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Dear Senator,

Please find our submission for the Senate Environment and Communications Committee's inquiry into "the threat of marine plastic pollution in Australia".

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Please do not hesitate to contact me if you require any further information.

Yours sincerely,

Mark Anthony Browne on behalf of co-authors.

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Threat of marine plastic pollution in Australian waters and guidance for policymakers for the next 5-10 years

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Introduction

This brief review of current research and scientific understanding of plastic pollution in the marine environment outlines current scientific understanding of sources, impacts (to individual organisms, species and the ecosystem) and options for policymakers about mitigation-measures and other management approaches.

Scale of the problem

By 2050, an estimated 33 billion tonnes of plastic will be added to our planet (Rochman et al 2013). Very little plastic is recycled (OECD 2007) and it degrades slowly, accumulating in all environments. The ensuing pollution is generally widespread but more extreme in areas with large human populations and increasing as populations grow (e.g. Thompson et al. 2004). Plastic production is an important industry for Australia which produces >1.2 million tonnes of plastic each year. The industry employs 85,000 people and represents ~10% of Australian manufacturing activity (PACIA 2010). Despite plastic debris (particularly microplastics) being recognized as a critical problem for global conservation and human health by the UN, Royal Society, EU, National Academy of Sciences, USEPA, NOAA and CSIRO, the scarcity of ecotoxicological research means we do not yet know how large, or serious, the microplastic problem is for most of earth's ecosystems (Sutherland et al. 2010)

Sources of marine plastic pollution

Plastic enters natural environments as waste – either as small particles (microplastic, < 1 mm) or as larger debris. The former includes clothing fibres and exfoliants used in cleaning products (Browne et al. 2011; Gregory 1996), whilst the latter includes packing materials, (e.g. polystyrene), plastic bags and pieces of solid plastic waste. These plastics enter aquatic environments through a number of sources including stormwater and sewage. Our recent work in Australia has shown that sewage and stormwater is an important pathway of microplastic to urbanized coastal habitats (Browne 2010; Browne et al. 2011).

Sewage and other domestic waste are frequently added to soils to improve nutrients and reduce water-loss, thus contaminating terrestrial habitats with microplastic fibres (Browne et al. 2011) that may then enter aquatic environments via terrigenous inputs.

Known impacts of plastic compared to other materials

Rochman et al. (2015) and Browne et al. (2015a) quantified potential and demonstrated impacts across levels of biological organization from subcellular to ecosystem. They identified 362 perceived threats 292 of these have been examined experimentally and 80% have been shown to occur. Most (82%) of demonstrated impacts were due to plastic, rather than other materials such as metal or glass. The vast majority (89%) were at suborganismal levels (e.g., molecular, cellular, tissue).

Impacts of plastic to individual organisms and humans

Particles eaten by animals physically block their digestive tracts, alter feeding behavior and dietary inputs (Rochman et al 2015; Browne et al 2015a). They are moved from the gut to the circulatory system, where they can be stored for months (Browne et al. 2008), thus accumulating in numbers and volume. If the animal is eaten by a predator, microplastic can transfer into the tissues of the predator (Farrell & Nelson 2013; Setälä et al. 2014). Particles introduced into cells and tissues reduce the health of animals (Lam et al. 1993; Brown et al. 2001; Hoet et al. 2004).

There are also indirect ecotoxicological effects, due to toxic chemicals from the manufacture of plastics or due to chemicals in the environment that are adsorbed by particles. Like many toxins, chemicals from microplastics can bio-accumulate (Browne et al. 2013; Rochman et al. 2013). Microplastics have large surface area to volume ratios, thus adsorbing large numbers and quantities of chemicals, which can make them extremely toxic. Toxins can be transferred into tissues of marine worms and freshwater fish, reducing functions strongly linked to health and biodiversity (Browne et al. 2013; Rochman et al. 2013). In some species, microplastics reduce digestive capacity and, some species, ingestion of microplastics reduces their capacity to deal with other chemical contaminants, compromising their immune systems (Browne et al. 2013). For most animals, however, little is known about the long-term consequences of such contamination. Some plastics are, however, strongly linked to cancers in animals and humans (Wagoner 1983).

Impacts of marine plastic debris on species and the ecosystem

Other impacts of marine plastics are deaths of individual organisms or changes in assemblages. These are largely due to plastic marine debris (>1 mm; e.g., rope, straws and fragments). For example, larger pieces of plastic debris alter assemblages because fishing-gear and tyres directly kill animals and damage habitat-forming plants. Floating bottles and packaging material may facilitate recruitment and survival of other species (for example: barnacles, bryozoans, seasquirts, hydrozoans, sponges and bivalves), potentially allowing them to be transported to, and then invade, other areas (Browne et al. 2015a). While there are studies of species that have recruited to floating plastic debris (e.g. Barnes 2002) and travelled across oceans, there are no confirmed cases of the establishment of an invasive species through this vector alone (Browne et al 2015a). Such a case would be extremely difficult to establish given the number of other potential vectors (e.g. vessels).

It is important to note that very little of the available research has investigated whether plastic debris is actually impacting organisms at the population or species level (Rochman et al. 2015). Frameworks for investigating this, and determining how important plastic debris is compared to other environmental issues, are outlined in Browne et al (2015a). The consensus of these reviews is that (i) there is evidence of ecological impacts from plastic marine debris, but over the next 5-10 years the quantity and quality of research requires improvement to allow the risk and relative importance of ecological impacts of plastic marine debris to be determined with precision; (ii) sufficient evidence exists for decision-makers to begin to mitigate problematic plastic debris now, to avoid risk of irreversible harm (Rochman et al. 2015; Browne et al. 2015a).

Policy-measures and resourcing for mitigation over the next 5-10 years
Potential management and mitigation approaches include product replacement and pollution prevention. Switching to non-plastic products or less harmful plastics may be an option for some products (e.g. plastic microbeads may be replaced by non-plastic exfoliants in facial scrubs). For some types of microplastic waste, e.g. particles produced by washing synthetic materials, better filtration at the source would prevent pollution. Better filtering in sewerage systems would also achieve this. Policies to ban unnecessary packaging, levies on the amounts of plastic used, a range of container deposit schemes, reclassifying plastic as hazardous materials, establishing and controlling inventories that detail the use and emissions of plastics in products would all help identify and mitigate plastic pollution. Seven states of the US have now enacted legislation that restricts or prohibits the use of plastic microbeads, however in many places, these and other approaches (e.g. container deposit schemes) have not been adopted for a variety of reasons, including a lack of scientific evidence for their effectiveness. Without this evidence it becomes difficult to estimate the costs and benefits of product replacement and pollution prevention options.

Any other relevant matters

Monitoring plastic debris. Managing economic and ecological impacts of plastic pollution in Australia, requires quantitative information on spatial patterns and trends in the amounts a types of plastic debris across Australia. Unfortunately, methods of defining debris, sampling, and interpreting patterns in space or time vary considerably among studies, so information cannot be easily compared across studies (Browne et al 2015b). To overcome this problem we need:

(1) Large-scale and long-term sampling of plastic debris with unified methods of sampling and the development of standardized, accurate and widely available techniques for the identification of plastic polymers within a variety of matrices.

(2) Different sampling protocols extended into more habitats, such as mangroves, salt marshes, soft sediments, coral reefs, and rocky reefs, for which there are currently very few data.

(3) More specific definitions of plastic marine debris categories and their specific threats, and a prioritization process for defining which types of debris have the largest ecological risk. Sampling of plastic debris should have, as its foundation, knowledge of its potential impacts. This would focus both spatial and temporal scales of sampling, including definitions of debris as has been done for studies of subtidal fishing gear which may affect coral reefs (Chiappone et al. 2002).

(4) Robust sampling designs. Designs for sampling diverse, patchily distributed assemblages are well understood and published throughout the ecological literature and easily implemented for sampling plastic marine debris. Clear hypotheses will determine appropriate levels of replication, especially if existing information can be used in power analyses.

(5) More experimental tests of hypotheses about the processes which cause different types of debris to accumulate at different times and places.

(6) Hypothesis-driven studies that focus on sources and pathways, especially to determine how patterns of plastic debris are affected by differences in managing, recycling and recovering waste.

(7) Hypothesis-driven studies of the ecotoxicological effect of plastics at different levels of biological organization, in particular to fill the current knowledge gap regarding higher order effects and transfer potential through food webs.

(8) Integrated analyses on the fates, adverse-outcomes and risks of plastics through food webs that establish the strength and length of the linkages between impacts of microplastics at lower (e.g. molecular changes) and higher levels of biological organization (populations, assemblages), including functions that sustain ecosystem health and biodiversity. More attention to the processes that link suborganismal impacts to ecological responses would guide population modelling. Models must, however, be constructed to determine whether populations are declining because of debris and which part(s) of the life cycle are being affected. Better models will identify what sorts of management, and at what life stage, could reduce exposure of the organisms to debris, or could mitigate impacts caused by the debris.

(10) The development of plastic alternatives and lower risk plastics.
Switching to plastics with smaller ecological risks and impacts is fundamental to developing more advanced techniques in the food industry, agriculture,

construction, communications, transport and medicine. Many methods for quantifying the microdebris are semi- or non-quantitative and cannot be used to determine quantities in tissues or whole organisms, or to assess the likelihood and extent of impacts to habitats. This makes it difficult to determine the ecological risks. Spatial and temporal patterns of presence and amounts of debris are poorly understood, and very little is known about how frequently organisms and habitats are exposed to debris in nature. The situation would be improved if studies of exposure to, or impacts from, debris included estimates of how much debris (including material type, size dimensions, volume, mass) is encountered by organisms in different habitats. Without this information, risk assessments cannot be used and policymakers will be managing debris using existing laws (Rochman et al. 2013). The ultimate goal of policies should be to replace problematic products with safer alternatives (before they are used) by tasking ecologists and engineers with working together to identify and remove features of products that (if found as debris in habitats) might cause ecological impacts. Similar approaches are already used to engineer infrastructure ecologically (Chapman & Underwood 2011; Browne & Chapman 2011; Dafforn et al. 2015) or to make less toxic 'biocompatible' medical devices (ISO/TC 194).

(10) The testing and implementation of a variety of filtration devices that remove microplastic particles at the source and prior to entering environments (e.g. washing machine and sewage plant filters).

References

Barnes D. K. A. 2002 Invasions by marine life on plastic debris. Nature 416, 808–809.

Brown DM, Wilson MR, MacNee W, Stone V, Donaldson K. 2001 Size-dependent proinflammatory effects of ultrafine polystyrene particles: a role for surface area and oxidative stress in the enhanced activity of ultrafines. Toxicology and Applied Pharmacology 175, 191–199.

Browne MA, Dissanayake A, Galloway TS, Lowe DM, Thompson RC (2008) Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis* (L.) Environmental Science and Technology 42, 5026-5031.

Browne MA (2010) Characterisation of microplastic debris in terrestrial, freshwater and estuarine habitats within the Hornsby Shire Catchment area. Final Report.

Browne MA, Galloway TS, Thompson RC (2010) Spatial patterns of plastic debris along estuarine shorelines. Environmental Science and Technology 44 (9) 3404-3409.

Browne MA, Chapman MG (2011) Water-tight solutions to engineering intertidal biodiversity in our cities. Environmental Science and Technology 45, 8204–820.

Browne MA, Crump P, Niven SJ, Teuten EL, Tonkin A, Galloway T, Thompson RC (2011) Accumulation of microplastic on shorelines worldwide: sources and sinks. Environmental Science and Technology 45, 9175–9179.

Browne MA, Niven SJ, Rowland SJ, Galloway TS, Thompson RC (2013) Microplastic moves pollutants and additives to worms reducing functions linked to health and biodiversity. Current Biology 23, 2388-2392.

Browne MA, Underwood AJ, Chapman MG, Williams R, Thompson RC., van Franeker JA (2015a) Linking effects of debris to ecological impacts. Proceedings of the Royal Society B: Biological Sciences, 282, 20142929.

Browne MA, Chapman MG, Thompson RC, Amaral Zettler LA, Jambeck J, Mallos NJ (2015b) Spatial and temporal patterns of stranded intertidal marine debris: is there a picture of global change? Environmental Science and Technology 49, 7082–7094.

Chapman MG, Underwood AJ (2011) Evaluation of ecological engineering of "armoured" shorelines to improve their value as habitat. Journal of Experimental Marine Biology and Ecology 400, 302–313.

Chiappone M, White A, Swanson DW, Miller SL (2002) Occurrence and biological impacts of fishing gear and other marine debris in the Florida Keys. Marine Pollution Bulletin 44, 597–604.

Dafforn KA, Glasby TM, Airoldi L, Rivero NK, Mayer-Pinto M, Johnston E. (2015) Marine urbanisation: an ecological framework for designing multifunctional artificial structures. Frontiers in Ecology and the Environment 13, 82–90.

Farrell P, Nelson K (2013) Trophic level transfer of microplastic: Mytilus edulis (L.) to *Carcinus maenas* (L.). Marine Pollution Bulletin 177, 1-3.

Gregory MR (1996) Plastic 'scrubbers' in hand cleansers: a further (and minor) source for marine pollution identified. Marine Pollution Bulletin 32, 867–871.

Hoet PHM, Brüske-Hohlfeld I, Salata OV (2004) Nanoparticles – known and unknown health risks. Journal of Nanobiotechnology 2, 12.
ISO/TC 194

Lam KH, Schakenraad JM, Esselbrugge H, Feijen J, Nieuwenhuis P (1993) The effect of phagocytosis of poly(L-lactic acid) fragments on cellular morphology and viability. Journal of Biomedical Materials Research 27, 1569-1577.

OECD (2007) Policy Brief: Improving Recycling Markets. http://www.oecd.org/env/waste/38093900.pdf

PACIA (2010) Annual Report. http://www.pacia.org.au/reports

Pauly JL, Stegmeier SJ, Allaart HA, Cheney RT, Zhang PJ, Mayer AG, Streck RJ, (1998) Inhaled cellulosic and plastic fibers found in human lung tissue. Cancer Epidemiology Biomarkers & Prevention 7, 419-428.

Rochman CM, Browne MA, Halpern BS, Hentschel BT, Hoh E, Karapanagioti HK, Rios-Mendoza LM, Takada H, Teh S, Thompson RC (2013) Policy: Classify plastic waste as hazardous. Nature 494, 7436, 169-171.

Rochman CM, Hoh E, Kurobe T, Teh SJ (2013) Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. Scientific Reports 3, 3263.

Rochman CM, Browne MA, Underwood AJ, Van Franeker JA, Thompson RC, Amaral-Zetler LA (2015) The ecological impacts of marine debris: unravelling the demonstrated evidence from what is perceived. Ecology

Setälä O, Fleming-Lehtinen V, Lehtiniemiet M (2014) Ingestion and transfer of microplastics in the planktonic food web. Environmental Pollution 77–83.

Sutherland WJ, Clout M, Côté IM, Daszak P, Depledge MH, Fellman L, Fleishman E, Garthwaite R, Gibbons DW, De Lurio J, Impey AJ, Lickorish F, Lindenmayer D, Madgwick J, Margerison C, Maynard T, Peck LS, Pretty J, Prior S, Redford KH, Scharlemann JPW, Spalding M, Watkinson AR (2010) A horizon scan of global conservation issues for 2010. Trends in Ecology and Evolution 25, 1–7.

Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AWG, McGonigle D, Russell AE (2004) Lost at sea: Where is all the plastic? Science 304, 5672, 838–838.

Wagoner JK (1983) Toxicity of vinyl chloride and poly(vinyl chloride): A critical Review. Environmental Health Perspectives 52, 61–66.