RURAL AND REGIONAL AFFAIRS AND TRANSPORT REFERENCES COMMITTEE

ANSWERS TO QUESTIONS ON NOTICE

REGULATION OF FARM PRACTICES THAT IMPACT WATER QUALITY OUTCOMES IN THE GREAT BARRIER REEF

27 July 2020

REFERENCE: Questions on notice (Hansard 27 July 2020, Page 61)

QUESTION: 1
Hansard extract

Senator GREEN: Sometimes there's a view that the data and the marine science aren't connecting with farm practices and things that are happening on the ground. I'm interested in how your work is making that connection or finding ways that that connection can happen and in how farm practices then can influence what happens out in the water.

Dr Taylor: Thank you for clarifying that. Just reflecting on some of the comments made in sessions this morning, some of the points raised talked to the issue of farmer knowledge and science. The work that we've done over recent years points to the fact that both of these sources of information are very important in complex problem solving. There is a lot of work underway which looks to introduce farming communities to the science. I'm directly involved in a number of projects where we're looking at how scientists and farmers work together to understand the problem better at the local scale and to develop cooperative solutions to fixing those problems.

Senator GREEN: Maybe on notice, if it's not already in the submission, if you could provide some examples of those projects, it would be really helpful.

ANSWER
A routine part of CSIRO's research methodology is to work in partnership with farmers and extension staff to (1) ensure the "research questions" being asked are directly relevant to farming communities and enterprises and (2) facilitate communication to end users. Recently we have used our advanced digital capability to develop and deploy a system called the 1622WQ app (Vilas et al., 2020, https://wq.1622.farm/) to provide farmers with "real time" data from local water quality activities. It is currently deployed in three water quality monitoring projects in the wet tropics, including the well-known "Project 25" where CSIRO is working closely with James Cook University colleagues, CANEGROWERS Cairns Region and a local Steering Committee of growers; the Wet Tropics Major Integrated Project; as well as the Queensland Government water quality monitoring program. Since the launch of 1622WQ in January it has acquired more than 1,100 users.

CSIRO's methodology also includes research on commercial farms (rather than research stations). Examples (for sugarcane) include testing new nitrogen fertiliser management strategies (Thorburn et al 2011a), assessing nitrogen losses from farms under conventional (Thorburn et al., 2011b) or new practices (Webster et al., 2012), or investigating whether seasonal climate forecasting can help in nitrogen fertiliser management (Thorburn et al., 2011c, Everingham et al., 2018). Many of these projects include economic analyses (e.g. Kandulu et al., 2018).

In the grazing sector, projects such as EcoGraze were established approximately 20 years ago and were focused on providing data and information regarding appropriate stock management for sustainable grazing (Ash et al., 2001). More recently, several projects have involved monitoring the water quality from different land use and stocking rates (e.g. Koci et al., 2020) and as part of the National Environmental Science Program (NESP) Program, CSIRO currently has seven paired real time monitoring stations on commercial grazing properties in the Burdekin catchment evaluating the effectiveness of gully remediation (Bartley et al., 2020). These sites have all had strong landholder engagement.

Publications cited above:

Ash, A., Corfield, J. and Ksiksi, T., 2001. The Ecograze Project: developing guidelines to better manage grazing country, CSIRO Sustainable Ecosystems and QDPI, Townsville.

Bartley R, Hawdon A, Henderson A, Abbott B, Wilkinson S, Goodwin N, Ahwang K. 2020. Quantifying the effectiveness of gully remediation on off-site water quality: preliminary results from demonstration sites in the Burdekin catchment in the 2019/20 wet season. Report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns. http://nesptropical.edu.au/index.php/technical-reports-round-2/. pp: 51.

Everingham, Y., Schroeder, B., Skocaj, D., Thorburn, P. (2018). How much N will that crop need? Incorporating climate forecasting to improve nitrogen management in the Wet Tropics. Final report, SRA project 2015/075.

Kandulu, J., Thorburn, P., Biggs, J and Verburg, K. (2018). Estimating economic and environmental trade-offs of managing nitrogen in Australian sugarcane systems taking agronomic risk into account. Journal of Environmental Management 223, 264–274.

Koci, J., Sidle, R.C., Kinsey-Henderson, A.E., Bartley, R., Wilkinson, S.N., Hawdon, A.A., Jarihani, B., Roth, C.H. and Hogarth, L., 2020. Effect of reduced grazing pressure on sediment and nutrient yields in savanna rangeland streams draining to the Great Barrier Reef. Journal of Hydrology, 582: 124520, https://doi.org/10.1016/j.jhydrol.2019.124520.

Thorburn, P.J., Biggs, J.S., Webster, A.J. and Biggs, I.M. (2011a). An improved way to determine nitrogen fertiliser requirements of sugar cane crops to meet global environmental challenges. Plant and Soil 339, 51-67.

Thorburn, P.J., Biggs, J.S., Attard, S.J. and Kemei, J. (2011b). Environmental impacts of irrigated sugarcane production: Nitrogen lost through runoff and leaching. Agriculture Ecosystems and Environment 144, 1-12.

Thorburn, P.J., Jakku, E., Webster, A.J. and Everingham, Y.L. (2011). Agricultural decision support systems facilitating co-learning: a case study on environmental impacts of sugarcane production. International Journal of Agricultural Sustainability 9, 322-333.

Vilas, M.P., Thorburn, P.J., Fielke, S., Webster, T., Mooij, M., Biggs, J.S., Zhang, Y., Adham, A., Davis, A., Dungan, B., Butler, R. and Fitch, P. (2020). 1622WQ: a web-based application to increase farmer awareness of the impact of agriculture on water quality. Environmental Modelling and Software, in press.

Webster, A.J., Bartley, R. Armour, J.D., Brodie, J.E. and Thorburn, P.J. (2012). Reducing dissolved inorganic nitrogen in surface runoff water from sugarcane production systems. Marine Pollution Bulletin 65, 128–135

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QUESTION: 2
Hansard extract

ACTING CHAIR: In your submission, in relation to the grazing management, you cite a range of ground-cover thresholds to filter sediment and reduce run-off, and you make reference to the CSIRO grazier developed Reef Trust program. In your experience, how effective has this program been?

Dr Steele: Maybe we'll take the question on notice. That might be useful.

ANSWER
With respect to ground-cover thresholds in grazing lands, a number of studies in the Burdekin and surrounding catchments have investigated the effect of changing ground cover (pasture) on runoff and erosion at the hillslope scale.

Runoff plot trials have shown that areas with high cover have lower runoff than areas with low cover (Scanlan et al., 1996b). Runoff varies considerably with the arrangement of cover (Bartley et al., 2006), however, cover may have little effect on overland flow during very large rainfall events (>100 mm with intensities between 45 and 60 mm/h) (McIvor et al., 1995; Scanlan et al., 1996b). Roth (2004) determined that ground cover needs to be >75% to enable infiltration during high intensity events.

Soil loss from grazed hillslopes increases as vegetation cover decreases, with the rate decreasing sharply as cover increases beyond 40% (Bartley et al., 2010a; McIvor et al., 1995; Scanlan et al., 1996b). When cover is <40%, both fine (<63 µm) and coarse (>63 µm) sediment fractions are eroded; however, when cover is high (>70%), coarse fractions are trapped on the hillslope, and only fine fractions move off the hillslope (Scanlan et al., 1996b; Silburn et al., 2011).

Ground cover is also very 'patchy' in these landscapes (Ludwig et al., 2007) and this results in large variability in sediment yields even for hillslopes under the same management regime (Bartley et al., 2006). Patchy vegetation on erodible soils within riparian zones can also lead to the initiation of alluvial gullies and scald features (Shellberg et al., 2016).

The Queensland Government is responsible for monitoring ground cover trends on grazing lands over time. CSIRO is unable to comment on how cover trends have changed outside of the research trials outlined above.

The current Reef Trust Program has a strong focus on reducing sediment and particulate nutrients from gullies and streambanks, rather than hillslopes or paddocks. The reason for this is that although hillslopes or paddocks are the main source of runoff (water), gullies and streambanks are the main sources of sediments (Wilkinson et al., 2013) The gully erosion control approaches that are being applied in GBR catchments are to stabilise gully headcut, walls and floors and to reduce runoff into gullies. Thirty-seven studies globally have all found that these approaches reduce sediment loss, by between 12% and 94%; typically, between 40 and 80% (Bartley et al., In press).

CSIRO provides technical advice and support to Reef Trust projects which are led by natural resource management groups and agencies. These projects estimate the expected reductions in sediment loss at each and every site before work commences based on standardised methods using historical erosion rates and the planned on-ground work. The estimated reductions in sediment loss at each site are each independently reviewed by CSIRO officers or other researchers. After work is complete the implementation is monitored at each site, including monitoring of ground cover. The first program to be completed using this method was estimated to reduce fine sediment loads to the GBR lagoon by 5,400 tonnes per year (Wilkinson et al., 2019). Case studies in the Mary River and Normanby River catchments described in that report found that formerly eroding gullies were now stable, and that the landholders contributed to the project implementation and supported the changed management of the project sites. Further reductions are accruing each year from ongoing Reef Trust projects.

At a subset of Reef Trust sites, researchers have been measuring the reductions in sediment loss. One study found 80% lower sediment concentrations from a reshaped and rock-capped gully in the Normanby River catchment relative to an adjacent untreated gully, and is currently undergoing peer review (Doriean et al., 2020). A second study in the Burdekin River catchment measured substantial reductions in sediment loss from runoff diversion banks and small gully check dams (Koci et al., In review). Such local evaluation studies are refining understanding of the reductions in sediment loss achieved using specific techniques in the GBR catchment area.

As described above, the current Reef Trust projects have been efficient and are effective relative to their scope. However, they will reduce GBR sediment loads by less than 3%, and to effectively meet the targeted 25% reductions in sediment loads (The State of Queensland, 2018) will require their continuation and an increase in scale.

Publications cited above:

Bartley R, Poesen J, Wilkinson SN, Vanmaercke M. In Press. A review of the magnitude and response times for sediment yield reductions following the rehabilitation of gullied landscapes. Earth Surface Proc. and Landforms. https://doi.org/10.1002/esp.4963.

Bartley, R., Corfield, J.P., Abbott, B.N., Hawdon, A.A., Wilkinson, S.N. and Nelson, B., 2010. Impacts of improved grazing land management on sediment yields, Part I: hillslope processes. Journal of Hydrology, 389(3-4): 237-248.

Bartley, R., Roth, C.H., Ludwig, J., McJannet, D., Liedloff, A., Corfield, J., Hawdon, A. and Abbott, B., 2006. Runoff and erosion from Australia's tropical semi-arid rangelands: influence of ground cover for differing space and time scales. Hydrological Processes, 20(15): 3317-3333.

Doriean NJC, Bennett WW, Spencer JR, Garzon-Garcia A, Burton JM, Teasdale PR, Welsh DT, Brooks AP. 2020. Landscape scale remediation reduces concentrations of suspended sediment and associated nutrients in alluvial gullies of a Great Barrier Reef catchment: evidence from a novel intensive monitoring approach. Hydrol. Earth Syst. Sci. Discuss., 2020: 1-27. https://doi.org/10.5194/hess-2020-268.

Koci J, Wilkinson SN, Hawdon AA, Kinsey-Henderson AE, Bartley B, Goodwin NR. In review. Rehabilitation effects on gully sediment yields and vegetation in a savanna rangeland. Earth Surface Proc. and Landforms.

Ludwig, J.A., Bartley, R., Hawdon, A., Abbott, B. and McJannet, D., 2007. Patch configuration non-linearly affects sediment loss across scales in a grazed catchment in north-east Australia. Ecosystems, 10(5): 839-845, 10.1007/s10021-007-9067-8.

McIvor, J.G., Williams, J. and Gardener, C.J., 1995. Pasture management influences runoff and soil movement in the semi-arid tropics. Australian Journal of Experimental Agriculture, 35(1): 55-65.

Roth, C., 2004. A framework relating soil surface condition to infiltration and sediment and nutrient mobilisation in grazed rangelands of north-eastern Queensland. Earth Surface Processes and Landforms, 29: 1093-1104.

Silburn, D.M., Carroll, C., Ciesiolka, C.A.A., deVoil, R.C. and Burger, P., 2011. Hillslope runoff and erosion on duplex soils in grazing lands in semi-arid central Queensland. I. Influences of cover, slope, and soil. Soil Research, 49(2): 105-117, doi:10.1071/SR09068.

Scanlan, J.C., Pressland, A.J. and Myles, D.J., 1996. Run-off and soil movement on mid-slopes in North-east Queensland grazed woodlands. Rangelands Journal, 18: 33-46.

Shellberg, J.G., Spencer, J., Brooks, A.P. and Pietsch, T.J., 2016. Degradation of the Mitchell River fluvial megafan by alluvial gully erosion increased by post-European land use change, Queensland, Australia. Geomorphology, 266: 105-120, http://dx.doi.org/10.1016/j.geomorph.2016.04.021.

Wilkinson SN, Hairsine PB, Hawdon AA, Austin J. 2019. Technical findings and outcomes from the Reef Trust Gully Erosion Control Programme. CSIRO. pp: 48. https://doi.org/10.25919/5d111dba0a72a

Wilkinson, S.N., Hancock, G.J., Bartley, R., Hawdon, A.A. and Keen, R., 2013. Using sediment tracing to assess processes and spatial patterns of erosion in grazed rangelands, Burdekin River basin, Queensland, Australia. Agriculture, Ecosystems and Environment, 180: 90-102, DOI: 10.1016/j.agee.2012.02.002

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QUESTION: 3
Hansard extract

Senator McDONALD: In your submission you stated:

There are a range of practical options that cane farmers can adopt to mitigate the effects of excessive drainage on flows and nitrogen export that are economically beneficial.

Can you take the committee through those alternatives?

Dr Steele: We'll take that question on notice as well. We'll come back to you.

Senator McDONALD: Excellent. What involvement has the CSIRO had with industry in exploring and implementing these options?

Dr Steele: That will follow on, I expect.

Senator McDONALD: You'll take that on notice as well

ANSWER
There are three broad ways to mitigate nitrogen export from farms: (1) better tailor applications of nitrogen to crops' needs; (2) use new fertiliser technology, i.e. enhanced efficiency fertilisers; or (3) deploy technologies to remove nitrogen from drainage water once it has left farms (e.g. through constructed wetlands or bio-reactors). CSIRO is working on the first two of these.

Achieving economic and water quality benefits of enhanced efficiency fertilisers is complex issue because the efficacy of these new products is highly variable (Verburg et al., 2018). We are working to understand the fundamental processes behind these products that cause this variability (Vilas et al 2019). One outcome of this work to date is development, in participation with the sugarcane industry, of prototype decision support system to identify situations where these fertilisers are most likely to be effective (Verburg et al., 2019).

CSIRO's previous research has shown that there are places or times where nitrogen fertiliser applications could be reduced below those recommended by the current sugarcane industry system (known as Six Easy Steps) without loss of production (Thorburn et al., 2011a). When applied to individual fields in specific years, Six Easy Steps provides quite general recommendations that don't necessarily align with optimal amount of nitrogen a crop needs in an individual field and year (Skocaj et al., 2020). The result is that optimal nitrogen can be lower (or higher) than the recommended rate resulting from the Six Easy Steps system (Skocaj et al., 2020, Thorburn et al., 2018).

What are the causes of these differences? Differences in optimal nitrogen rates occur because of differences in soil properties and seasonal rainfall patterns (Skocaj et al., 2020). Most of those soil properties are not accounted for in Six Easy Steps (Schroeder et al., 2015, Skocaj et al., 2019). Climate also affects optimal nitrogen (Skocaj, 2015). Thus, effort put into refining Six Easy Steps to take account of a broader range of soil attributes and, if possible, seasonal climate forecasts would likely reveal places and/or times where nitrogen application could be reduced without compromising productivity.

Similarly, refining Six Easy Steps may also identify places where additional nitrogen inputs are needed to ensure maximum production. Realising this improvement would yield environmental and economic benefits to all stakeholders.

Publications cited above:

Skocaj DM (2015) Improving sugarcane nitrogen management in the Wet Tropics using seasonal climate forecasting. Research thesis, James Cook University, Townsville

Skocaj Schroeder Wood 2020 Are responses to nitrogen fertiliser predictable under similar conditions? ASSCT 42, 161–168.

Skocaj Schroeder et al 2019 Spatial distribution of potential soil constraints affecting nitrogen management in the Wet Tropics. ASSCT 41, 371–379.

Verburg, K., Vilas, M.P., Biggs, J.S., Thorburn, P.J., Bonnett, G.D. (2019). The use of "virtual" trials to fill gaps in experimental evidence on EEFs. Proc. Aust. Soc. Sugar Cane Technol. 41, 383–393.

Verburg, K., Biggs, J., and Thorburn, P. (2018). Why benefits from controlled release fertilisers can be lower than expected on some soils. Proceedings of the Australian Society of Sugar Cane Technologists 40, 237–249.

Vilas, M., Verburg, K., Thorburn, P.J., Probert, M.E. and Bonnett, G.D. (2019) A framework for analysing nitrification inhibition: A case study on 3,4-dimethylpyrazole phosphate (DMPP). Science of the Total Environment 672, 846–854.

REFERENCE: Questions on notice (Hansard 27 July 2020, Page 63-64)

QUESTION: 4
Hansard extract

Senator McDONALD: You note work on observed and modelled pollutant loads and their impact on marine ecosystems is conducted by AIMS, James Cook University and UQ. Has the CSIRO had any involvement in reviewing this work?

Dr Bartley: Reviewing, explicitly, the work done by others?

Senator McDONALD: You note work on observed and modelled pollutant loads—this is in your submission—and their impact on marine ecosystems conducted by the other facilities. Have you had any involvement in this work, being a part of it or reviewing it? What has your involvement been or are you just noting it?

Dr Bartley: The CSIRO currently built and designed the eReefs model, which is a very important component, which connects to the catchment models currently run by the Queensland government. eReefs models the distribution of flows and currents into the Great Barrier Reef.

Senator McDONALD: What monitoring and data collection is there to check against the eReefs model that it's performing as you would have expected?

Dr Bartley: I'd have to take on notice the specifics, but there are several publications which I remember we put in the submission. They're very rigorously peer reviewed and they use as much data that is available to calibrate the models.

Senator McDONALD: So I can go back and look at your submission as to what data you've been able to find to use. I mean, that's the ultimate question. You've done a model, so how good is it? Are you satisfied with how the eReefs model is playing out?

Dr Bartley: It's not my direct field of research, but my understanding is the data should be available on the CSIRO data portal. We could take that on notice to find out, but most of all of the data layers are publicly available.

Senator McDONALD: I would be really interested to know, based on the modelling and the data that's now being collected, how long that's been running for.

Dr Steele: Since 2012, or something like that, if I remember correctly.

Senator McDONALD: Terrific. That's seven years, so you should start getting some real assessments against what you modelled and how close you were to the reality.

Dr Steele: We can provide an answer on notice that goes to the essence of the question you're asking.

ANSWER
The eReefs hydrodynamic and biogeochemical models have been carefully configured to represent the processes occurring in Great Barrier Reef waters. The configuration includes many components that are based on physical observations (bathymetry, river flows, meteorological forcings). Further components of the configuration relate to biogeochemical properties, such as the light attenuation rate of coloured organic matter in freshwater flows, that have been calibrated to the GBR environment.

An example of a peer-reviewed study undertaken to assist in the calibration to GBR waters is Soja-Wozniak et al., (2019).

The skill of the eReefs configuration has been assessed against a wide range of observations (i.e. remote-sensing, in situ moorings and water sampling etc.) over the nine year run of the eReefs model. Almost all available high-quality data streams from the CSIRO, AIMS and IMOS have been considered.

An example of the comprehensive skill assessment undertaken is available in the supplement of a recent Geoscientific Model Development discussion paper which can be found online at https://gmd.copernicus.org/preprints/gmd-2019-115/gmd-2019-115-supplement.pdf[1]

As would be expected, there is a variability in the ability of the model to represent processes, from highly skilfully predicted hydrodynamic properties (currents, river plumes etc.) to less skilfully predicted complex chemical and ecological properties.

Two further examples of model-observation comparisons are published in the peer-review literature are Robson et. al., (2020) and Skerratt et al., (2019).

The Robson et al., (2020) study is particular-noteworthy for its application of a model evaluation procedure that considers the skill of the model to represent:

(1) conceptual understanding of the system (e.g. nutrients drive increasing microalgae growth),
(2) the system state (e.g. predictions of chlorophyll concentration),
(3) important processes (e.g. rate of nitrogen fixation), and
(4) emergent system behaviour (e.g. reduced water clarity in wet years).

The performance of the eReefs model is continually being checked and improved and its suitability for prediction of a broader range of processes evaluated. For example, the eReefs model provided good skill at predicting bleaching in 2016 (Baird et al., 2018).

For the purposes of assessing the water clarity state of the GBR for report cards, the eReefs system employs data assimilating techniques similar to those used in weather forecasting. Data assimilation provides a further mechanism for observations to inform model simulations. This is described in Jones et al., (2016).

In summary, all details relating to the model input data, model setup, testing, application and publications are available at the eReefs model website (https://ereefs.org.au/ereefs).

References cites above:

Baird, M. E., M. Mongin, F. Rizwi, L. K. Bay, N. E. Cantin, M. Soja-Wozniak and J. Skerratt (2018) A mechanistic model of coral bleaching due to temperature-mediated light-driven reactive oxygen build-up in zooxanthellae. Ecol. Model 386: 20-37.

Jones, E., M. Baird, M. Mongin, J. Parslow, J. Skerratt, Lovell, J. N. Margvelashvili, R. Matear, K. Wild-Allen, B. Robson, F. Rizwi, P. Oke, E. King, T. Schroeder, A. Steven, and J. Taylor (2016) Use

[1] Full paper available at: https://gmd.copernicus.org/preprints/gmd-2019-115/

of remote-sensing reflectance to constrain a data assimilating marine biogeochemical model of the Great Barrier Reef. Biogeosciences 13, 6441–6469.

Robson, B., J. Skerratt, M. Baird, C. Davies, M. Herzfeld, E. Jones, M. Mongin, A. Richardson, F. Rizwi, K. Wild-Allen, A. D.L. Steven (2020) Enhanced assessment of the eReefs biogeochemical model for the Great Barrier Reef using the Concept/State/Process/System model evaluation framework. Environ. Mod. Soft. 129:104707.

Skerratt J.H., M. Mongin, K. A. Wild-Allen, M. E. Baird, B. J. Robson, B. Schaffelke, M. Soja-Wozniak, N Margvelashvili, C. H. Davies, A. J. Richardson, A. D. L. Steven (2019) Simulated nutrient and plankton dynamics in the Great Barrier Reef (2011-2016). J. Mar. Sys. 192, 51-74.

Soja-Wozniak, M., M. Baird, T. Schroeder, Y. Qin, L. Clementson, B. Baker, D. Boadle, V. Brando, A. Steven (2019). Particulate backscattering ratio as an indicator of changing particle composition in coastal waters: Observations from Great Barrier Reef waters. Journal of Geophysical Research: Oceans, 124. https://doi.org/10.1029/2019JC014998.

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QUESTION: 5
Hansard extract

Senator RENNICK: Okay. Earlier on, Dr Bartley, you mentioned that there were examples of where regulation has improved reefs. Can you name those reefs, please.

Dr Bartley: Ecologically, no, I can't tell you the reefs, but the different countries. Eastern European countries, where lobsters declined on their cold-water reefs, actually went broke and stopped using fertiliser, and there was evidence of ecological recovery. So we do not want to support that. In other areas, such as China—

Senator RENNICK: Are there tropical—

Dr Bartley: Not tropical reefs, no. There are all sorts of marine ecosystems—

Senator RENNICK: In Eastern Europe, is that the Black Sea?

Dr Bartley: I'd have to take that on notice, but there's a publication we can send you that outlines the whole review. There are other reefs off Africa, Indonesia and Hawaii as well.

Senator RENNICK: Okay.

ANSWER
Given that agricultural pollution threatens ~25% of total global reef area, Kroon et al., (2014) undertook a review of the International literature to help understand the conditions required to support an improvement in water quality reaching sensitive marine systems from land-based sources. In general, there are very few published studies documenting a reduction in pollutant delivery from catchments to coastal ecosystems due to the long time frames (and associated expense) of monitoring. Even fewer studies document measured ecological improvement.

The well-known case of Kane'ohe Bay, Hawaii, is the only example demonstrating partial reversal of coral reef degradation following a reduction in terrestrial nutrient fluxes. Following sewage diversion in 1978, turbidity, nutrients and chlorophyll a concentration's, as well as macroalgae biomass, declined within months (Laws and Allen, 1996; Smith et al., 1981). In the next few decades, coral cover more than doubled and subsequently stabilized.

However, we also identified multiple examples in the global literature where reductions of land-based pollution to coastal ecosystems have been achieved (e.g. Yellow River, China; Danube River, Elbe River and Lielupe Rivers in Europe). Most examples comprise reduced nutrient fluxes from point sources, such as waste-water treatment plants, through legislative mandates and regulatory enforcement (Boesch, 2002; Cloern, 2001). More recent examples also include studies demonstrating reduced sediment and nutrient fluxes from agricultural land use (Chu et al., 2009; Duarte et al., 2009; GEFUNDP, 2006; Pastuszak et al., 2012; Stålnacke et al., 2003; Windolf et al., 2012). In almost of these cases, the management approaches that have resulted in reduced agricultural pollution to coastal ecosystems have all been non-voluntary.

For example, regulation has reduced the contributions from waste water treatment plants and industrial discharges to total annual average N and P loads to the Danish coast from ~50% to <10%, and from 59% to ~20%, respectively, over 14 years (Carstensen et al., 2006). The nutrient regulation in Denmark followed lobster mortality in coastal waters in the 1980s which was attributed to algal blooms and hypoxia induced by agricultural nutrient run-off (Windolf et al., 2012). Similar declines in nutrient loads from point sources have resulted in reductions in coastal nutrient and chlorophyll a (chl a) concentrations (Greening and Janicki, 2006), seagrass recovery (Tomasko et al., 2005), and concomitant decline in macroalgae (Cardoso et al., 2010; Vaudrey et al., 2010), including on coastal coral reefs (Laws and Allen, 1996; Smith et al., 1981).

Based on the insights obtained from this review, Kroon et al (2014) recommend that future protection of coral reef ecosystems demands policy focused on desired ecosystem outcomes, targeted regulatory approaches, up-scaling of watershed management, and long-term maintenance of scientifically robust monitoring programs linked with adaptive management.

Publications cited above:

Kroon, F.J., Schaffelke, B. and Bartley, R., 2014. Informing policy to protect coastal coral reefs: Insight from a global review of reducing agricultural pollution to coastal ecosystems. Marine Pollution Bulletin, 85(1): 33-41, http://dx.doi.org/10.1016/j.marpolbul.2014.06.003.

References cited within Kroon et al., 2014

Boesch, D.F., 2002. Challenges and opportunities for science in reducing nutrient over-enrichment of coastal ecosystems. Estuaries 25, 886–900.

Cardoso, P.G., Leston, S., Grilo, T.F., Bordalo, M.D., Crespo, D., Raffaelli, D., Pardal, M.A., 2010. Implications of nutrient decline in the seagrass ecosystem success. Mar. Pollut. Bull. 60, 601–608.

Carstensen, J., Conley, D.J., Andersen, J.H., Aertebjerg, G., 2006. Coastal eutrophication and trend reversal: a Danish case study. Limnol. Oceanogr. 51, 398–408.

Chu, Z.X., Zhai, S.K., Lu, X.X., Liu, J.P., Xu, J.X., Xu, K.H., 2009. A quantitative assessment of human impacts on decrease in sediment flux from major Chinese rivers entering the western Pacific Ocean. Geophys. Res. Lett. 36, 1–5.

Cloern, J.E., 2001. Our evolving conceptual model of the coastal eutrophication problem. Mar. Ecol.Prog. Ser. 210, 253–253.

Duarte, C.M., Conley, D.J., Carstensen, J., Sanchez-Camacho, M., 2009. Return to neverland: shifting baselines affect eutrophication restoration targets. Estuaries Coasts 32, 29–36.

GEF-UNDP, 2006. Trends in nutrient loads from the Danube River and trophic status ofthe Black Sea. Joint Report of the GEF-UNDP Black Sea Ecosystem Recovery Project and the GEF-UNDP Danube Regional Project, Istanbul, Istanbul, Turkey, p. 26.

Greening, H., Janicki, A., 2006. Toward reversal of eutrophic conditions in a subtropical estuary: water quality and seagrass response to nitrogen loading reductions in Tampa Bay, Florida. USA. Environ. Manage. 38, 163–178.

Hussian, M., Grimvall, A., Petersen, W., 2004. Estimation of the human impact on nutrient loads carried by the Elbe River. Environmental Monitoring and Assessment 96, 15–33.

Laws, E.A., Allen, C.B., 1996. Water quality in a subtropical embayment more than a decade after diversion of sewage discharges. Pac. Sci. 50, 194–210.

Mee, L.D., 2001. Eutrophication in the Black Sea and a basin-wide approach to its control. In: Von Bodungen, B., Turner, R.K. (Eds.), Science and Integrated Coastal Management. Dahlem University Press, Berlin, Germany

Pastuszak, M., Stalnacke, P., Pawlikowski, K., Witek, Z., 2012. Response of Polish rivers (Vistula, Oder) to reduced pressure from point sources and agriculture during the transition period (1988–2008). J. Mar. Syst. 94, 157–173.

Smith, S.V., Kimmerer, W.J., Laws, E.A., Brock, R.E., Walsh, T.W., 1981. Kaneohe Bay sewage diversion experiment – perspectives on ecosystem responses to nutritional perturbation. Pac. Sci. 35, 279–402.

Stålnacke, P., Grimvall, A., Libiseller, C., Laznik, A., Kokorite, I., 2003. Trends in nutrient concentrations in Latvian rivers and the response to the dramatic change in agriculture. J. Hydrol. 283, 184–205.

Vaudrey, J.M.P., Kremer, J.N., Branco, B.F., Short, F.T., 2010. Eelgrass recovery after nutrient enrichment reversal. Aquat. Bot. 93, 237–243.

Windolf, J., Blicher-Mathiesen, G., Carstensen, J., Kronvang, B., 2012. Changes in nitrogen loads to estuaries following implementation of governmental action plans in Denmark: a paired catchment and estuary approach for analysing regional responses. Environ. Sci. Policy 24, 24–33.