, E., Cannard, T., Dichmont, C. M. (2015) Selecting and assessing social objectives for Australian fisheries management. *Marine Policy*, 53, 111-122.

Burke, L., Reytar, K., Spalding, M. D. (2012) Reefs at Risk Revisited in the Coral Triangle, World Resources Institute, Washington.

Butchart, S., Walpole, M., Collen, B., van Strien, A., Scharlemann, J., Almond, R., Baillie, J., Bomhard, B., Brown, C., Bruno, J., Carpenter, K. E., Carr, G. M., Chanson, J., Chenery, A. M., Csirke, J., Davidson, N. C., Dentener, F., Foster, M., Galli, A., Galloway, J. N., Genovesi, P., Gregory, R. D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M. A., McRae, L., Minasyan, A., Morcillo, M. H., Oldfield, T. E. E., Pauly, D., Quader, S., Revenga, C., Sauer, J. R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S. N., Symes, A.,Tierney, M., Tyrrell, T. D., Vié, J.-C., Watson, R. (2010) Global Biodiversity: Indicators of Recent Declines. *Science*, 328(5982), 1164-1168.

Chu, C. (2009) Thirty years later: the global growth of ITQs and their influence on stock status in marine fisheries, *Fish and Fisheries,* 10(2), 1467-2979.

Cissé, A. A., Gourguet, S., Blanchard, F., Doyen, L., Pereau, J.-C. (2013) A bio-economic model for the viable management of the coastal fishery in French Guiana. *Environmental and Development Economics*, 18(3), 245-269.

Cissé, A. A., Blanchard, F., Guyader, O. (2014) Sustainability of tropical small-scale fisheries: Integrated assessment in French Guiana. *Marine Policy*, 44, 397 - 405.

Cissé, A., Blanchard, F., Doyen, L., Pereau, J.-C. (2015) Ecoviability for small-scale fisheries in the context of food security constraints. *Ecological Economics*, 119, 39-52.

Clark, C. W. (1990) *Mathematical Bioeconomics*, second edn. New York: Wiley.

Clark, W. C., Mangel, M. (2000) *Dynamic State Variable Models in Ecology: Methods and Applications*, Oxford Series in Ecology and Evolution.

Cury, P., Mullon, C., Garcia, S., & Shannon, L. J. (2005) Viability theory for an ecosystem approach to fisheries. *ICES Journal of Marine Science*, 62(3), 577-584.

Darby, C.D., Flatman, S. (1994) Virtual Population Analysis: Version 3.1 (Windows-DOS) In: *User Guide* Vol. 1. Information Technology Series, MAFF Directorate of Fisheries Research, Lowestoft, pp. 85.

Deffuant, G., Gilbert, N. (2011) *Viability and Resilience of Complex Systems.* Springer.

DeLara, M., Doyen, L., Guilbaud, T., Rochet, M.-J. (2007) Is a management framework based on spawning-stock biomass indicators sustainable? A viability approach. *ICES Journal of Marine Science*, 64, 761-767.

De Lara, M., Ocana Anaya, E., Oliveros-Ramos, R., Tam, J. (2012) Ecosystem Viable Yields. *Environmental Modeling & Assessment*, 17(6), 565-575.

Doyen, L., DeLara, M., Ferrari, J., Pelletier, D. (2007) Sustainability of exploited marine ecosystems through protected areas: A viability model and a coral reef case study. *Ecological Modelling*, 208(2), 353-366.

DeLara, M., & Doyen, L. (2008) *Sustainable Management of Natural Resources: Mathematical Models and Methods.* Springer.

Doyen, L., DeLara, M. (2010) Stochastic viability and dynamic programming, Systems and Control Letters. 59, 10, 629-634.

Doyen, L., Martinet, V. (2012) Maximin, Viability and Sustainability. *Journal of Economic Dynamics and Control*, 36(9), 1414-1430.

Doyen, L., Pereau, J.-C. (2012) Sustainable coalitions in the commons. *Mathematical Social Sciences*, 63(1), 57-64.

Doyen, L., Thébaud, O., Martinet, V., Gourguet, S., Béné, C., Bertignac, M., Fifas, S., Blanchard, F. (2012) Stochastic viability to ecosystem-based management of multi-species fisheries. *Ecological Economics*, 75, 32-42.

Doyen, L., Cissé, A., Gourguet, S., Mouysset, L., Hardy, P.-Y., Béné, C., Blanchard, F., Jiguet, F., Pereau, J.-C. and Thébaud, O. (2013) Ecological-economic modeling for the sustainable management of biodiversity. *Computational Management Science*, 10, 353-364.

Eisenack, K., Scheffran, J., Kropp, J.P. (2006) Viability analysis of management frameworks for fisheries. *Environmental Modeling Assessment*, 11, 69-79.

FAO (2003) The ecosystem approach to fisheries. *FAO Technical Guidelines for Responsible Fisheries* 4, Suppl. 2. FAO. 112 pp.

FAO (2013) *FAO Statistical Yearbook 2013*, FAO, Rome.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., Toulmin, C. (2010) Food Security: The Challenge of Feeding 9 Billion People. *Science*, 327(5967), 812-818.

Gourguet, S., Macher, C., Doyen, L., Guyader, O., Thébaud, O. (2013) Bio-economic modeling for the viable management of mixed fisheries. *Fisheries Research*, 140, 46-62.

Gourguet, S., Thébaud, O., Dichmont, C., Jennings, S., Little, L. R., Pascoe, S., Deng, R. A., Doyen, L. (2014) Risk versus Economic Performance in a Mixed Fishery. *Ecological Economics*, 99, 110-120.

Gourguet, S., Thébaud, O., Jennings, S., Little, L. R., Dichmont C. M., Pascoe, S., Deng, R. A., Doyen, L. (2015) The Cost of Co-viability in the Australian Northern prawn fishery. *Environmental Modeling and Assessment*, 1–19.

Govan, H. et al. (2009). Status and potential of locally-managed marine areas in the South Pacific: meeting nature conservation and sustainable livelihood targets through wide-spread implementation of LMMAs. SPREP/WWF/WorldFish-Reefbase/CRISP.

Green, A., Lokani, P., Atu W., Ramohia, P., Thomas, P., et al. (2006) Solomon Islands Marine Assessment: Technical report of survey conducted May 13 to June 17, 2004. 106, The Nature Conservancy, Brisbane.

Gutiérrez, N.L., Hilborn, R., Defeo, O. (2011) Leadership, social capital and incentives promote successful fisheries. *Nature*, 470, 386-389.

Hardy, P-Y., Doyen, L., Béné, C., Schwartz, A.-M. (2013) Food security-environment conservation nexus: a case study of Solomon Islands' small-scale fisheries. *Environmental Development*, 8, 38-56.

Hardy, P-Y., Doyen, L. Béné, C., Mills, D. (2016) Viability and resilience of small-scale fisheries through cooperative arrangements. *Environmental and Development Economics*, 21, 6, 713 - 741.

Heal, G. (1998) *Valuing the Future, Economic Theory and Sustainability.* Columbia University Press, New York.

Hilborn, R. (2007) Future directions in ecosystem based fisheries management: A personal perspective. *Fisheries Research*, 108, 235-239.

ICES (2009) *Report of the working group on the assessment of southern shelf stocks of hake, monk and megrim (WGHMM).* ICES Headquarters, Copenhagen, p. 537.

Jennings, S. (2005) Indicators to support an ecosystem approach to fisheries, *Fish and Fisheries*, 6, 212-232.

Krawczyk, J. A., Pharo, A., Serea, O. S., Sinclair, S. (2013) Computation of viability kernels: A case study of by-catch fisheries. *Computational Management Science*, 10(4), 365-396.

Langley, A., Hampton, J. (2008) Stock assessment of skypjack tuna in the western and central pacific ocean. Oceanic Fisheries Programme, Secretariat of the Pacific Community, New Caledonia.

Leopold, M. (2004) *Poisson de mer de Guyane, Guide Illustré*. Quae.

Maynou, F. (2014) Coviability analysis of Western Mediterranean fisheries under MSY scenarios for 2020. *ICES Journal of Marine Science*, 71, 7, 1563-1571.

Martinet, V., Thébaud, O., Doyen, L. (2007) Defining viable recovery paths towards sustainable fisheries. *Ecological Economics*, 64, 411-422.

Millenium Ecosystem Assessment (2005) *Ecosystems and human well-being*, Island Press, Washington, DC.

Milton, D. A., Zhou, S., Fry, G. C., Dell, Q. (2008) *Risk assessment and mitigation for sea snakes caught in the Northern prawn fishery. Final report on FRDC Project 2005/051.* CSIRO, Cleveland, p. 123.

Morris, W. F. and Doak, D. F. (2003) *Quantitative Conservation Biology: Theory and Practice of Population Viability Analysis*. Sinauer Associates.

Mouysset, L., Doyen, L., Jiguet, F. (2014) Co-viability of farmland biodiversity and agriculture. *Conservation Biology*, 28(1), 187-201.

Mullon, C., Curry, P., Shannon, L. (2004) Viability model of trophic interactions in marine ecosystems. *Natural Resource Modeling*, 17(1), 27-58.

Pahl-Wostl C. (2007) Requirements for Adaptive Water Management. In Pahl-Wostl, Kabat and Möltgen (eds): Adaptive and Integrated Water Management. Coping with Complexity and Uncertainty, Springer Verlag, 2007

Pereau, J.-C., Doyen, L., Little, R. and Thébaud O. (2012) The triple bottom line: Meeting ecological, economic and social goals with individual transferable quotas. *Journal of Environmental Economics and Management*, 63, 419-434.

Pikitch, E. K., Santora, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D. O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E. D., Link, J., Livingston, P. A., Mangel, M., McAllister, M. K., Pope, J., Sainsbury, K. J. (2004) Ecosystem-Based Fishery Management. *Science*, 305, 5682, 346-347.

Pitcher, T. J., Kalikoski, D., Short, K., Varkey, D. & Ganapathiraju, P. (2009) An evaluation of progress in implementing ecosystem-based management of fisheries in 33 countries. *Marine Policy*, 33 (2), 223–232.

Plagànyi, É. (2007) Models for an ecosystem approach to fisheries (No. 477). Food & Agriculture Organisation, Rome.

Plagànyi, É., Punt, A. E, Hillary, R., Morello, E .B., Thébaud, O., Hutton, T., Pillans, R. D., Thorson, J. T., Fulton, E. A, Smith, A. D. M., Smith, F., Bayliss, P., Haywood, M., Lyne, V. and Rothlisberg, P. C. (2014) Multispecies fisheries management and conservation: tactical applications using models of intermediate complexity. *Fish and Fisheries*, 15(1), 1-22.

Pope, J.G. (1983) Fisheries resource management theory and practice. *Proceedings of the conference of Fisheries Research Division.*

Punt, A. E., Deng, R. A., Dichmont, C. M., Kompas, T., Venables, W. N., Zhou, S., Pascoe, S., Hutton, T., Kenyon, R., van der Velde, T., and Kienzle, M. (2010) Integrating size-structured assessment and bioeconomic management advice in Australian Northern prawn fishery. *ICES Journal of Marine Science*, `doi:10.1093/icesjms/fsq037`.

Rice, J., Garcia, S. (2011) Fisheries, Food Security, Biodiversity and Climate Change. *ICES Journal of Marine Science*, 68, 1343-1353.

Sanchirico, J. N., Smith, M. D., Lipton, D. W. (2008) An empirical approach to ecosystem-based management. *Ecological Economics*, 64, 586-596.

Sanogo, C., Raissi, N., Miled, S.B., Jerry, C. (2013) A Viability Analysis of Fishery Controlled by Investment Rate. *Acta Biotheoretica*, 61(3), 341-52.

Schuhbauer, A., Sumaila, U. R. (2016) Economic viability and small-scale fisheries — A review. *Ecological Economics*, 124: 69-75.

Shepherd, J.G. (1999) Extended survivors analysis: an improved method for the analysis of catch-at-age data and abundance indices. *ICES Journal of Marine Science*, 56, 584-59.

Squires, D. & Vestergaard, N. (2013) Technical Change and The Commons. *The Review of Economics and Statistics*, MIT Press, 95(5), 1769-1787.

Squires, D. & Vestergaard, N. (2013) Technical change in fisheries. *Marine Policy*, 42, 286-292.

Thébaud, O., Smith, T., Doyen, L., Planque, B., Lample, M., Mahevas, S., Quaas, M., Mullon, C., Vermard, Y., Innes, J. (2013) Building ecological-economic models and scenarios of marine resource systems: workshop report. *Marine Policy*, 43, 382-386.

Thébaud, O., Ellis, N., Little, L.R., Doyen, L., Marriott, R. (2014) Viability trade-offs in the evaluation of strategies to manage recreational fishing in a marine park. *Ecological Indicators*, 46, 59-69.

Ward, T., Tarte, D., Heger, E., Short, K. (2002) Policy proposals and operational guidance for ecosystem-based management of marine capture fisheries. Worldwide fund for nature. Sydney, Australia.

Wilen, J. (1979) Fisherman behaviour and the design of efficient fisheries regulation programs, *J. Fish. Res. Board Can*, 36: 855-858.

WorldFish Center (2010) Community-based adaptive resource management in Solomon Islands: lessons learned, The WorlFish Center, Penang. 12 p. http://www.worldfishcenter.org/content/community-based-adaptive-resource-management-solomon-islands-lessons-learned

List of Tables

Case study	French Guiana	Bay of Biscay	Gulf Carpenteria	Solomon Islands
Notation	FG	BoB	NPF	SI
Scale	SSF	IF	IF	SSF
Data	++	++	++	+
Targeted biodiversity	++	++	+	++
	(≈ 30 species)	(≈ 10 species)	(4 prawn species)	(≈ 100 species)
Trophic Interactions	++	+	0	++
Metier diversity	+	+	0	+
Technical Interactions	++	+	+	+
Bycatch	+	+	++	0
Regulation	Limited entry	TAC (MSY)	Limited entry (MEY)	
		selectivity	Closure	
Food security issue	+	0	0	++

Table 1

	FG	BoB	NPF	SI
Source	Cissé *et al.* (2015)	Gourguet *et al.* (2013)	Gourguet *et al.* (2015)	Hardy *et al.* (2013)
States $x(t)$	14 fish species	3 fish species	4 fish species	8 fish groups
Control (effort) $e(t)$	4 (fishing duration)	16 (number of vessels)	1 (number of vessels)	3 (fishing duration)
Maximum age or size structured A		9	41	
Time step Δt	month	year	week	week
Trophic interactions	+	0	0	+
Biological uncertainties	+	+	+	
Economic uncertainties	0	+	+	0
Species growth rates r_i	14			8
Species recruitment parameters		3	3x4	
Species mean weight υ	13	3x9	3 + 4*41	8
Species proportions of mature individuals		3x9	4 x41	
Species interactions s_{ij}	14x14	0	0	6x6 + 2
Species mortality rates M_i		3x9	3	
Catchability $q_{i,k,a}$	13x4	3x16x9	1+3x2x41x52	3x8
Species discards $d_{i,k}$	0	3x16x9	0	0
Initial states $x(t_0)$	14	3x9	3 + 2*41	8
Initial effort $e(t_0)$	4	16	1	3

Table 2

		FG	BoB	NPF	SI
Constraints	ICES precautionary limits B_{pa}		x	x	
	Targeted species richness	x			x
	Non valuable by-catch species			x	
	Food security	x			x
	Profitability	x	x	x	x
Number of parameters	Species trophic levels T_i	13	0	0	8
	Species prices p_i	13	3x9	2+ 2*41	8
	Fleet variable costs c_k^v	4	16	3	3
	Fleet fixed costs c_k^f	4	16	1	3
	Human demographic growth	1	0	0	1
	Replicates for stochasticity	100	1000	1000	1

Table 3

	FG	BoB	NPF	SI
Effort 1	(canot créole)	(nephrops trawlers)	(prawn trawlers)	(sea cucumber)
	↗↗	↘↘	↘	↘↘
Effort 2	(canot amélioré)	(fish trawlers)		(coral fish)
	↗	↘↘		↘↘
Effort 3	(pirogue)	(sole netters)		(inshore tuna)
	↗↗	↘		↗↗
Effort 4	(tapouille)	(fish netters)		
	↗	↘		
Total effort	↗↗	↘	↘	↗↗

Table 4

List of Figures

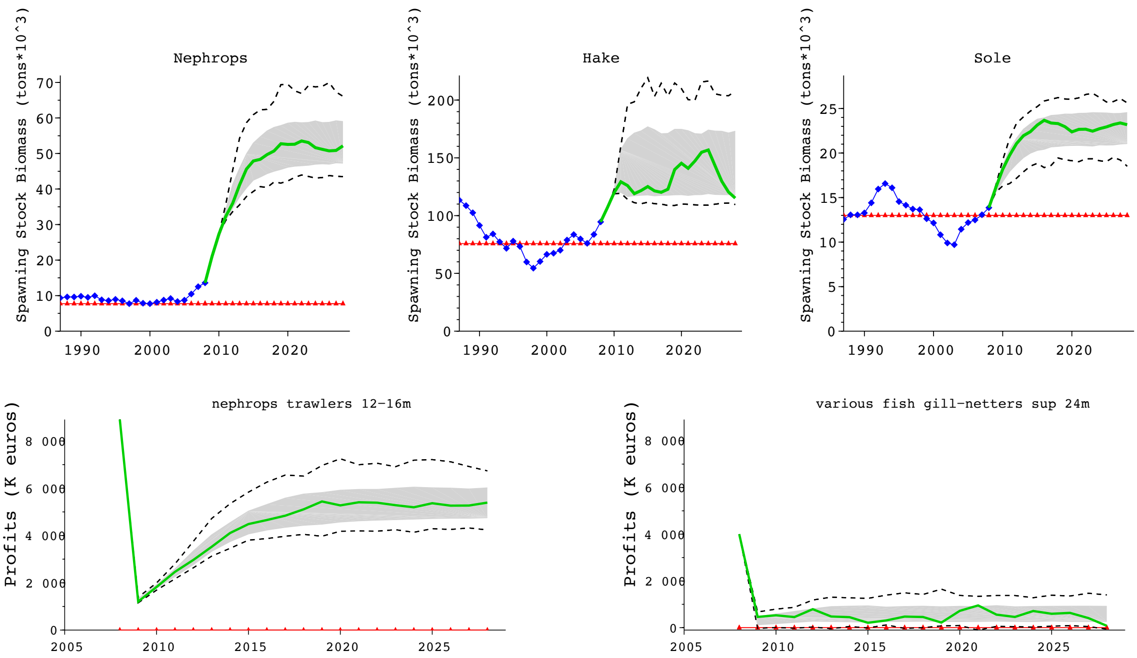

Nephrops
Hake
Sole
Spawning Stock Biomass (tons*10^3)
nephrops trawlers 12-16m
various fish gill-netters sup 24m
Profits (K euros)

Figure 1

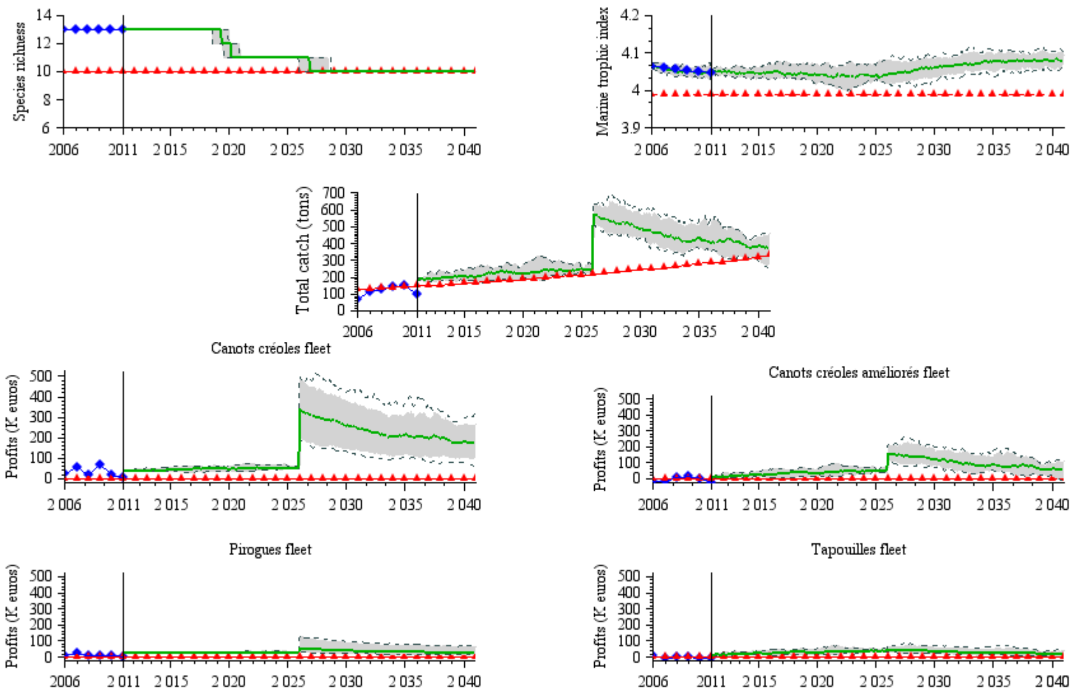

Species richness
Marine trophic index
Total catch (tons)
Canots créoles fleet
Canots créoles améliorés fleet
Pirogues fleet
Tapouilles fleet
Profits (K euros)
2006
2011
2015
2020
2025
2030
2035
2040

Figure 2

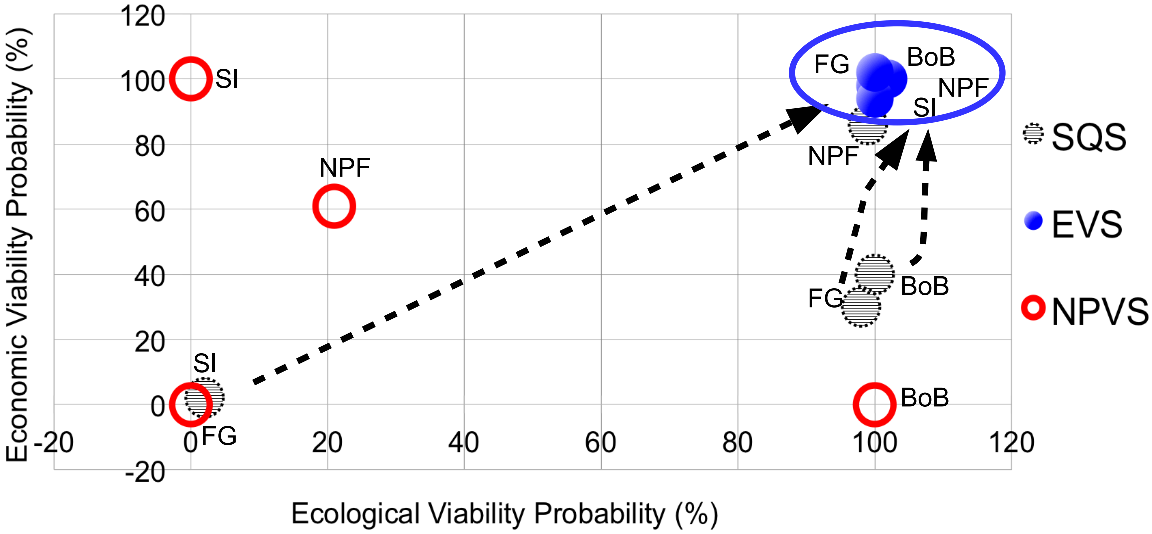
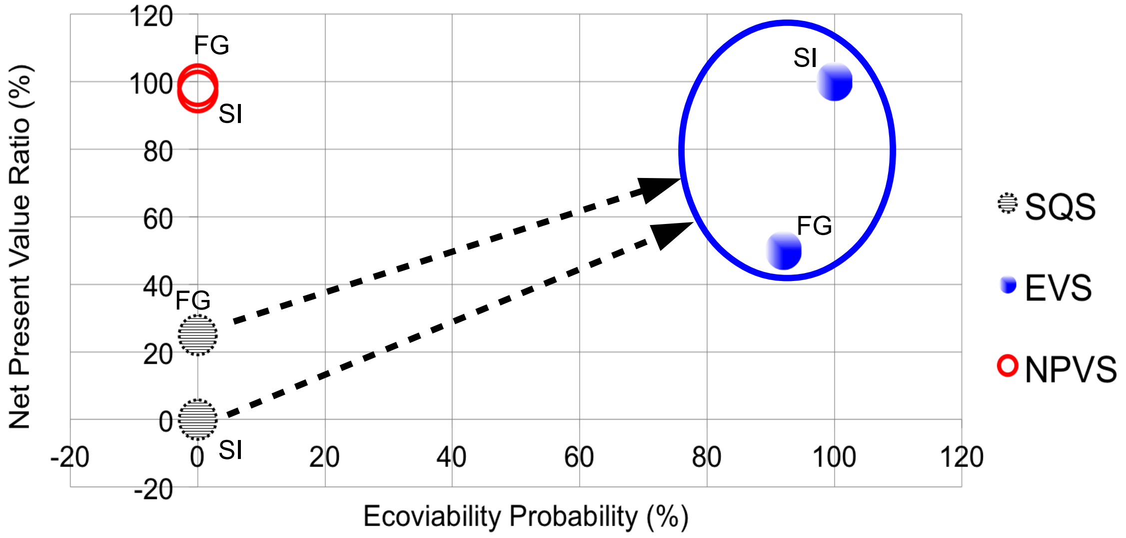
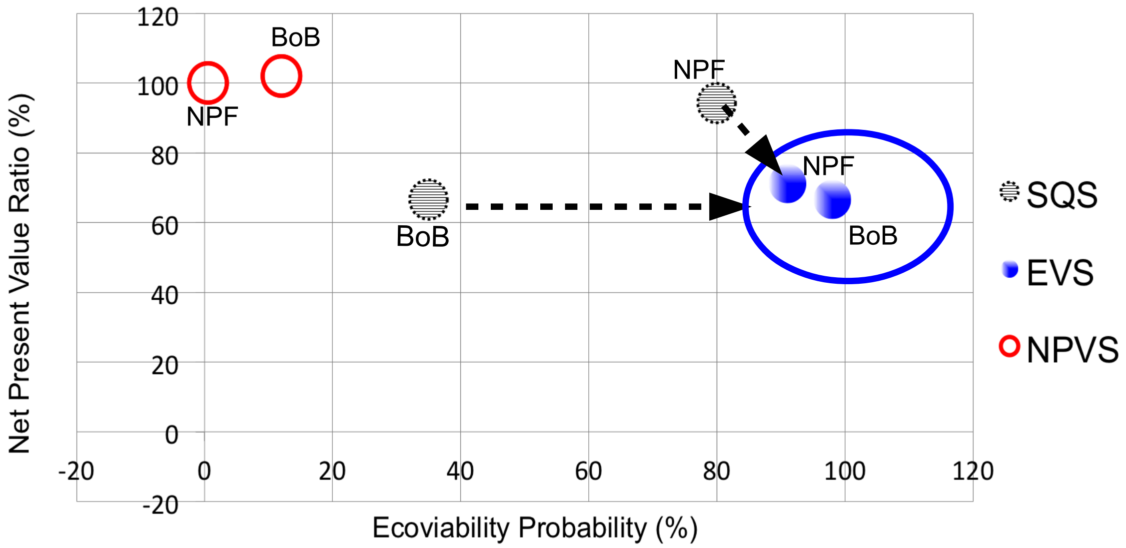

Economic Viability Probability (%)
Ecological Viability Probability (%)
120
100
80
60
40
20
0
-20
-20
0
20
40
60
80
100
120
SI
NPF
FG
BoB
FG
BoB
NPF
SI
NPF
FG
BoB
SQS
EVS
NPVS

Figure 3



a) Small scale fisheries



b) Large scale fisheries

Figure 4

S Appendix

S.1 Computation of optimal expected value for scenario NPVS

The normative scenario NPVS defined in (8) based on the maximization of the expected net present value is defined as follows:

$$\max_{e(t_0),\ldots,e(T)} \mathbb{E}_\omega \left(\mathrm{NPV}(e,\omega)\right) \tag{15}$$

with the net present value

$$\mathrm{NPV}(e,\omega) = \sum_{t=t_0}^{T} \rho^t \sum_{\text{fleets } j} \mathrm{Profit}_j\big(x(t), e_j(t), \omega(t)\big)$$

and where $\mathbb{E}$ refers to the expected value of returns with respect to random variables ω and ρ stands for the discount factor. The numerical approximation of the expected value first relies on the mean over a finite number of replicates of the random variables $\omega(.)$ underlying the uncertainties. In other words, we consider the following K replicates $\omega_k(.)$ over time $t_0, \ldots, T$

$$\begin{cases} \omega_1(t_0), \ldots, \omega_1(T) \\ \vdots \\ \omega_K(t_0), \ldots, \omega_K(T), \end{cases}$$

and we approximate the expected value by the mean over the K replicates as follows

$$\mathbb{E}_\omega \left(\mathrm{NPV}(e,\omega)\right) \approx \frac{1}{K}\sum_{k=1}^{K} \mathrm{NPV}(e,\omega_k)$$

Using the scientific software SCILAB available online `http://www.scilab.org/en`, the replicates are obtained from the function entitled GRAND.

Regarding the way to compute the optimal control e, we have to distinguish between the case studies. For Bay of Biscay and NPF case studies, the control is kept fixed during the whole period $t_0, ..T$. But for French Guiana and Solomon Islands, the control can change and adapt to the uncertainty at several periods using optimal feedback controls and non anticipative strategies. For two periods of decision, as explained in the Cissé *et al.* (2015), closed-loop efforts are solution of the following optimization problem

$$\max_{e(t_0)} \mathbb{E}_{\omega_0}\left[\sum_{t=t_0}^{t_1-1}\rho^{t-t_0}\text{Profit}(x(t),e(t_0),\omega_0)+\max_{e(t_1,\omega_0)}\mathbb{E}_{\omega_1}\sum_{t=t_1}^{T-1}\rho^{t-t_1}\text{Profit}(x(t),e(t_1,\omega_0),\omega_1)\right]$$

From a numerical point of view approximating the expected value by the average with respect to the $K = K_0 * K_1$ (K_0 in first period; K_1 in second period) replicates of ω gives

$$\max_{e(t_0)} \max_{\begin{cases} e(t_1,\omega_{0,1}) \\ \vdots \\ e(t_1,\omega_{0,K_0}) \end{cases}} \frac{1}{K_0}\sum_{\omega_0=\omega_{0,1}}^{\omega_{0,K_0}}\left[\sum_{t=t_0}^{t_1-1}\rho^{t-t_0}\text{Profit}(x(t),e(t_0),\omega_0)+\frac{1}{K_1}\sum_{\omega_1=\omega_{1,1}}^{\omega_{1,K_1}}\sum_{t=t_1}^{T-1}\rho^{t-t_1}\text{Profit}(x(t),e(t_1,\omega_0),\omega_1)\right]$$

The optimal control problem above then becomes a more usual mathematical optimization problem where the number of unknown variables is the number of efforts e multiplied by (K_0+1). The feedback (adaptive) fishing effort controls at time t_1 are given by the different optimal $e(t_1,\omega_0)$ associated with the K_0 replicates of random variables ω_0. To approximate this optimal value and identify optimal efforts with the scientific software SCILAB we used the optimizing function entitled OPTIM_GA.

S.2 Computation of optimal viability probability value for scenario EVS

Efforts in the Ecoviability EVS scenario defined in (10) are computed in a similar way using the fact that the probability is the expected value of an indicator (boolean) function. More specifically, we rewrite the viability probability as follows

$$\mathbb{P}\big(\text{Constraints are fulfilled for } t=t_0,..,T\big)=\mathbb{E}\left[\prod_{t=t_0}^{T}\mathbf{1}_C(x(t),e(t),\omega(t))\right]$$

with the indicator function

$$\mathbf{1}_C(x,e,\omega)=\begin{cases}1 & \text{if constraints are satisfied}\\ 0 & \text{otherwise.}\end{cases}$$

We compute the maximal viability probability as well as optimal controls associated with viability scenario using again the optimizing function in scilab entitled OPTIM_GA

S.3 Details of the model and data in French Guiana

Dynamic model: The fishery population dynamics model used in this case is a multi-species, multi-fleet dynamic model in discrete time as in Cissé *et al.* (2013, 2015). The model accounts for trophic interactions between 13 exploited species and a fourteenth stock aggregating other marine resources. The biomass $x_i(t)$ of the species i is assumed to be governed by a dynamic system based on Lotka-Volterra trophic relationships and fishing effort of the different fleets:

$$x_i(t+1) = g_i(x(t) - h(t), \omega_i(t)), \tag{16}$$

with growths and catches by species defined respectively by

$$g_i(x_1, \dots, x_n, \omega_i) = x_i\left(1 + r_i - \frac{r_i}{K_i}x_i + \sum_{j \neq i} s_{i,j}x_j + \omega_i\right), \tag{17}$$

$$h_i(t) = \sum_{k=1}^{m} h_{i,k}(t) = \sum_{k=1}^{m} q_{i,k}e_k(t)x_i(t). \tag{18}$$

In equation (17), r_i and K_i stand respectively for the intrinsic growth rate and the carrying capacity of the species i. $s_{i,j}$ is the trophic effect of species j on species i. The noise ω_i captures the environmental stochasticies affecting the growth of each species i at each step t. It is assumed that the random variables $\omega_i(t)$ follow a Gaussian law, independent and identically distributed : $\omega \rightsquigarrow \mathcal{N}(0, \sigma)$. The control $e_k(t)$ in equation (18) represents the fishing effort of fleet k (time spent at sea, in hour) and $q_{i,k}$ measures the catchability of species i by fleet k. The number of the fleet k (from $k = 1$ to $k = 4$) corresponds respectively to Canot Créoles, Canot Créoles Améliorés, Pirogues and Tapouille.

Calibration: The model calibration relies on monthly observations of catches and fishing efforts from the landing points all along the coast available from January 2006 to December 2010. Initial stocks, catchabilities, trophic intensities values of the ecosystem as well as the standard deviation of growth were estimated through a least square method. This method involved minimizing the mean square error between the monthly observed catches $h_{i,k}^{\text{data}}$ and the catches $h_{i,k}$ simulated by the model as defined by equation (18):

$$\min_{x_0,\ s,\ q,\ \sigma} \mathbb{E}_\omega \left[\sum_{t=\text{ January } 2006}^{\text{December } 2010} \sum_{i=1}^{13} \sum_{k}^{4} \Big(h_{i,k}^{\text{data}}(t) - h_{i,k}(t) \Big)^2 \right]. \tag{19}$$

Figure (S.1) shows how catches generated by the calibrated model fit the historical catches by fleet.

Indicators: Regarding biodiversity metrics, the species richness and marine trophic indicators were selected. Species richness $\text{SR}(t)$ indicates the estimated number of species represented in the ecosystem. In our model, it is assumed that a species disappears whenever its biomass falls under a predetermined viability limit B_{lim}. This threshold B_{lim} which corresponds to a proxy of the ICES precautionary reference points is here set to 1/1000 of the initial biomass B_0. The indicator SR is computed as follows:

$$\text{SR}(t) = \sum_i \mathbf{1}_i(x_i(t)), \tag{20}$$

with the boolean function

$$\mathbf{1}_i(x) = \begin{cases} 1 & \text{if} \quad x \geq B_{\text{lim},i} \\ 0 & \text{otherwise.} \end{cases}$$

The marine trophic index $\text{MTI}(t)$ of an ecosystem is computed as follows

$$\text{MTI}(t) = \frac{1}{N(t)} \sum_{i=1}^{13} T_i N_i(t) \quad \text{with abundances } N_i(t) = \frac{x_i(t)}{\upsilon_i} \tag{21}$$

where υ_i is a fixed average weight by species.

The total catches $H(t)$ within the fishery plays the role of food supply:

$$H(t) = \sum_k \sum_i h_{i,k}(t). \tag{22}$$

The profit $\text{Profit}_k(t)$ of each fleet k is derived from the landings of each species $h_{i,k}$, the landing prices $p_{i,k}$, fixed costs c_k^f, variable costs c_k^v and the crew share earnings c_k^L as follows:

$$\text{Profit}_k(t) = (1 - c_k^L)\left(\sum_i p_{i,k} h_{i,k}(t) - c_k^v e_k(t)\right) - c_k^f. \tag{23}$$

Prices, variable costs and fixed costs are those collected for year 2010. They are assumed to remain unchanged throughout the simulations. Variable costs c_k^v include fuel consumption, ice, food and lubricants. Equipment depreciation, maintenance and repairs are incorporated in the fixed costs c_k^f.

Ecoviability constraints: This ecological constraint is about maintaining both the SR index and the MTI above the minimum observed for the status quo scenario SQS defined in equation (7):

$$\text{SR}(t) \geq \min_{t=t_1,\ldots,T} \text{SR}^{SQS}(t), \quad \text{MTI}(t) \geq \min_{t=t_1,\ldots,T} \text{MTI}^{SQS}(t). \qquad . \tag{24}$$

The food security constraint is linked to the ability of the fishery to satisfy the local food consumption. Consequently the food security reads

$$H(t) \geq H(2010) \cdot (1 + d)^t, \qquad \text{for} \quad t = t_1, \ldots, T, \tag{25}$$

where d stands for the growth rate of the population and 2010 catches stand for the baseline. To analyze the economic risks, we define the profit constraint for every fleet at any time:

$$\text{Profit}_k(t) \geq 0, \qquad \text{for} \quad t = t_1, \ldots, T., \quad \text{for every } k = 1, .., 4. \tag{26}$$

S.4 Details of the model and data in Bay of Biscay

Dynamic Models: As detailed in Gourguet *et al.* (2013), population dynamics of the three species included in the analysis (hake, nephrops and sole) were modeled using an age-structured population model. Parameters were derived from stock assessments carried out by ICES (2009) using a virtual population model. The model was then fitted for each species separately, using data on catch and abundance from surveys or derived from commercial cpues. Fish population dynamics are modeled using an age-structured population model derived from the standard fish stock assessment approach. Population dynamics are described on a yearly basis and integrate uncertainties regarding recruitment. The age-structured dynamics of the three species are governed by :

$$x_{i,a}(t+1) = x_{i,a-1}(t)\exp\left(-M_{i,a-1} - F_{i,a-1}(t)\right), \quad a = 2,\dots,A_i - 1 \tag{27}$$

where $x_{i,a}(t)$ stands for the abundance of the exploited species $i = 1,2,3$ (Nephrops, Hake and Sole, respectively) at age $a = 1,\dots,A_i$. Thus the state evolves according to both natural $M_{i,a}$ and total fishing $F_{i,a}(t)$ mortality rates of the species i at age a. Total fishing mortality of species i at age a $F_{i,a}$ is derived from the sum of fishing mortality from all 17 sub-fleets:

$$F_{i,a}(t) = \sum_{k=1}^{17} F_{i,a,k}(t) = \sum_{k=1}^{17} q_{i,a,k}e_k(t_0)\mathrm{K}_k(t) \tag{28}$$

where $e_k(t_0)$ is the mean value of fishing effort by vessel of sub-fleet k expressed in number of days at sea and $\mathrm{K}_k(t)$ is the number of vessels by sub-fleet k. The reference year is set at $t_0 = 2008$. The catchability $q_{i,a,k}$ corresponds to the fishing mortality of species i at age a associated with one unit of effort from a vessel of sub-fleet k. The parameter values are derived from the ICES databases.

The recruits $x_{i,1}(t+1)$ for each species are assumed to be uncertain functions of the Spawning Stock index (biomass here) $SSI_i(t)$ at time t:

$$x_{i,1}(t+1) = \phi_i\Big(SSI_i(t), \omega_i(t)\Big). \tag{29}$$

The Spawning Stock biomass $SSI_i(t)$ of the species i is given by:

$$SSI_i(t) = \sum_{a=1}^{A_i} \gamma_{i,a} \upsilon_{i,a} x_{i,a}(t), \tag{30}$$

with $(\gamma_{i,a})_{a=1,\dots,A_i}$ the proportions of mature individuals of species i at age a and $(\upsilon_{i,a})_{a=1,\dots,A_i}$ the weights of individuals of species i at age a. In the present case-study, the recruitment relationship of the species is set using an Ockham-Razor function:

$$\phi_i(SSI_i, \omega_i) = \begin{cases} \omega_i \rightsquigarrow \mathcal{U}_i & \text{if } SSI_i \geq B_i^{\mathsf{lim}}, \\ SSI_i \dfrac{\overline{R}_i}{B_i^{\mathsf{lim}}} & \text{if } SSI_i \leq B_i^{\mathsf{lim}}. \end{cases} \tag{31}$$

Here $\mathcal{U}_i$ stands for the uniform distribution relying on the historical time series of recruitment R_i^t of species i and the notation $\omega_i \rightsquigarrow \mathcal{U}_i$ means that the random variable ω_i is governed by the uniform probability distribution $\mathcal{U}_i$. Threshold B_i^{lim} is the ICES limit reference biomass and $\overline{R}_i$ the mean historical recruitment values by species. The three species have different biology and life cycles, therefore their recruitments are assumed to be uncorrelated.

Calibration: Parameters underlying the dynamics (27) and (29) were derived from stock assessments carried out by ICES (2009) using a virtual population model. The model was then fitted for each species separately, using data on catch and abundance from surveys or derived from commercial CPUEs. Figure S.2 displays the comparison between the historical and simulated spawning biomass $SSI_i(t)$ for the three species at play.

Indicators: For each period t, the exploitation of the three species is described by the catches $h_{i,a,k}(t)$. These catches depend on initial fishing mortalities $F_{i,a,k}(t_0)$ and abundances $x_{i,a}(t)$ through the Baranov catch equation:

$$h_{i,a,k}(t) = x_{i,a}(t) F_{i,a,k}(t) \frac{1 - \exp\left(-M_{i,a} - \sum_{k=1}^{m} F_{i,a,k}(t)\right)}{M_{i,a} + \sum_{k=1}^{m} F_{i,a,k}(t)}. \tag{32}$$

The gross income from catches of each sub-fleet denoted by $\mathrm{Inc}_k(t)$ is then estimated by introducing the market price of the species along with the estimates of discard rates, such that:

$$\mathrm{Inc}_k(t) = \sum_i \sum_{a=1}^{A_i} p_{i,a}(t)\upsilon_{i,a,k}h_{i,a,k}(t)(1-d_{i,a,k}). \tag{33}$$

where $\upsilon_{i,a}$ is the mean weight of landed individuals of species i at age a and $d_{i,a,k}$ represents the discard rate of individuals of age a by the sub-fleet k. Discard ratios were calibrated on the data available from the ICES working group WGHMM. Prices $p_{i,a}(t)$ correspond to the market value (euros by kg) of species i at age a for year t and are assumed to be uncertain. Uncertainties on annual market price by species are introduced through a random price by species following a Gaussian law as:

$$p_i(t) \rightsquigarrow \mathcal{N}(\mu_i^P, \sigma_i^P). \tag{34}$$

Gaussian laws are calibrated from ex-vessel prices for the three species for the 2000-2009 period, recorded in French harbours (data from Ifremer, SIH, DPMA). Prices by species $p_i(t)$ are assumed to be independent by species and by year. The profit Profit_k of a sub-fleet k is estimated as follows:

$$\mathrm{Profit}_k(t) = \Big(\mathrm{Inc}_k(t)+\alpha_k\mathrm{K}_k(t)e_k(t_0)\Big)(1-\tau_k)-\Big(\mathrm{V}_k^{fuel}p_{fuel}(t)e_k(t_0)+c_k^v e_k(t_0)+c_k^f\Big)\mathrm{K}_k(t). \tag{35}$$

Here the parameter α_k corresponds to the income per unit of effort of sub-fleet k derived from catches of species not explicitly modelled. We assume that biomass and price of other species are constant, and that the impacts of modelled fleets on these species are relatively negligible. Rate τ_k is the landing cost by sub-fleet as a proportion of the gross income. V_k^{fuel} corresponds to the volume of fuel (in litres) used by fishing effort unit (i.e. days at sea) for one vessel of sub-fleet k and $p_{fuel}(t)$ is the fuel price by litre of the year t that can be subjected to projection scenarios. The other variable cost c_k^v of a fishing effort unit by a vessel of sub-fleet k includes oil, supplies, ice, bait, gear and equipment costs while c_k^f corresponds to the annual costs associated with vessel of the sub-fleet k, including maintenance, repair, management and crew costs, fishing firms, licenses, insurance premiums and producer organisation charges. Cost parameter values in the model are based on the economic data available for 2008 (Ifremer, SIH, DPMA) and are assumed to be constant over the simulation period.

Ecoviability constraints: Ecological viability is defined as the requirement that the Spawning Stock Biomass of each individual species is maintained above a threshold value. In this study, the thresholds correspond to B_i^{pa}, the biomass of precaution of the species i estimated by the International Council for the Exploration of the Sea. The constraint is specified as:

$$SSI_i(t) \geq B_i^{\mathsf{pa}}, \qquad i = 1, 2, 3. \tag{36}$$

We also consider the economic objective of maintaining positive profits for the sub-fleets over time as follows

$$\text{Profit}_k(t) > 0, \qquad k = 1, \ldots, 16. \tag{37}$$

S.5 Details of the model and data in the Northern prawn fishery

Dynamic Model: As described in Gourguet *et al.* (2014) and Gourguet *et al.* (2015), three prawn species in Australia's Northern prawn fishery were modeled explicitly using a size and sex-structured population model (with Ricker stock-recruitment relationship and environmental uncertainties) that operates on a weekly time-step. The parameters of this multi-species population model were estimated using data on catches and effort, catch rates, as well as length frequency data from both surveys and commercial landings (Punt *et al.*, 2010). The dynamics of the three species are governed by:

$$x_i(t+1) = \quad g_i\left(x_i(t), F_i(t), \omega(t) \right), \quad i = 1, 2, 3 \tag{38}$$

where $x_i(t)$ is the matrix of abundance $x_{i,sex,l}(t)$ of the exploited prawn species $i = 1, 2, 3$ (grooved and brown tiger and blue endeavour prawns, respectively) of sex female or male in size-class l alive at the start of time t which corresponds to one time step, i.e. one week. The dynamic function g_i accounts for species recruitment and mortality mechanisms of species i as detailed in Punt *et al.* (2010). $F_i(t)$ is the matrix of fishing mortality $F_{i,l}(t)$ of animals of species i and size-class l at time t and is derived from the sum of fishing mortality from the two tiger prawn fishing strategies:

$$F_{i,l}(t) = \sum_{k=1}^{2} F_{i,l,k}(t) = \sum_{k=1}^{2} q_{i,l,k}(t) e_k(t) \mathrm{K}\big(y(t)\big), \tag{39}$$

where $e_k(t)$ is the mean value of fishing effort (in days at sea) by vessel associated with tiger prawn fishing strategy $k = 1, 2$ at time t, and $\mathrm{K}\big(y(t)\big)$ is the number of vessels involved in the fishery during the year $y(t)$ (which is the year[1] corresponding to the time t). Catchability $q_{i,l,k}(t)$ corresponds to the fishing rate of species i in size-class l associated with one unit of fishing effort of fishing strategy k (as in 2010) which depends on week t because the relative availability of species i varies with time. Recruits in the fishery for species $i = 1, 2, 3$ during a 'biological' year are assumed to be related to the spawning stock size index of species i for the previous

[1] Year $y(t)$ is a function of week t, where weeks are numbered 1,. . . , 52, 53,. . . , 102, 103, . . .

year, according to a Ricker stock-recruitment relationship fitted assuming temporally correlated environmental variability and down-weighting recruitments, as described in Punt *et al.* (2010). The annual spawning stock size indices $SSI_i\big(y(t)\big)$ of the three species i for the year $y(t)$ are calculated as in Punt *et al.* (2010) and are described by

$$SSI_i\big(y(t)\big) = \frac{1}{52} \sum_{t=52\big(y(t)-1\big)+1}^{52y(t)} \beta_i(t) \sum_l \gamma_{i,l} \frac{1-\exp\left(-(M_i + F_{i,l}(t))\right)}{M_i + F_{i,l}(t)} x_{i,female,l}(t). \tag{40}$$

where $x_{i,female,l}(t)$ is the abundance of prawns of species i of sex $female$ in size-class l alive at the start of time t, and M_i is the natural mortality of animals of species i. $\beta_i(t)$ measures the relative amount of spawning of species i during the time t, and $\gamma_{i,l}$ corresponds to the proportion of females of species i in size-class l that are mature.

A fourth prawn species, the white banana prawn is represented without an explicit density-dependence mechanism, due to its highly variable recruitment and in the absence of a defined stock-recruitment relationship. The biomass of this species is thus modeled as a uniform i.i.d. random variable, described by equation (41).

$$x_4\big(y(t)\big) \rightsquigarrow \mathcal{U}(B_4^-, B_4^+), \tag{41}$$

with $x_4\big(y(t)\big)$ the stochastic biomass of white banana prawn for the year $y(t)$, and B_4^- and B_4^+ the uniform law bounds. Numerical values are given in Gourguet *et al.* (2014).

Indicators: Weekly catches $h_{i,l,k}(t)$ of species $i = 1, 2, 3$ in length-class l by tiger prawn fishing strategies ($k = 1, 2$); and annual catches $h_{i=4,k=3}\big(y(t)\big)$ of prawn species $i = 4$ by banana prawn fishing strategy ($k = 3$) for the year $y(t)$ are defined by

$$\begin{aligned} h_{i,l,k}(t) &= \sum_{sex=male}^{female} \upsilon_{i,sex,l} x_{i,sex,l}(t) F_{i,l,k}(t) \frac{1-\exp\left(-M_i - \sum_{k=1,2} F_{i,l,k}(t)\right)}{M_i + \sum_{k=1,2} F_{i,l,k}(t)} && i = 1,2,3;\ k = 1,2 \\ h_{i,k}\big(y(t)\big) &= q_{i,k} x_i\big(y(t)\big) e_k\big(y(t)\big) \mathrm{K}\big(y(t)\big) && i = 4;\ k = 3 \end{aligned} \tag{42}$$

with $\upsilon_{i,sex,l}$ the mass of an animal of species $i = 1, 2, 3$ and sex *sex* in size-class l. The annual gross income by fishing strategy $k = 1, 2, 3$ is calculated such that:

$$\begin{aligned} \mathrm{Inc}_k\big(y(t)\big) &= \sum_{t=52\left(y(t)-1\right)+1}^{52y(t)} \left(\sum_{i=1}^{3}\sum_{l} p_{i,l} h_{i,l,k}(t)\right), \quad i = 1,2,3;\ k = 1,2 \\ \mathrm{Inc}_k\big(y(t)\big) &= p_i h_{i,k}\big(y(t)\big), \quad i = 4;\ k = 3 \end{aligned} \tag{43}$$

where $p_{i,l}$ is the average market price per kilogram for animals of species $i = 1, 2$ and 3 in size-class l. The average price per kilogram of prawn species $i = 4$ is denoted by $p_{i=4}$. Total annual profit of the whole fishery $\mathrm{Profit}\big(y(t)\big)$ for year $y(t)$ is then formulated as follows:

$$\mathrm{Profit}\big(y(t)\big) = \left(\sum_{k=1}^{3} \mathrm{Inc}_k\big(y(t)\big)\right)(1 - c^L) - \left(c^M \sum_{k=1}^{3}\sum_{i=1}^{4} h_{i,k}(t)\right) - \left(\sum_{k=1}^{3} (c_k^v e_k\big(y(t)\big)) + c^f\right) \mathrm{K}\big(y(t)\big) \tag{44}$$

where c^L is the share cost of labour (crew are paid a share of the income) and c^M is the cost of packaging and gear maintenance (assumed to be proportional to the fishery catch in weight). The other variable cost c_k^v includes the costs of repair, maintenance, fuel and oil per unit of effort of fishing strategy k; while c^f is the annual fixed cost by vessel (i.e. those costs that are not related to the level of fishing effort). More details are given in Punt *et al.* (2010) and Gourguet *et al.* (2014).

Total annual sea snake catch $h_{seasnake}(y(t))$ is considered as an indicator of the impacts of fishing on sea snakes. Annual sea snake catches are estimated based on data available in Banks *et al.* (2012) from linear regressions. To model a progressive adoption over time of more effective Bycatch Reduction Devices (Milton *et al.*, 2008), the coefficient values from the linear regressions are reduced progressively by 8.7% each year to have a total reduction of 87% (compared to the initial year) after a period of 10 years. More details are given in Gourguet *et al.* (2015).

Ecoviability constraints: Ecological viability is defined as the requirement that the spawning stock index of each individual species $i = 1, 2, 3$ is maintained above a threshold value. In this study the thresholds $SSI_i^{\lim}$ correspond to 50% of the 2010 spawning stock size indices, based on a precautionary approach. The constraint is specified as:

$$SSI_i\big(y(t)\big) \geq S_i^{\lim}, \qquad i = 1, 2, 3. \tag{45}$$

We also consider a sea snake conservation objective which requires maintaining the catch of sea snakes below or equal to a maximum 'allowed' level:

$$h_{seasnake}\big(y(t)\big) \leq h_{seasnake}^{\lim} \tag{46}$$

with $h_{seasnake}^{\lim}$ the maximum allowed total catch of sea snakes set to the sea snake catch estimated with 2010 (i.e. reference year) effort levels.

The economic objective in this study requires maintaining a minimum total annual profit for the NPF such that:

$$\text{Profit}\big(y(t)\big) \geq \text{Profit}^{\lim} \tag{47}$$

where $\text{Profit}^{\lim}$ is set to 50% of the 2010 annual profit.

S.6 Details of the model and data in Solomon Islands

Dynamic Models: Following Hardy *et al.* (2013), the state of the socio-ecosystem corresponds to the biomass of eight fish families including the Holothurian $i = 1$, Serranidae $i = 2$, Lutjanidae $i = 3$, Lethrinidae $i = 4$, Acanthuridae $i = 5$, the Scaridae $i = 6$ and others coral-reef fishes $i = 7$ while the pelagic family $i = 8$ relates to the skypjack tuna and the Scombridae family. The dynamics of the eight fish groups are assumed to be governed by Lotka-Volterra type interactions and by fishing efforts associated with 3 fleets k including the fleet $k = 1$ associated with sea cucumber fishing, the fishing of the coral-reef fishes $k = 2$ and tuna fishing $k = 3$. Thus, the biomass $x_i(t + 1)$ of family i at time $t + 1$ depends on previous stocks' biomasses $x_i(t)$, fishing efforts $e_k(t)$ and labour intensity $L_k(t)$ of fleet k through the relation :

$$x_i(t+1) = x_i(t) \cdot \left(1 + r_i + \sum_{j=1}^{8} s_{i,j} \cdot x_j(t) - \sum_{k=1}^{3} q_{i,k} \cdot e_k(t) \cdot L_k(t)\right) \tag{48}$$

with $x(t)$ in kg/m^2, $e_k(t)$ in hours/fishers, $L_k(t)$ in number of fishers. Parameter r_i stands for the intrinsic growth rate of the population i while $s_{i,j}$ is the trophic effect of family j on family i. The parameter $q_{i,k}$ measures the catchability on family i of fleet k.

The catch $h_{i,k}$ of stock i by fleet k at time t is given by:

$$h_{i,k}(t) = q_{i,k} \cdot e_k(t) \cdot L_k(t) \cdot x_i(t) \cdot \qquad k = 1, 2, 3 \tag{49}$$

The total fishing effort is assumed to grow linearly since 2004 in proportion with the total population of the islands following a yearly demographic rate of $d = 2.14\%$ by year.

$$L_k(t) = L_k(2004)(1 + d)^t \tag{50}$$

Calibration: For the sea cucumber and coral fish groups, parameters were calibrated based on data extracted from the literature including Green *et al.* (2006) and FishBase. The parameterization of the model for skipjack was carried out in two steps. First, a Western Pacific assessment (Langley & Hampton, 2008) was used to estimate the industrial fishery's parameters.

Then, the model including all fleets (industrial and artisanal) was fitted to data on catches from 1982 to 2006 using a least square method. The free access Scilab software was used for the code and computation of the simulations. The figure S.3 displays the fitness beween simulated and historical catches for the tuna.

Indicators: Species (family) richness SR and the Simpson index SI are used to depict structural aspects of the marine ecosystem. A family is here assumed to become extinct whenever its abundance falls below a minimum threshold set at a certain proportion of its initial biomass $x_i(0)$. The Simpson index SI complements the SR index by estimating the probability that two individuals belong to the same family.

The choice of economic indicators, a subsistence index and a cash index, reflects the dual function of fishing in the case study. The subsistence index computed per capita corresponds to the quantity of fish kept by households for self-consumption:

$$h_{\text{sub}}(t) = \sum_k \alpha_k \sum_i \frac{h_{i,k}(t)}{L_k(t)} \tag{51}$$

where α_k represents the shares of the catch kept for self-consumption. The other shares $(1-\alpha_k)$ correspond to the share of fish sold on local or regional markets. Like the subsistence index, the cash index remains per capita:

$$\text{Profit}(t) = (1 - \alpha_k) \cdot \sum_i p_i \cdot \sum_k \frac{h_{i,k}(t)}{L_k(t)}. \tag{52}$$

with the prices p_i assumed to be fixed and the costs to be null. The proportion of fish retained by households for self-consumption averaged around 60% (i.e. 40% sold for cash). We therefore used this value for households' self-consumption of reef fish and tuna, i.e. $\alpha_3 = \alpha_2 = 60\%$. In contrast, $\alpha_1 = 0\%$ as sea cucumber is not consumed but only harvested for cash.

Ecoviability constraints: In this study the ecological constraint relates to the attempt to maintain the various fish families above their respective extinction thresholds (using the Simpson and Species Richness Indexes as indicators), while the economic and social constraints attempt to ensure households food and cash security.

The ecological constraints are:

$$\begin{cases} \mathrm{SR}(t) \geq \ 0.9\ \mathrm{SR}(2004) \\ \mathrm{SI}(t) \geq \ 0.9\ \mathrm{SI}(2004) \end{cases} \tag{53}$$

The levels of the two economic constraints (food and cash security) were defined by international standards. The food security constraint relies on a weekly amount of 0.8 g/kg protein per person and reads here

$$h_{\mathrm{sub}}(t) \geq h_{\mathrm{sub}}^{lim} = 2.1 \quad kg/hh/week$$

while the second economic constraint relies on the weekly basic need poverty line estimated at 47\$SB per household

$$\mathrm{Profit}(t) \geq \mathrm{Profit}^{lim} = 47 \quad \$SB/hh/week.$$

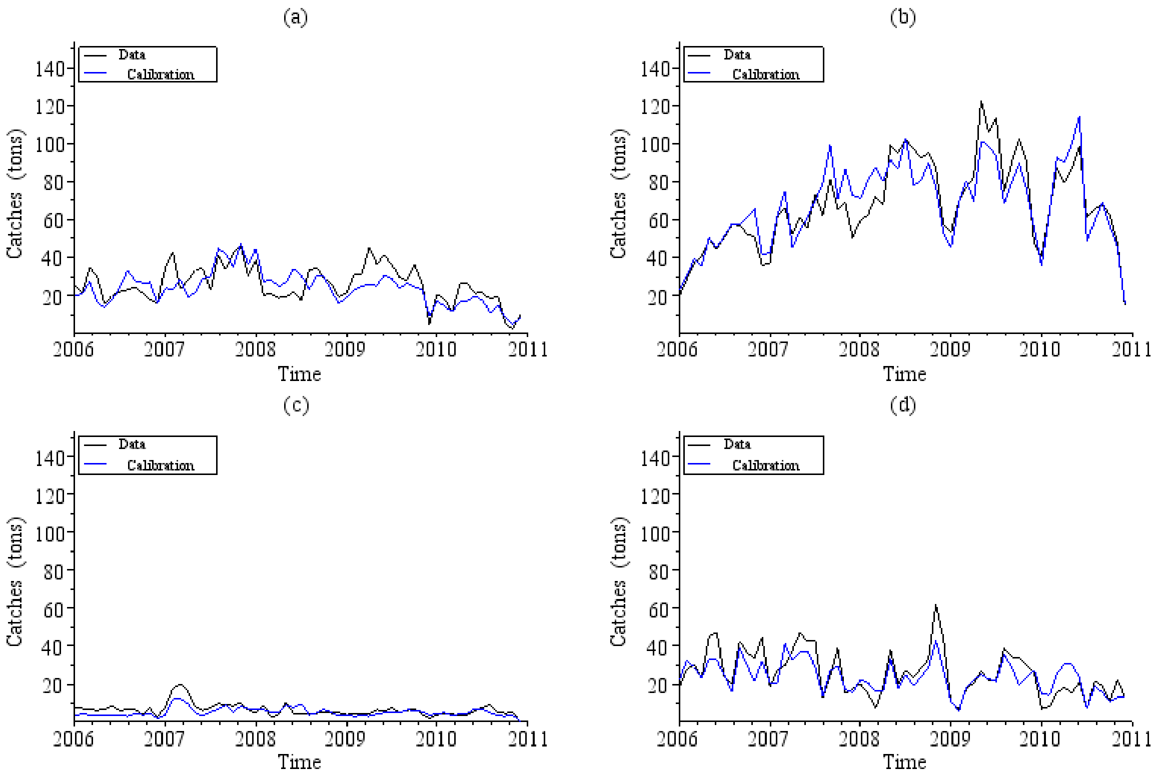


Figure S.1 – French Guiana: Comparison by fleet k between historical catches $\sum_i h_{i,k}^{\text{data}}(t)$ and simulated catches $\sum_i h_{i,k}(t)$.

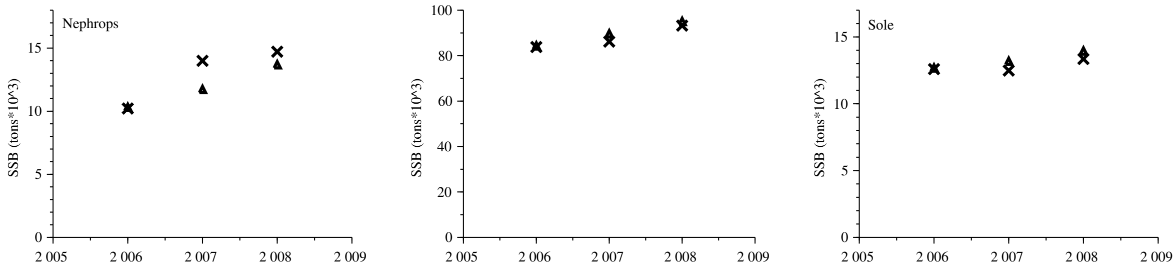


Figure S.2 – Bay of Biscay: Comparison between historical and simulated spawning biomass $SSI_i(t)$ for the three species at play over 2006-2008. Crosses stands for the historical values while the triangles stands for the values estimated by the model.

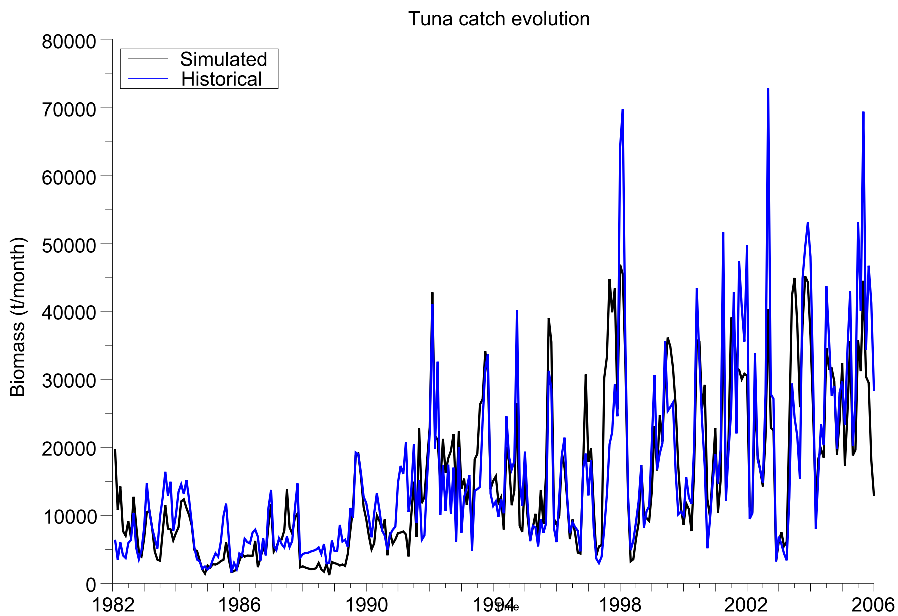


Figure S.3 – Solomon Islands: The historical $h_{8,3}^{data}(t)$ in blue) and simulated catch $h_{8,3}(t)$ (in black) for the pole and line tuna fishery.

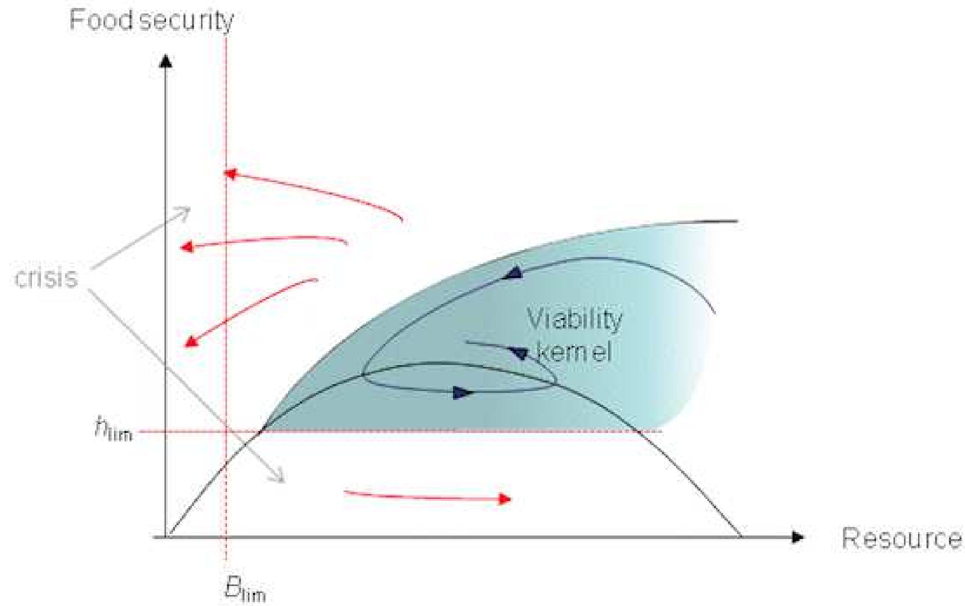


Figure S.4 – Viability kernel and bio-economic viability: In blue the viability kernel represents the set of initial conditions of the system which ensures that the controlled dynamics (illustrated by the system trajectories) will satisfy the viability constraints at any time. In the present case, (for sake of simplicity) we only represent two constraints: the ecological and food security ones (the economic constraint is omitted). These constraints are indicated on the diagram by the two green dotted lines and the associated two thresholds: B_{lim} and h_{lim}. Below these two thresholds the viability constraints are violated (the system is in crisis). Above the thresholds, for red trajectories, initial conditions are viable at $t = 0$ but the dynamics of the system is such that future crisis can not be avoided. Only within the viability kernel is the system viable and will remain so at any time in the future (blue trajectories).

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ORIGINAL ARTICLE

WILEY FISH and FISHERIES

Atlantic and Pacific halibut co-management initiatives by Canadian fishermen's organizations

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Abstract

Many fisheries managers and neoliberal fisheries economists promote Individual Transferable Quotas (ITQs) as a solution to the race for fish which can cause rent dissipation under competitive quota or open access fisheries. These actors consider the Canadian Pacific halibut ITQ fishery an example of successful achievement of these objectives. However, critics note the weak performance of this management model in distribution of benefits, increased capital costs to fishermen, deteriorating safety conditions, reductions in crew income and barriers to entry. They point to the layup system which successfully managed effort in the Pacific halibut fishery for four decades prior to the introduction of ITQs. A system similar to the layup has been used for Atlantic halibut since 2013, initiated by the Fish Food and Allied Workers (FFAW) representing owner-operator license holders in the halibut fishery off the coast of western Newfoundland and southern Labrador. The FFAW rejected the two halibut management plan options presented to them by Fisheries and Oceans Canada: the status quo (a competitive 12-hr "derby" fishery) or IQs, likely leading to ITQs. Instead, the FFAW worked with license holders to develop a management plan that required harvesters to choose between different fishing periods that spread fishing opportunities over time. This approach improved conservation results, delivered strong economic returns, distributed benefits widely to active fishermen, and allowed an even flow into the market. The authors consider the advantages of these Canadian east and west coast halibut co-management systems and their broader application.

KEYWORDS

benefits, conservation, costs, equity, Individual Transferable Quotas, markets

1 | INTRODUCTION: FISHERMEN-DESIGNED ALTERNATIVES OUTPERFORM ITQS ON BOTH COASTS OF CANADA

This paper considers the contributions of fishermen's organizations to addressing a number of fisheries management problems without resorting to the use of Individual Transferable Quotas (ITQs). Although ITQs have been adopted in a number of jurisdictions, this method of privatizing a public good has proved highly controversial and suffers from distributional inequities and other problems (Macinko & Bromley, 2002; Pinkerton & Edwards, 2009). The solutions offered by these organizations, on the other hand, benefit fishermen, government and fish buyers in that they relieve government of significant costs, are considered legitimate and equitable and thus enforceable, return greater benefits to a larger number of fishermen, and provide more stable and predictable supply of fish to buyers.

Fishermen-designed co-management systems for the closely related Pacific halibut (*Hippoglossus stenolepis*) and Atlantic halibut (*Hippoglossus hippoglossus*) on the west and east coasts of Canada respectively are compared to better characterize what forms of co-management they constitute and how these forms help produce the benefits they deliver. This analysis allows us to confirm old and establish new hypotheses about conditions favouring co-management which have broader applicability.

The west coast layup system which operated for four decades 1933–1976 (interrupted because of World War II and various disagreements 1941–1956) illustrates the simplicity and practicality of the annually designed and enforced fishermen's harvest regulations, while the contemporary east coast example which began in 2013 and is still operating shows how this strategy can be supplemented by attention to traceability, unique regulation of the relationship with buyers and developing management service branches of fishermen's organizations to administer the program. Both these examples supplement a rich maritime anthropology, sociology, economics and political science literature about how fishermen's communities or organizations have made their own rules to prevent the race for fish by allocating fishing opportunity in time, space and/or by specific gear (e.g., Acheson, 2003; Armitage, Berkes, & Doubleday, 2007; Berkes, 1999; Jentoft & McCay, 1995; Langdon, 2007; Ostrom, 1990; Pinkerton, 1989; Pinkerton & Weinstein, 1995; Schlager & Ostrom, 1993; Wilson, Kleban, & Acheson, 1994; Wilson, Nielsen, & Degnbol, 2003). Together with this literature and existing hypotheses about conditions favourable to fisheries co-management, the conditions identified in this paper advance theoretical development in the understanding of optimal design and effectiveness of co-management.

2 | METHODS

The desire to write this paper emerged from discussions among the authors about the importance of documenting fishermen-led management systems and their advantages over market-driven ITQ systems. The similarities between the historical fishermen-led layup scheme for Pacific halibut documented most recently by Pinkerton (2013) and a contemporary management plan for Atlantic halibut devised by the Fish, Food and Allied Workers (FFAW) offered the opportunity to compare two of the creative, socially derived fisheries management approaches developed by fishermen's organizations. With the support of the FFAW and the Canadian Fisheries Research Network (CFRN), Allain conducted interviews with Decker and Carew—the main designers of the Atlantic halibut plan—as well as with FFAW's staff, and produced all figures and tables. He also interviewed the two main Canadian Department of Fisheries and Oceans (DFO) managers responsible for implementing the plan, the Area Chief, Resource Management, in Corner Brook, Newfoundland and the Senior Advisor—Groundfish, at DFO Regional headquarters in St. Johns, Newfoundland. Pinkerton drew on these and other materials to revisit her findings on the Pacific layup system in light of the Atlantic halibut experience, and to consider broader and more universal requirements of a co-managed fishery delivering the benefits identified above. Carew, Allain, and Decker reviewed and revised multiple drafts.

3 | A BRIEF HISTORY OF THE PACIFIC HALIBUT LAYUP SYSTEM

As explained in more detail elsewhere (Pinkerton, 2013), the layup system was initiated by the Seattle Vessel Owners Association in 1933 as an attempt to delay the start of fishing to prevent a drop in price at the start of the fishing season when there was a carry-over of frozen halibut in storage. It was soon endorsed by 18 organizations in the US and Canada and its operation clearly buoyed halibut prices (Thomson, 1975).

The system consisted of rules requiring fishermen to stop fishing (or "lay up") for 6–10 days (depending on the year) following catch delivery, so that deliveries became staggered because of different lengths of individuals' fishing trips. These rules extended the fishing season, created an orderly distribution of landings, leading to higher prices, allowing for in-season rest and repair, and promoting greater safety because fishermen were under no pressure to fish during bad weather. The longer season allowed the supply chain to absorb the product more easily and predictably, reducing the overloading of port facilities and marketing costs/risks of inventory holders. A higher percentage of the catch could be sold fresh, creating upward pressure on prices. There were special rules for smaller, part-time vessels.

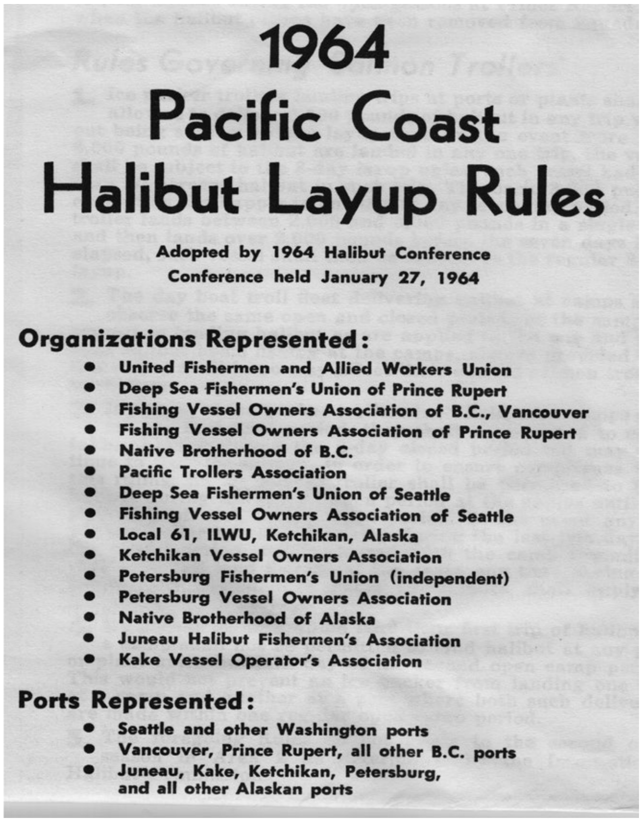
The rules were designed and revised annually by local organization meetings and an annual regional conference of all the participating organizations 1933–1941 and 1957–1976. The rules were simple enough to print on both sides of one sheet of 8.5 × 11 in. paper, which was folded into a pamphlet and distributed to every fisherman (Figure 1). Each participating vessel had a crew delegate who was responsible for reporting its arrivals and departures from port. Reports were made to the "union office or other enforcement officer of the Layup Program," which kept track of compliance with the rules (Crutchfield & Zellner, 2003). The United Fishermen and Allied Workers Union of British Columbia and the Deep Sea Fishermen's Union in the US and Canada, played an important role in enforcing the layup rules because fish processing workers, Halibut Exchange workers (see below), and many crew were unionized and would refuse to deliver or accept halibut from non-compliant vessels. They were also constantly monitoring and reporting on vessels at sea.

The rules were de facto harvest management rules (openings and closings) as effective as any other government-designed system at addressing key problems, at no expense to government, since each organization levied a fee from and enforced the rules on its own members, and those of the other organizations. Most halibut fishermen paid $0.30–$0.50 per 1,000 lbs. of halibut landed to the Halibut Curtailment Fund, which supported the costs of meetings and enforcement.

Rules in the 1950s and later required that halibut be delivered to ports which "have shore-based cold storage and a regular fish exchange where trips are listed and bid for." A "Halibut Exchange" operating in the major ports of Prince Rupert, Vancouver, and Seattle was a public auction at which buyers bid for specific amounts of halibut at a particular price, while cold storage facilities sold ice to fishermen, thus relieving them of the standard industry practice of having to deliver at a lower price to processors who supplied ice and credit in advance (Marchak, Guppy, & McMullan, 1987). The Halibut Exchange auction prices exerted upward pressure on all prices, so that halibut prices in any major port remained fairly competitive within that port and among ports (Pinkerton, 1987).

The Halibut Exchange was also important in maintaining more accurate record of landings and landed value than processors' records alone, as a crew member of each vessel was required to observe the weighing. Thus by requiring fish deliveries through the Exchange, the layup system contributed to both price competition and more accurate catch and price monitoring.

Meetings of the fishermen's organizations which made the layup rules annually were coordinated with those of the International Pacific


1964
Pacific Coast
Halibut Layup Rules

Adopted by 1964 Halibut Conference
Conference held January 27, 1964

Organizations Represented:

- United Fishermen and Allied Workers Union
- Deep Sea Fishermen's Union of Prince Rupert
- Fishing Vessel Owners Association of B.C., Vancouver
- Fishing Vessel Owners Association of Prince Rupert
- Native Brotherhood of B.C.
- Pacific Trollers Association
- Deep Sea Fishermen's Union of Seattle
- Fishing Vessel Owners Association of Seattle
- Local 61, ILWU, Ketchikan, Alaska
- Ketchikan Vessel Owners Association
- Petersburg Fishermen's Union (independent)
- Petersburg Vessel Owners Association
- Native Brotherhood of Alaska
- Juneau Halibut Fishermen's Association
- Kake Vessel Operator's Association

Ports Represented:

- Seattle and other Washington ports
- Vancouver, Prince Rupert, all other B.C. ports
- Juneau, Kake, Ketchikan, Petersburg, and all other Alaskan ports

FIGURE 1 The organizations which made the halibut lay-up rules. Source: front of pamphlet distributed to halibut fishermen in 1964

Halibut Commission (IPHC) which conducted stock assessment, set a Total Allowable Catch, and set the fishing season and fishing areas, so that the fishermen's rules were presented to the IPHC and approved annually, with considerable interaction between scientists and fishermen. Fishermen recommended and got changes, such as where area boundaries should be drawn for ease of monitoring. The IPHC regulators liked the way the layup system distributed effort to early, late, and underexploited stocks. They valued the slowed season, which made it easier to track the catch, while economists liked the longer season which allowed the supply chain to absorb the product more easily and predictably (Crutchfield & Zellner, 2003).

The de facto allocation by fishermen's organizations to smaller part-time and larger full-time fishermen discouraged casual part-time halibut fishermen, and spared DFO the necessity of making difficult allocative political decisions. DFO and the IPHC also valued the fact that the rules were enforced by fishermen's organizations. Since these were virtually harvest management rules, they relieved government regulators of in-season harvest rule-making, allocation, monitoring and enforcement.

In summary, the Pacific layup system prevented a race for fish and congestion on the grounds by staggering fishing and deliveries, designed and revised fishing rules annually, balanced allocations among sectors, monitored deliveries, enforced its rules, funded the foregoing activities, and reported annually to the IPHC, which advocated for the layup system to continue.

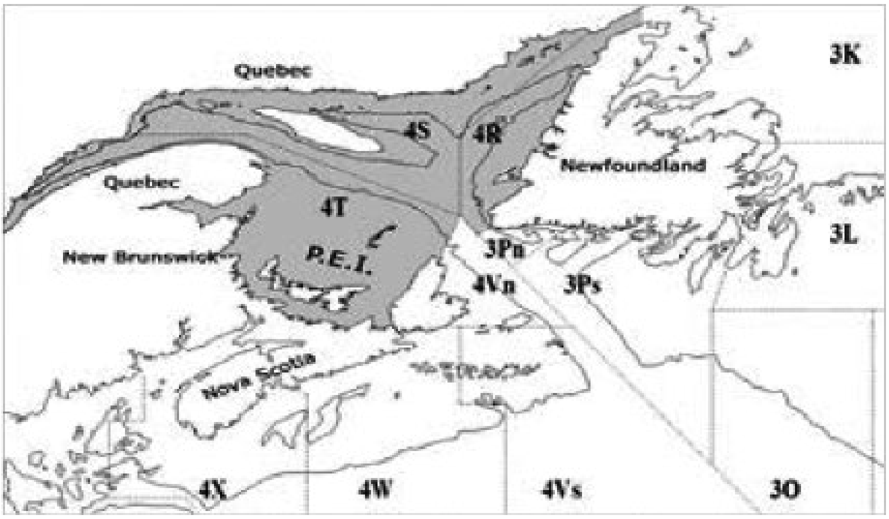


FIGURE 2 Gulf of St. Lawrence NAFO Area 4RST(shaded), 4R and 3Pn. Source: CSAS Science Advisory Report 2015/023

4 | WHAT BENEFITS WERE LOST WHEN PACIFIC HALIBUT WENT TO ITQS

The layup system was discontinued in the mid 1970s when new entrants became numerous but did not join organizations, and the US and Canada would not make the layup rules mandatory. Without the layup system, the fishery became a derby and was ITQed by 1992. ITQs were government's solution to overcapacity and the derby race for fish but had disastrous socioeconomic consequences for many as ITQ ownership or control began to move from active fishermen to investors and processors. For one-third of the fleet which could not afford to own quota, ITQ lease prices cost over 70% of the landed value, making these lessees economically unviable. Crew who had formerly worked on a share system became such poorly-paid wage workers (Pinkerton & Edwards, 2009) that the industry began having difficulty finding reliable and skilled crew and discussed bringing in foreign workers. The cost of fishing for new entrants into the halibut fishery a decade after the ITQ system had been introduced was some 600% higher because of the capital investment required in quota and license under an ITQ. In addition, fishermen had to pay for camera monitoring on board and dockside monitoring, whose annual costs were in the range of $7,875 and $1,800, respectively (Davidson, 2010).

5 | FLEET MANAGED QUOTAS IN THE WESTERN NEWFOUNDLAND OWNER-OPERATOR HALIBUT FISHERY: A CURRENT EAST COAST ALTERNATIVE TO ITQS

5.1 | History of the 2012 management dilemma

To understand the management problems which both DFO and the FFAW were attempting to address, a brief history of the Atlantic halibut fishery is necessary. The Atlantic halibut fishery in the Gulf of St. Lawrence (NAFO Area 4RST, Figure 2) began at the end of the 19th century with landings initially over 4,000 t. During the first half of the 20th century annual landings fell significantly but still averaged 1,500 t before falling sharply in the early 1950s and reaching an all-time low of 91 t in 1982. Total Allowable Catch (TAC) limits were introduced in 1988 but were only reached four times until the early 2000s when halibut abundance and catch rates began to increase significantly. Landings surpassed 800 t in 2013 and 2014; their highest levels in more than 60 years (Fisheries and Oceans Canada, 2015).

A total of 12 different fishing fleets have access to halibut allocations in the Gulf of St Lawrence (Area 4RST). For the purposes of this paper the authors examine the management measures put in place in Division 4R which is limited to Western Newfoundland and Southern Labrador.

By the late 1980s because of the low halibut abundance, participation in the 4R fishery by the fixed gear fleet had dwindled to about 20 longliners (40–50 ft LOA) fishing 30–50 miles offshore (Figure 2). However, these larger boats represented a small segment of the under 65 ft fixed-gear, groundfish fleet sector eligible to fish for halibut in 4R: mostly small, open boats under 35 ft, (often 18–30 ft), fishing within five miles of the coast.

As halibut abundance increased in the early 2000s and moved into coastal inshore areas, these small boat fishermen began to enter the halibut fishery in larger and larger numbers. From the approximately 20 larger boats fishing halibut offshore in the 1990s, participation increased to 185 enterprises (including multi-species vessels) fishing inshore in 2004 and by 2012 participation in the targeted halibut fishery had jumped to 316 enterprises (Figure 3).

The challenges this increasing participation presented to DFO conservation objectives were significant. The DFO used both output (TAC) and effort controls (length of fishery openings and gear restrictions) to manage this fishery and the available 4R halibut TAC was fished on a competitive basis, i.e., each individual enterprise licensed to participate in the fishery could land as much of the TAC as possible under the effort controls available to it until the overall TAC was reached. This increasing participation quickly lead to very significant TAC overruns.

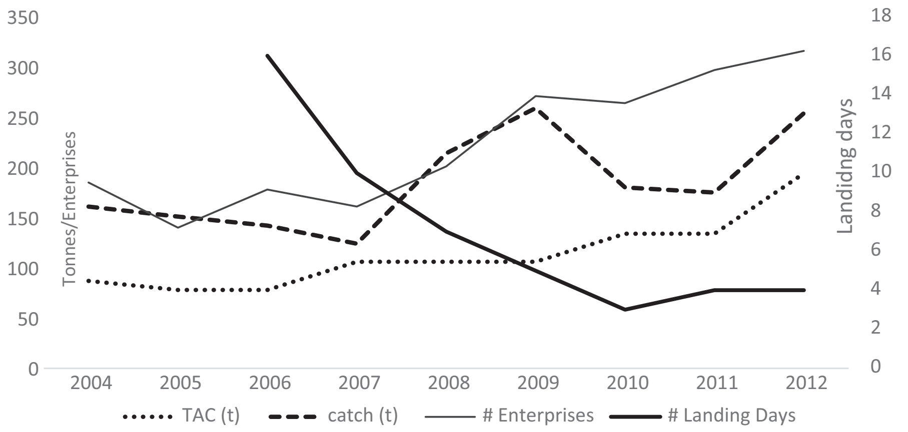


FIGURE 3 Overview 4R halibut fishery 2004–2012. Source: DFO statistics and FSSSB

During the nine-year period from 2004 to 2012 TAC overruns averaged 69% per year and the TAC was exceeded by more than 100% in both 2008 and 2009 (Figure 3). The DFO attempted to deal with these massive quota overuns by severely cutting back on the length of fishery openings. At the end of the 2012 season the halibut fishery in 4R had become a classic derby fishery with 316 individual boats rushing to land as much halibut as they could within the few hours available to them.

From a management perspective the prospects for 2013 were alarming because of a looming latent capacity problem on the horizon. The participation rate could potentially more than double as 691 enterprises (license holders) were entitled to fish halibut in 4R and an additional 82 enterprises could enter this fishery from the neighbouring 3Pn management area. (Sub-division 3Pn has its own quota but is not a scientific stock. Fishermen can choose 4R or 3Pn but not both).

The FFAW was concerned about the deteriorating situation of the fishery: the latent capacity problem, equity issues related to advantages for larger boats under a competitive fishery, conservation problems from TAC overruns, the excessive and increasing effort, product glut, poor quality, low prices, and safety in the race for fish—the same problems which the layup system had addressed in the Pacific halibut fishery. As the certified representatives of all fishermen in the province of Newfoundland and Labrador, the FFAW began holding meetings of 4R groundfish fishermen to discuss alternatives to the competitive fishery. Community level meetings were held in Western Newfoundland over the fall and winter months of 2012–2013 to discuss an alternative management approach for halibut developed by the FFAW. In total, between 500 and 600 fishermen attended these meetings and they voted 95% in favour of the Atlantic Halibut Sustainability Plan (AHSP).

5.2 | The 2013 AHSP

The AHSP applied to fixed gear (<65 ft) groundfish fleets based in Division 4R and was intended to be the first step in (a) addressing ongoing conservation challenges associated with the Atlantic halibut fishery in Division 4R, (b) providing flexibility in the timing of fishing and improving fishermen's incomes, and (c) introducing a branding and traceability program for Atlantic halibut that would help contribute to increased market demand and economic returns in future.

In discussing below how these three intentions were implemented, it is useful to understand the role of two support organizations created by the FFAW, which increased the capacity of the FFAW and the DFO to work together: the FSSSB and the FRC.

5.3 | The AHSP's support and service organizations

The Fisheries Science Stewardship and Sustainability Board (FSSSB) is a not-for-profit company that administers the AHSP. The FSSSB was formed by the FFAW in 2011 to deliver fisheries research and management support by an arm's length organization. It is governed by a five-person Board of Directors comprised of two FFAW representatives, two independent representatives and an independent Chair. The majority of the Board (i.e., the Chair and two Board members) have no affiliation with the FFAW or the fishing industry. All three of these members meet the arm's length criteria as defined under DFO policy. The administrative work for the AHSP carried out by the FSSSB is covered by an administrative fee paid by eligible 4R fishermen who choose to participate in the halibut fishery. In 2017, this fee was $200 for a single participant which covers all costs associated with the delivery of the plan: dockside monitoring costs, tag costs (and costs associated with the distribution of the tags), program material costs, program administration costs including the salary of a program manager and an administrative assistant, costs associated with the appeals process, costs associated with the catch limit reconciliation process, etc.

The Fish Harvester' Resource Centre (FRC), created by the FFAW in 1993, is one of three companies in Newfoundland currently authorized by DFO to provide dockside monitoring services to fishermen. The FRC provides dockside monitoring for virtually all of the catch taken by inshore fishing enterprises in Newfoundland. The FRC is governed by an 11-member Board of Directors, five of which are either fish harvesters or are affiliated with the FFAW. All of these members meet the DFO policy requirement that they be independent and at arm's length from the FFAW.

In addition to these support organizations, critical post-season review, pre-season planning and any necessary in-season management decision-making for the AHSP is provided by a small committee made up of the Program Manager of the AHSP, the FFAW's Regional Staff representative, Inshore Director and Secretary-Treasurer, and the DFO's Area Director, Area Chief for Resource Management, Area Chief for Conservation and Protection, and the Senior Advisor—Groundfish at DFO Regional headquarters. Additional DFO representatives with special expertise (e.g., statistics) may also participate on the committee as needed.

5.4 | The AHSP fishing income test

The first major component of the AHSP involved addressing the "latent capacity" problem by instituting a minimal *fishing income test* as a barrier to entry favouring active, small boat fishermen. Starting in 2013, anyone applying for a license to fish halibut in Division 4R must have made at least $5,000 from fisheries *other than halibut* in the previous year. Limiting access to full-time, active, multi-species fishermen—owner-operators in the fixed gear under 65 ft fleet—who could not make this money either leasing in or leasing out their license—eliminated many part-time or opportunistic fishermen and gave priority to fishermen with a serious commitment to fishing as a significant part of their livelihood. Applications are reviewed by the *AHSP Review Committee*, comprised of two representatives from DFO, two representatives from the FFAW and one independent member appointed by the FSSSB. Applicants who are denied can then submit additional information and a request for further review to the Review Committee.

5.5 | The AHSP individual catch limits and catch reconciliation

A second way the plan addressed TAC overruns was by introducing individual catch limits called "individual harvesting caps." All applicants are assigned an equal cap amount. However, this cap is reduced on a lb- for- lb basis for applicants who exceeded their cap by more than 35 lbs. in the previous year. If appropriate, the initial cap is then adjusted upward or downward by a modest amount (usually by 50 or 100 lbs.) based on an assessment of several factors including the anticipated number of applicants who will be inactive or deemed ineligible and the overall reduction in the aggregate cap amount for applicants who exceeded their cap in the previous year. Each harvester is issued a limited number of tags with his/her license, and each halibut caught has to be tagged before it can be off-loaded from the vessel. This catch limit is applied to all Atlantic halibut caught by the license holder in any fishery, e.g., bycatch of halibut in the turbot fishery. Since the Atlantic halibut fishery is by nature multi-species, there is little or no bycatch of non-target species.

High-grading and discarding of undersized or smaller fish is not considered an important issue in the halibut fishery because of the high survival rate of released halibut (because halibut do not have swim bladders) (Kaimmer & Trumble, 1998; Trumble, Kaimmer, & Williams, 2011). In addition, discarding is not common because baiting and setting hooks on longline gear is time-intensive and bait is expensive; fishermen generally prefer to change their location if they are catching undesired sizes of halibut or non-target species, rather than discarding these. An industry-DFO collaborative Gulf-wide longline survey and tagging program was implemented in 2017 with participation by fish harvester organizations in five provinces (Fisheries and Oceans Canada, 2018, p. 12). Size composition of halibut caught in that survey could be used to determine whether size selection of halibut occurs in the longline fishery and the extent.

5.6 | The AHSP replacement of the derby with week-long fishing periods

A third way the plan attempted to reduce TAC overruns and also improve product quality and safety was to provide alternatives to the derby fishery in a manner which resembled the layup system. Although in 2013 fishermen could choose the option of a 12-hr derby fishery, by 2014 the derby option was eliminated and fishermen had to choose to fish during one of several week-long fishing periods spread out over the season. The purpose was to spread out fishing effort, and was not expected to affect revenue. In 2013 these were four 5-day periods to choose from which, after post-season consultations, became six 7-day periods in subsequent years, with a week closed to fishing between each period.

5.7 | The AHSP's improved catch reporting and monitoring

In addition to the above, the AHSP introduced a series of obligations for harvesters to improve catch reporting and monitoring. Before fish was moved from the landing site, fishermen had to provide a Catch Tally Sheet with: (a) the tag number for each fish, (b) its landed condition, (c) its weight and (d) confirmation it had been properly weighed. This report was telephoned to the FRC dispatch office. The FRC would not issue the required authorization number to move the halibut from the landing site until the information on the Catch Tally Sheet was received. FRC staff monitored the fishery and carried out spot checks on an ad-hoc basis. DFO Conservation and Protection staff throughout Western Newfoundland and Southern Labrador also played a key role doing spot checks to ensure that the halibut catch was being accurately recorded.

5.8 | The AHSP's major innovations in product traceability and marketing

The aspects of the AHSP described so far parallel most of the components of the layup system, with additional attention to bycatch of halibut in other fisheries, which was not addressed by the layup system. The AHSP went far beyond the layup system in two other areas, however: product traceability and a unique collective agreement with buyers which returned far higher prices to fishermen (which may be better than those achieved in the layup system's auctions, although data is lacking on this).

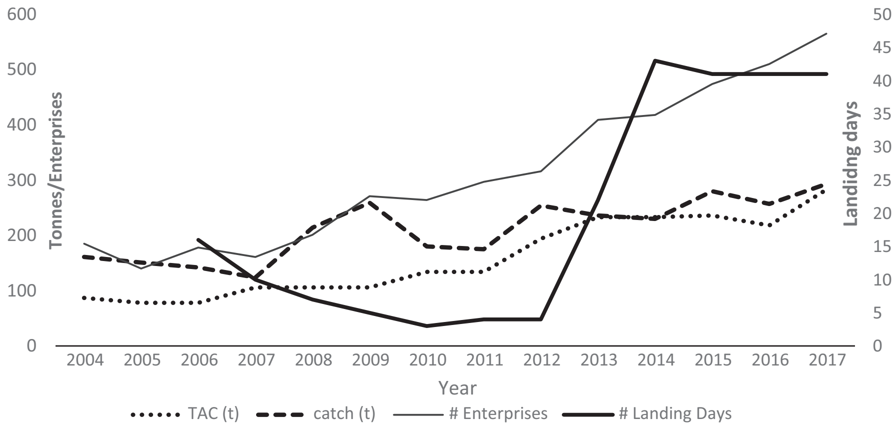


FIGURE 4 Overview 4R halibut fishery 2004–2017. Source: DFO statistics and FSSSB

Product traceability was designed to meet increasing demands from retailers to demonstrate that wild seafoods are sourced from sustainable fisheries. To respond to these market demands the FFAW created *the Newfoundland Seafood Branding and Traceability Program* in conjunction with the FRC and in partnership with Ecotrust Canada's "This Fish" (http://thisfish.info/). The program allows consumers to trace the fish back to the fisherman, establishing a direct connection between consumers and fishermen. This Fish promotes personal storytelling by fishermen permitting a branding of their catch. About 185 fishermen (40%) who applied to fish under the AHSP in 2014 elected to participate in this program by choosing traceability tags instead of the generic DFO monitoring tag.

5.9 | The AHSP's innovation in collective bargaining

Parallel to the AHSP, the FFAW, as the official bargaining agent for Newfoundland and Labrador fishermen, began negotiating a new contract with halibut buyers to leverage some of the quality and supply improvements that the AHSP was expected to deliver. The negotiations led to the 2014 Halibut Collective Agreement which linked the dockside price to the wholesale price paid to buyers/processors. This Agreement included a multi-step process for determining price, using actual receipts provided by the five main buyers of halibut to determine the average price obtained for halibut in the wholesale market (Decker, 2015). These receipts are submitted to an independent auditor who calculates the average and then determines the return based on a negotiated sharing arrangement and the final price. Effectively, the collective agreement provides fishermen with an actual share of what the buyer receives in the market. Overall, fishermen receive approximately 75% of the value of the halibut sold to the wholesale market, which is among the highest for any species.

6 | THE RESULTS OF THE AHSP

6.1 | Meeting conservation challenges

The impacts of the AHSP on the fishery's conservation objectives were immediate. There were no TAC overruns in 2013, 2014 and 2017 (Figure 4) and, although in 2015 and 2016 landings surpassed the TAC by 19 and 18 percent, respectively, these were anticipated as part of the "risk management" approach the co-management partners—the DFO and FFAW adopted. Under this approach the risk of overruns was considered small enough not to be a conservation concern, especially since the overruns would be made up in the following year through individual catch reconciliation and the anticipated increases in quota from the projected increases in halibut abundance.

The FFAW preferred this approach rather than adjusting the harvesting caps by small amounts on an annual basis; instead harvesting caps were raised a few years later. Additionally, DFO reported that the plan made the fishery much more predictable and manageable and that the improvement in safety because fishermen could pick their weather was a significant gain.

6.2 | Providing flexibility in timing of fishing and improving incomes

The elimination of the derby fishery option and having fishermen choose to fish from a series of fishing periods spread over the season produced a five-fold increase in landing days in 2013 and a ten-fold increase in landing days in subsequent years compared to the last year of the competitive fishery in 2012 (Figure 4). As catches per vessel were relatively equal across these time periods, the movement of additional fishing effort toward the later part of the season did not have a detrimental impact on catch rates, fishermen's incomes or supply levels. This spreading out of effort and supply, however, created a more even and predictable flow of product into the market, higher quality fish and better prices in the US market where most of this fish was sold. Because of the price formula agreed to with the buyers under the collective agreement, this led to significant price increases for fishermen.

During the 5-year period (2008–2012) prior to the AHSP and the entry into force of the Collective Agreement, the average price for halibut received by fishermen was \$3.90 per lb. In 2013, the first year of the AHSP but before the Collective agreement came into force, the average price for halibut was \$4.93 per lb. By comparison, the average price paid to fishermen has been \$6.55 per lb. during the four-year

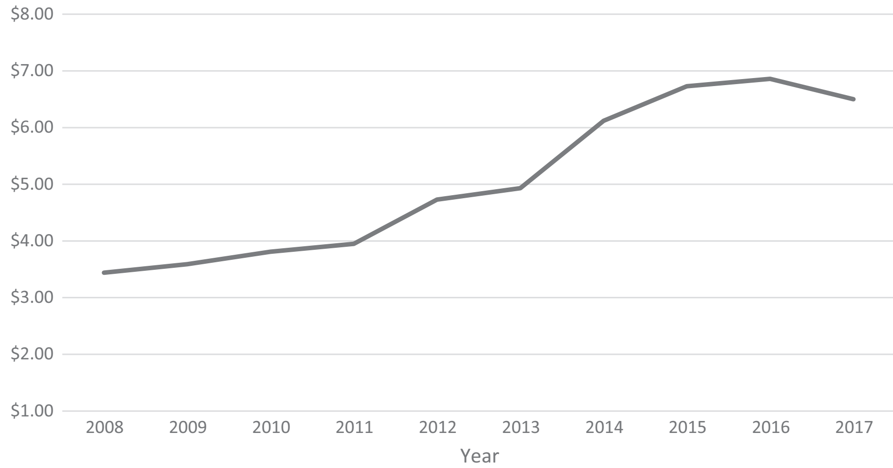


FIGURE 5 Price of Newfoundland halibut (head off, gutted) 2008–2017. Source: FFAW and DFO web site

period since the AHSP and Collective Agreement have both been in place (2014–2017), a 68% increase (Figure 5). These improvements in price are directly linked to the elimination of product glut and the spreading of supply over weeks and months, plus the improvements in product quality through more careful at sea handling that the AHSP allowed. Buyers realized that they could get a better price with a steady flow of higher quality product than they could with a glut of product of varying quality all at once. This allowed them to build relationships in the supply chain and, because this was achieved, the FFAW could build trust, especially with those buyers that were dealing with a lot of the halibut. In turn, this arrangement helped those fishing under the AHSP recognize that, without the current halibut fishing plan, the current collective agreement on halibut would not be possible. This recognition increased the legitimacy and enforceability of the plan.

6.3 | Catch monitoring and reporting

As described above, the AHSP increased the reporting requirements and monitoring of landings which also brought immediate results. Beginning in 2013 individual harvesting caps were not exceeded 83% of the time and have continued to improve. In 2015 DFO proposed 100% dockside monitoring, meaning FRC staff would be at all landing sites, but with some 80 landing sites in Division 4R, the FRC thought the DFO proposal was too costly and also unwarranted, given the comprehensiveness of existing reporting. It proposed an alternative. By having dockside monitoring strategically planned for each fishing period based on where the majority of the catch was projected to be landed in that period, it was able to get dockside monitoring at about 20 of the major landing sites, covering 60% of the catch by 2015, 72% in 2016 and 69% in 2017. Knowledge of the dynamics of the fishery allowed for efficient use of the available monitoring resources, thereby keeping costs down. The DFO Area Chief stated that the most important aspect of the AHSP was that, although the TAC was a little exceeded, the fishery was much improved and that it was much easier to manage the amount of fish coming out of the water than it had been under the derby fishery. "We were relatively happy with the level of coverage sustained by the dockside monitoring company."

6.4 | Costs of the AHSP to fishermen and DFO

What were the costs to fishermen of the entire AHSP? Fishermen paid $200 for a license to catch 1,250 lbs. or $300 to catch 2,100 lbs. under the buddy-up system. These included all costs associated with the implementation of the AHSP: fish tags, dockside monitoring fees, costs associated with the move toward a fish branding and traceability system, and costs of the general administration of the plan as discussed above. Notably, the cost to fishermen of operating under the AHSP were significantly less than the costs of fishing under the Pacific halibut ITQ system detailed above where quota leasing costs can absorb upwards of 70 percent of the landed value, and on board cameras plus dockside monitoring can be over $9,000.

What were the costs to government of the entire AHSP? The AHSP is funded entirely by the $200 administrative fee that each harvester pays upon application. In 2017, this amounted to about $110,000 in gross revenue. As noted above, all costs associated with the delivery of the Plan - including costs related to dockside monitoring, fish tags, program materials and administrative support are covered out of this administrative fee. The Plan does not receive any funding from DFO or other government agencies and is not "cross-subsidized" by any government funding which the FSSSB derives from other projects.

DFO officials did identify some additional administrative workload with the AHSP. The AHSP rests on the allocation of individual catch limits to individual license holders and the annual reconciliation of these limits with the license holder's actual catch. Most of the administrative work associated with the catch reconciliation is carried out by the FSSSB. The reconciliation is on a lb. for lb. basis for all harvesters who exceed their cap by more than 35 lbs. or the approximate weight of a single halibut. The FSSSB provides the DFO with a Microsoft-Excel spreadsheet containing data on the individual catch history of each fisherman who participated in the fishery. However, because the DFO's licensing data base is not compatible with Microsoft-Excel, the FSSSB's data must be re-entered manually into the DFO data base for each fisherman. This administrative task creates additional workload for the DFO compared to the simplicity of automatically allocating equal individual catch shares under an IQ system, as each fisherman could potentially have a different individual cap based on his/her catch history. This problem is further compounded by the lack of administrative flexibility within a large administrative apparatus like the DFO. For example, the license conditions (i.e., individual catch limits) have to be issued via the Department's National Online Licensing System (NOLS). As such, the system is not only incompatible with Microsoft Excel, but also difficult to modify to accommodate a regional initiative such as the AHSP. In other words, regional DFO personnel do not have the freedom to modify or adapt a national system to accommodate a regional system no matter how beneficial the regional system may be to the department's overall mandate and core objectives, i.e., conservation and sustainable use of fisheries resources.

7 | DISCUSSION: WHAT TYPE OF CO-MANAGEMENT IS THE AHSP AND THE LAYUP SYSTEM?

The institutional arrangements in the AHSP demonstrate the existence of most dimensions of "complete" co-management (Pinkerton, 2003; Pinkerton & Weinstein, 1995), seven dimensions of which are identified and discussed below in italics. First and most important, the FFAW took action at the highest level of power to *create, and continue to evaluate, management policy* by proposing the plan and convincing DFO it would be effective. Had the FFAW not done so, DFO would most likely have enacted an IQ system which would likely have evolved into an ITQ system. This would have radically changed many other aspects of the management system, as discussed above, creating a fundamentally different policy direction for the halibut fishery, particularly in the area of equitable distribution of benefits to active fishermen. In the discussion below, we characterize the AHSP as a system of cooperatively held rights, rights exercised by DFO, the FFAW, and the independent service and support organizations administering the AHSP. Once initiated, what we will call simply "the AHSP" continues to exercise *policy-making and evaluation rights*, in that the plan continues to evolve in response to analysis of results.

Second, the AHSP allows the collective exercise of *access and exclusion rights* by defining *who* could qualify for a license: active fishermen, owner-operators, excluding part-time, opportunistic fishermen or investors. This was an important exercise in producing equity, as it allowed many active fishermen to participate in the halibut fishery as part of their multi-species livelihood, instead of a few having exclusive benefits from the system, as occurs in many rationalized limited entry fisheries.

Third, the AHSP *prevented the exercise of the alienation rights* present de facto in many other Canadian fisheries by not allowing the sale, lease or transfer of licenses to non-fishermen to use as commodities and investment instruments. Fishermen apply annually for a halibut license, and must continue to meet qualification standards. By being willing to raise the bar in future on the amount of earnings in other fisheries which qualify an applicant for a halibut license, the FFAW is also working to ensure that benefits are not spread too thinly. This attention to distributional effects is a key to the legitimacy of the system.

Fourth, the AHSP permits the exercise of *harvest management rights* by defining *when* fishing could take place by spreading out fishing times and requiring members to select a time period, thereby creating non-derby conditions such as greater safety and less crowding on the grounds. It is continually revising and improving these rules through meetings with fishermen members to get feedback and revise the plan. Although the rule about counting halibut bycatch in other fisheries towards one's individual halibut harvest cap could be considered part of harvest management, we prefer to consider it the exercise of a *conservation right* (Jones, Rigg, & Pinkerton, 2017), i.e., the right to prevent overfishing, and a fifth right.

Sixth, the AHSP permits the exercise of *monitoring and enforcement rights* for both the access rules and the harvest management rules that it had made. The FSSSB insured that fishermen properly qualified for access, while tagging and reporting rules, supplemented by dockside monitoring, insured that any fish exceeding individual cap limits was deducted from the following year's cap.

Finally, the AHSP as it evolved gave fishermen *the right to recover optimum value* from the fishery by being able to plan for supply flow and product quality. This enabled the negotiated collective agreement with processors which connected the wholesale price to the landed value.

The only co-management right/duty not mentioned in the plan, and not yet apparent as being exercised, is fish habitat protection. However, this may be a right which is undeclared in this context, or one which will evolve in the case of threats to marine habitat.

The AHSP management system could be considered de facto nearly complete co-management. It is important to note that *co-management* means that de jure rights are retained by government, while a large set of de facto rights are allocated to the FFAW and to boards on which the FFAW serves. It is notable that both DFO and the FFAW make decisions cooperatively in their pre- and post-season review committee and in the AHSP Review Committee. The fact that Carew, who serves as the Program Manager for the AHSP and the independent Chair of the AHSP Review Committee, is a former DFO employee, adds considerably to the trust which is being continually built.

Most of the co-management roles played by the FFAW and other parties on the FSSSB and FRC which are identified above were also played by fishermen's organizations in the layup system, except that under the layup they had much weaker exclusion rights for smaller part-time boats and no control over the access and alienation rights of fishermen, whose licenses could be owned by and sold to anyone. The layup system also had no rules accounting for bycatch of halibut in other fisheries and no traceability provisions; the layup had possibly equal rights to recover optimum value for fishermen through its auctions. However, the de facto monitoring and enforcement rights exercised under the layup system were stronger than those in the AHSP, even though there were no de jure rights in this area.

A notable common condition in both systems is the presence of enabling, supporting or "bridging" institutions or organizations (Crona & Parker, 2012) which provide capacity for co-management, bridge fragmented understandings (Weiss, Hamann, & Marsh, 2013), share knowledge and experience to enable adaptive learning and problem solving (Plummer et al., 2012; Tengo, Brondizio, Elmqvist, Malmer, & Spierenburg, 2014), and enable the formation of issue networks and coalitions at a local, regional and state level (Pahl-Wostl, 2009; Scott, 1990). This occurred informally between the layup rule-making body and the IPHC, as well as among the varied organizations participating in the layup system, while it was a formal arrangement between the FFAW, DFO, the FSSSB and FRC. In the layup situation, the IPHC pleaded with the US and Canada to make the layup rules mandatory when new entrants became numerous in the 1970s and did not join organizations, but this necessary de jure enforcement situation was not allowed to develop, leading to the demise of the layup system. In other words, the de facto support which the IPHC offered the layup system was not allowed to become primary, and the de jure legal support by the in-country federal and state agencies was not forthcoming, even though they found the layup system useful. In contrast, the FSSSB and FRC supported and provided capacity for the AHSP while DFO both experienced its usefulness and gave it a de jure role.

It is these institutional arrangements surrounding the implementation of the AHSB and the layup system in halibut which allow us to generate new middle-range hypotheses or confirm and refine existing hypotheses about conditions supporting fisheries co-management. This common sociological approach contributes to theory building (Merton, 1968), using findings from case studies inductively to generate hypotheses, rather than attempting to deduce conclusions from a large sample. Building on Agrawal (2003), Pinkerton and John (2008) proposed a comprehensive set of conditions supporting fisheries co-management in the nature of the resource, the community, the government agency, and in the nature of the institutional arrangement itself. The hypotheses below contribute to those on the nature of the institutional arrangement, the nature of the community, and what we might call "bridging conditions," a category incompletely theorized in the co-management literature, as discussed below.

1. Co-management arrangements are more likely to develop and persist if a system of allocation between large and small operations, as well as between full-time and opportunistic fishermen is based on equity principles embraced by the majority of fishermen. Jentoft (2000) has noted that to have complete legitimacy, a system must be justified according to moral principles and values which underpin the rational, legalistic, logistical and scientific grounds for management, while Pinkerton and John (2008) hypothesized that political legitimacy is an additional important dimension of legitimacy creation, when the local leadership is perceived as an effective defender of local fishing rights, effective at voicing issues to the state when necessary. Hypothesis 1 supports and extends both these hypotheses by applying them to a particular type of equity (large vs. small operations, full-time vs. part-time) which is very important in fishing. The FFAW was effective in creating a united fishermen's voice in articulating this ethical principle and in producing a number ($5,000 minimum catch in another species) which could be used to implement it.
2. Co-management arrangements are more likely to develop and persist if there is united fishery-wide leadership in the non-governmental parties. This was evident in the fact that the FFAW legally represents all fishermen in Newfoundland and Labrador, that it has a long history of highly legitimate leadership, and that it effectively mobilized support for new co-management arrangements based on fishermen's values about conservation, equity and optimum value. The existence of a unified leadership in a fishery allows a fishing organization like the FFAW to mediate among the competing interests in its membership (geographic, gear sector, etc.) and to present consensus positions to the state regulator, thereby avoiding having these different interests in open competition and conflict with each other over management decisions were they represented by separate organizations. This homogeneity reduces transaction costs of decision-making both for fishermen and for government (Taylor & Singleton, 1993).
3. Co-management arrangements are more likely to develop and persist in the presence of independent supportive bridging organizations. The FSSSB and the FRC played key roles in the ability of the co-managers to implement the AHSP, while the layup system ultimately collapsed at least partly because the US and Canada would not make mandatory the voluntary role of its member organizations, which might have served this purpose, or respond to the pleas of the IPHC which collaborated with the member organizations. This hypothesis builds on the work of scholars such as Crona and Parker (2012) who emphasize the importance of bridging organizations which bring together actors across science, policy and management sectors. In the case of the layup system, it was science and multiple industry sectors which worked together to produce and enforce rules, while the FSSSB and the FRC were made up of industry, and retired civil servants. Pahl-Wostl (2009) emphasizes that it is such initiatives from outside government which produce innovative solutions to management problems, while privatization, such as ITQs and centralized political systems impede social learning. Weis et al. (2013) emphasize that the trust and legitimacy discussed in hypothesis 1 are the two central variables which influence the uptake of knowledge across social groups such as these bridging organizations.

8 | CONCLUSIONS

This paper has considered the advantages and disadvantages of two management systems for the halibut fishery which were designed by fishermen's organizations to space out the delivery of halibut into the market, to create a fairer allocation of access, to increase safety on the fishing grounds, and to get better returns for fishermen. Because the fishermen's organizations in both cases contributed significantly to making harvest management rules, and because the rules were supported by their membership, monitoring and enforcement costs were significantly reduced and overall costs and stress on the management authority was also greatly reduced. The orderly flow of halibut into the market in a high quality condition allowed fishermen to obtain a high price, through an auction in the case of the layup system and through a guaranteed share of about 75% of the wholesale price in the case of the AHSP. Both systems also contributed to conservation, the layup system by spreading out effort to a larger number of areas and underutilized stocks and the AHSP by significantly reducing TAC overruns through individual harvesting caps and by monitoring and reducing halibut bycatch in other fisheries. The solutions offered by these organizations are highly beneficial to fishermen, government and fish buyers. These systems nonetheless required capacity to administer and collaborate with government agencies who, in the case of the AHSP, worked with fishermen's organizations through various support, service and bridging organizations especially overseeing participation and catch monitoring.

The AHSP is notable in enabling the exercise of seven management rights, constituting a rare and nearly complete form of co-management. Most of these rights have been documented in other cases, but seldom in combination. What has not been previously documented is the development of enabling service branches of fishermen's organizations which have the capacity to administer the co-management plan, and the co-management relationships built into the boards of these service branches which jointly run them. The second new condition for co-management adopted in the AHSP is the effort to spread benefits broadly to full-time large and small boat fishermen, while not spreading benefits too thinly. Finally, the existence of a broadly-representative organization of fishermen whose determination to continue working with their membership and experimenting until they "get it right" is an important indicator or adaptability in the search for equity.

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REFERENCES

Acheson, J. (2003). *Capturing the commons: Revising institutions to manage the Maine lobster industry*. Hanover, NH: University Press of New England.

Agrawal, A. (2003). Sustainable governance of common-pool resources: Context, methods, politics. *Annual Review of Anthropology*, *32*, 243–262. https://doi.org/10.1146/annurev.anthro.32.061002.093112

Armitage, D., Berkes, F., & Doubleday, N. (Eds.) (2007). *Adaptive co-management: Collaborative learning and multi-level governance*. Vancouver, BC: University of Columbia Press.

Berkes, F. (1999). Cree fishing practices as adaptive management. In F. Berkes (Ed.), *Sacred ecology: Traditional knowledge and resource management* (pp. 111–126). Philadelphia, PA: Taylor & Francis.

Crona, B., & Parker, J. (2012). Learning in support of governance. Theories, methods, and a framework to assess how bridging organizations contribute to adaptive resource governance. *Ecology and Society*, *17*(1), 32–50.

Crutchfield, J., & Zellner, A. (Eds.) (2003). *The economics of marine resources and conservation policy: The Pacific halibut case study with commentary*. Chicago, IL: University of Chicago Press.

Davidson, A. (2010). The cost-benefit ledger of quota leasing. *Marine Policy*, *34*, 1115–1116. https://doi.org/10.1016/j.marpol.2010.01.013

Decker, D. (2015). Atlantic halibut returns continue to rise. *Union Forum*. Fall, 35–36.

Fisheries and Oceans Canada. (2015). Stock assessment of Atlantic halibut of the Gulf of St. Lawrence (NAFO Divisions 4RST) for 2013 and 2014. Canadian Science Advisory Secretariat, Science Advisory Report 2015/023.

Fisheries and Oceans Canada. (2018). Stock assessment of Atlantic halibut of the Gulf of St. Lawrence (NAFO Divisions 4RST) for 2016. Canadian Science Advisory Secretariat, Science Advisory Report 2017/0252.

Fisheries Science Stewardship and Sustainability Board (FSSSB). (2015). Atlantic Halibut Sustainability Plan – Division 4RST. Information brochure.

Jentoft, S. (2000). Legitimacy and disappointment in fisheries management. *Marine Policy*, *24*, 141–148. https://doi.org/10.1016/S0308-597X(99)00025-1

Jentoft, S., & McCay, B. (1995). User participation in fisheries management: Lessons drawn from international experiences. *Marine Policy*, *19*, 227–246. https://doi.org/10.1016/0308-597X(94)00010-P

Jones, R., Rigg, C., & Pinkerton, E. (2017). Strategies for assertion of conservation and local management rights: A Haida Gwaii herring story. *Marine Policy*, *80*, 154–167. https://doi.org/10.1016/j.marpol.2016.09.031

Kaimmer, S., & Trumble, R. (1998). Injury, condition, and mortality of Pacific halibut bycatch following careful release by Pacific cod and sablefish longline fisheries. *Fisheries Research*, *38*, 131–144. https://doi.org/10.1016/S0165-7836(98)00153-2

Langdon, S. (2007). Sustaining a relationship: Inquiry into the emergence of a logic of engagement with salmon among the southern Tlingits. In M. E. Harkin, & D. R. Lewis (Eds.), *Native Americans and the environment: Perspectives on the ecological Indian* (pp. 233–276). Lincoln, NB: University of Nebraska Press.

Macinko, S., & Bromley, D. (2002). *Who owns America's fisheries?* Washington, DC: Island Press.

Marchak, P., Guppy, N., & McMullan, J. (Eds.) (1987). *The fishing and fish processing industries of British Columbia*. Vancouver, BC: University of British Columbia Press.

Merton, R. K. (1968). *Social theory and social structure* (1968 Enlarged ed.).New York, NY: Free Press.
Ostrom, E. (1990). *Governing the commons. The evolution of institutions for collective action*. New York, NY: Cambridge University Press. https://doi.org/10.1017/CBO9780511807763
Pahl-Wostl, C. (2009). A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change*, *19*, 354–365. https://doi.org/10.1016/j.gloenvcha.2009.06.001
Pinkerton, E. (1987). Competition among B.C. fish processing firms. In P. Marchak, N. Guppy & J. McMullan (Eds), *Uncommon property: The fishing and fish processing industries of British Columbia* (pp. 66–91). Vancouver, BC: University of British Columbia Press.
Pinkerton, E. (1989). Introduction: Attaining better fisheries management through co-management: Prospects, problems and propositions. In E. Pinkerton (Ed.), *Cooperative management of local fisheries: New directions for improved management and community development* (pp. 1–33). Vancouver, BC: University of British Columbia Press.
Pinkerton, E. (2003). Toward specificity in complexity: Understanding co-management from a social science perspective. In D. C. Wilson, J. R. Nielsen, & P. Degnbol (Eds.), *The fisheries co-management experience: Accomplishments, challenges and prospects* (pp. 61–77). Dordrecht, The Netherlands: Kluwer. https://doi.org/10.1007/978-94-017-3323-6
Pinkerton, E. (2013). Alternatives to ITQs in equity–efficiency–effectiveness trade-offs: How the lay-up system spread effort in the BC halibut fishery. *Marine Policy*, *42*, 5–13. https://doi.org/10.1016/j.marpol.2013.01.010
Pinkerton, E., & Edwards, D. (2009). The elephant in the room: The hidden costs of leasing Individual Transferable Fishing Quotas. *Marine Policy*, *33*, 707–713. https://doi.org/10.1016/j.marpol.2009.02.004
Pinkerton, E., & John, L. (2008). Creating local management legitimacy. *Marine Policy*, *32*, 680–691. https://doi.org/10.1016/j.marpol.2007.12.005
Pinkerton, E., & Weinstein, M. (1995). *Fisheries that work. Sustainability through community-based management*. Vancouver, BC: David Suzuki Foundation. http://davidsuzuki.org/publications/reports/1995/fisheries-that-work/
Plummer, R., Crona, B., Armitage, D., Olsson, P., Tengo, M., & Yudina, O. (2012). Adaptive co-management: A systematic review and analysis. *Ecology and Society*, *17*(3), 11–32.
Schlager, E., & Ostrom, E. (1993). Property rights regimes and coastal fisheries: An empirical analysis. In T. L. Anderson, & R. T. Simmons (Eds.), *The political economy of customs and culture: Informal solutions to the commons problem* (pp. 13–41). Lanham, MD: Rowman and Littlefield.
Scott, A. (1990). *Ideology and the new social movements*. London, UK: Unwyn Hyman.
Taylor, M., & Singleton, S. (1993). The communal resource: Transaction costs and the solution of collective action problems. *Politics & Society*, *21*(2), 195–214. https://doi.org/10.1177/0032329293021002004
Tengo, M., Brondizio, E., Elmqvist, T., Malmer, P., & Spierenburg, M. (2014). Connecting diverse knowledge systems for enhanced ecosystem governance: The multiple evidence base approach. *Ambio*, *43*, 579–591. https://doi.org/10.1007/s13280-014-0501-3
Thomson, A. (1975). *The Pacific halibut fishery 1888-1974*. MA thesis presented to the graduate faculty, Central Washington State University.
Trumble, R., Kaimmer, S., & Williams, G. (2011). Estimation of discard mortality rates for Pacific halibut bycatch in groundfish longline fisheries. *North American Journal of Fisheries Management*, *20*(4), 931–939.
Weiss, K., Hamann, M., & Marsh, H. (2013). Bridging knowledges: Understanding and applying Indigenous and western scientific knowledge for marine wildlife management. *Society and Natural Resources*, *26*(3), 285–302. https://doi.org/10.1080/08941920.2012.690065
Wilson, J., Kleban, P., & Acheson, J. (1994). Chaos, complexity and community management of fisheries. *Marine Policy*, *18*, 291–305. https://doi.org/10.1016/0308-597X(94)90044-2
Wilson, D. C., Nielsen, J. R., & Degnbol, P. (Eds.) (2003). *The fisheries co-management experience: Accomplishments, challenges and prospects*. Dordrecht, The Netherlands: Kluwer.

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