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CSIRO Submission 15/535

Inquiry into the Threat of Marine Plastic Pollution in Australia and Australian Waters

Environment and Communications References Committee

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Introduction

CSIRO welcomes the opportunity to provide input to the Environment and Communications References Committee inquiry into the threat of marine plastic pollution in Australia and Australian waters.

CSIRO is well placed to respond to the Senate Inquiry into the threat of marine plastic pollution in Australia and Australian waters. CSIRO has had a significant research program addressing a wide range of questions related to marine debris, including each of the items outlined in the Inquiry. CSIRO's research leadership in this area is recognized both nationally and internationally, with recent recognition as a Eureka Award finalist, contracts from industry, along with national and international government and nongovernment bodies, invitations for the lead scientists from the team to serve on a number of expert advisory panels both nationally and internationally. The CSIRO research team has published 18 papers in the international scientific literature to date.

CSIRO is making the submission on the basis of several years of research including (1) CSIRO's national marine debris project that was originated to address knowledge gaps identified in the EPBC Threat Abatement Plan for the impacts of marine debris on vertebrate wildlife; (2) CSIRO's research on exploring sources, impacts and methods for amelioration of ghost nets as a threat to marine species. CSIRO's expertise in this area is exemplified by the publication of more than fifteen peer-reviewed scientific articles on the subject, which are drawn upon in the submission.

CSIRO will address the following Terms of Reference identified in the inquiry:

(a) The review of current research and scientific understanding of plastic pollution in the marine environment;

(b) Sources of marine plastic pollution;

(c) The impacts of marine plastic pollution, including impacts on species and ecosystems, fisheries, small business, and human health;

(d) Measures and resourcing for mitigation; and

(e) Any other relevant matters.

CSIRO response to the Terms of Reference (ToR)

a) *The review of current research and scientific understanding of plastic pollution in the marine environment;*

There is an increasing understanding of sources, threats, and exposure to plastic pollution in Australia and Australian waters, with recent peer reviewed research quantifying the quantity of plastic entering the oceans each year and a recent national Australia wide survey of sources, hotspots and distribution of coastal and marine litter, from land and sea-based surveys.

CSIRO has led a major national study, available online (www.csiro.au/Marine-debris). This study documents the state of marine debris in Australia, with coastal and offshore surveys around the continent, analysis of the impacts of this debris on marine wildlife, evaluation of the likelihood of domestic and foreign sources, and investigation of the effectiveness of council, regional, and state policy in reducing debris entering the marine environment.

This work suggests that most debris on Australian coastlines is from local, land-based sources. Initiatives like container deposit schemes, outreach programs, prosecution of illegal dumping, and investment in coastal waste control facilities all significantly reduce plastic pollution in coastal areas (26). Impacts to wildlife are significant, with impacts on seabirds, marine turtles, and recreationally and commercially important fish.

CSIRO's recent research is summarized in the executive summary of our final report (attached) and presented in several peer-reviewed scientific articles (see included publications list). CSIRO's research specific to the substantive questions raised in the review are discussed below.

b) *Sources of marine plastic pollution;*

Sources of marine plastic pollution are typically local, with specific items in particular areas (e.g. ghost nets in the Gulf of Carpentaria) likely originating from overseas. Most debris appears to come from land (>80%). Plastic debris is composed of a wide variety of industrial, commercial and consumer items; however, the most common items are associated with consumers, e.g. single-use food and beverage containers. There also appears to be a significant contribution from illegal dumping of domestic rubbish around urban margins in Australia. In remote areas, particularly where there are strong onshore winds, local fishing-related debris is common.

c) *The impacts of marine plastic pollution, including impacts on species and ecosystems, fisheries, small business, and human health;*

We have a reasonable understanding of the exposure of marine species to the plastic pollution threat. Population, species and ecosystem level *impacts* from plastic pollution in the marine environment are less well understood. However, we have quantitative estimates of impact for particular target taxa/geographic regions.

- The numbers of turtles affected by entanglement in abandoned, lost or derelict fishing gear in the northern Gulf region is estimated to be 15,000-20,000 turtles.
- The southern ocean between Australia and New Zealand as a hotspot of potential impact for plastic ingestion by seabirds, with lesser but still significant impacts within the EEZ.

- We predict that 99% of the world's seabirds will have ingested plastic by 2050.
- Currently, 52% of all marine turtles are estimated to have ingested debris.
- Marine turtle hotspots for ingestion include the Australian continental shelf.
- The cost of debris to fisheries, small business and human health remain poorly understood.
- Littering costs to local government due to remediation and tourism losses are substantial.

d) Measures and resourcing for mitigation;

Opportunities exist for mitigation with potential for numerous creative/innovative solutions to reduce coastal and marine litter and the subsequent impacts on wildlife. Our analysis of the relationship between debris in the coastal environment and council, regional, and state waste policies suggests litter and waste reduction is effectively achieved by:

- Prosecution of illegal dumping;
- Direct outreach to community members;
- Implementation of container deposit schemes and other regulations to reduce loss of single use plastics into the environment; and
- Provision of waste facilities in coastal regions.

e) Any other relevant matters;

There remain areas of major uncertainty that are important to be resolved including:

- The costs of local, regional, and state waste control programs in terms of reducing plastic lost to the marine environment, particularly in comparison with their effectiveness as noted above.
- The cost of debris to fisheries and small businesses in Australia
- Quantitative information regarding links to human health
- The population level impacts of ingestion on marine fauna (particularly for ingestion), including commercially important food fish, recreationally caught food fish, and marine mammals.
- The frequency and potential economic impact of invasive species transport via hitchhiking on marine debris

While the Commonwealth Department of Environment is in the process of renewing its Threat Abatement Plan (TAP) for the impacts of marine debris on wildlife, many uncertainties remain as to the state of the problem and the cost-effectiveness of the available solutions. Given the focus of the TAP on implementing and encouraging feasible, cost-effective solutions in the face of significant uncertainties (outlined in the TAP), information on both the state of the problem and the potential solutions will be essential.

We further include for consideration the following documents:

- A list of relevant peer-reviewed publications, articles and reports (Appendix 1)
- The executive summary from CSIRO's recent national marine debris project (Appendix 1)
- The Commonwealth Environment Department solicited CSIRO response to the Threat Abatement Plan (Appendix 3);
- A recent marine debris factsheet highlighting knowledge, potential solutions (Appendix 4)

Appendix 1 Relevant CSIRO publications

Peer reviewed journal articles

1. Schuyler Q, C Wilcox, E van Sebille and BD Hardesty 2015. Risk analysis reveals global hotspots for marine debris ingestion by sea turtles. *In press* Global Change Biology.
2. Wilcox, C, E van Sebille, BD Hardesty. 2015. The threat of plastic pollution to seabirds is global, pervasive and increasing. Proceedings of the National Academy of Sciences.
3. Jambeck, J. A. Andrady, R. Geyer, R. Marayan, M. Perryman, T. Siegler, C. Wilcox. 2015. Plastic waste input to the oceans from land. Science. 347(62230):768-771. DOI: 10.1126/science.1260352
4. Hardesty, BD, T Good and C Wilcox. 2015. Novel methods, new results and science-based solutions to tackle marine debris impacts on wildlife. *In press* Ocean and Coastal Management.
5. Lawson, TJ, K Johns, P Dann, C Wilcox and. BD Hardesty. 2015. Net characteristics that entangle Australian Fur Seals in Southern Australia. Marine Pollution Bulletin. doi:10.1016/j.marpolbul.2015.05.053
6. Hardesty BD, D Holdsworth, A Revill and C Wilcox. 2015. A biochemical approach for identifying plastics exposure in live wildlife. Methods in Ecology and Evolution. doi: 10.1111/2041-210X.12277, http://onlinelibrary.wiley.com/doi/10.1111/2041-210X.12277/pdf
7. Vegter A, M Barletta, C Beck, J Borrero, H Burton, M Campbell, M Eriksen, C Eriksson, A Estrades, K Gilardi, BD Hardesty, J Assunção I do Sul, J Lavers, B Lazar, L Lebreton, WJ Nichols, E Ramirez Llodra, C Ribic, PG Ryan, Q Schuyler, SDA Smith, H Takada, K Townsend, C Wabnitz, C Wilcox, L Young, M Hamann 2014. Global research priorities for the management and mitigation of plastic pollution on marine wildlife. Endangered Species Research, 25: 224-247. DOI: 10.3354/esr00623
8. Wilcox C, G Heathcote, J Goldberg, R Gunn, D Peel and BD Hardesty 2014. Understanding the sources, drivers and impacts of abandoned, lost and discarded fishing gear in northern Australia. Conservation Biology. DOI: 10.1111/cobi.12355
9. Reisser J, J Shaw, G Hallegraeff, M Proietti, D Barnes, M Thums, C Wilcox, BD Hardesty and C Pattiaratchi. 2014. Millimeter-sized marine plastics: a new pelagic habitat for microorganisms and invertebrates. PLoS ONE 9(6): e100289. doi:10.1371/journal.pone.0100289.
10. Schuyler, Q, K Townsend, C Wilcox, BD Hardesty and J Marshall. 2014. Marine debris through a turtle-eyed view. BMC Ecology. http://www.biomedcentral.com/1472-6785/14/14
11. Reisser J, J Shaw, C Wilcox, BD Hardesty, M Proietti, M Thums, C Pattiaratchi 2013. Marine plastic pollution in waters around Australia: characteristics, concentrations and pathways. PLOS One. 8(11): http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0080466
12. Acampora, H, Q Schuyler, K Townsend and BD Hardesty 2013. Comparing plastic ingestion between juvenile and adult stranded Short-tailed Shearwaters (*Puffinus tenuirostris*) in Eastern Australia. Marine Pollution Bulletin. http://doi.org/10.1016/j.marpolbul.2013.11.009
13. Schuyler, Q, BD Hardesty, C. Wilcox and K Townsend 2013. A global analysis of anthropogenic debris ingestion by sea turtles. Conservation Biology. 28:129-139. DOI: 10.1111/cobi.12126
14. JRA Butler, R Gunn, HL Berry, GA Wagey, BD Hardesty, C Wilcox. 2013. Value chain analysis of ghost nets in the Arafura Sea: identifying trans-boundary stakeholders, intervention points and livelihood trade-offs. Journal of Environmental Management 123: 14-25.
15. Wilcox, C, BD Hardesty, R Sharples, DA Griffin, TJ Lawson and R Gunn. 2013. Ghost net impacts on globally threatened turtles, a spatial risk analysis for northern Australia. Conservation Letters, DOI: 10.1111/conl.12001.
16. Schuyler, Q, K Townsend, BD Hardesty and C Wilcox. 2012. To eat or not to eat: debris selectivity by marine turtles. PLOS One 7(7): e40884. DOI:10.1371/journal.pone.0040884.
17. Gunn, R, BD Hardesty, and J Butler 2010. Tackling 'ghost nets': Local solutions to a global issue in northern Australia. Ecological Management and Restoration, 11: 88-98.
18. Donlan, C.J. D.K. Wingfield, L.B. Crowder, and C. Wilcox. 2010. Assessing anthropogenic hazards to endangered species using expert opinion surveys: a case study with sea turtles. Conservation Biology 24(6):1586-95

Selected manuscripts currently in review or revision

19. Roman, L, QA Schuyler, BD Hardesty and KA Townsend. Prevalence and selectivity of anthropogenic debris ingestion in eastern Australian avifauna. *In revision.* PLoS One.
20. Hardesty BD, TJ Lawson, T van der Velde, M Lansdell, G Perkins and C Wilcox. Estimating quantities and sources of marine debris at a continental scale. *In review* Frontiers in Ecology and the Environment.
21. Van der Velde, T., Milton, D.A., Lawson, T.J., Lansdell, M., Wilcox, C., Davis, G., Perkins, G., & BD Hardesty. Is citizen science data worth our investment? *In review* Biological Conservation.
22. Wilcox, C. N Mallos, GH Leonard, A Rodriguez and BD Hardesty. Estimating the consequences of marine litter on seabirds, turtles and marine mammals using expert elicitation. *In review* Marine Policy.
23. Lavender-Law K, N Maximenko, F Galgani, J van Franeker, BD Hardesty and C Wilcox. A global estimate of the quantity of floating plastic marine debris. *In review*. Environmental Research Letters.

Popular articles, edited volumes, and technical reports

24. Hardesty BD and C Wilcox 13 February 2015. Eight million tons of plastic are going into the ocean each year. The Conversation https://theconversation.com/eight-million-tonnes-of-plastic-are-going-into-the-ocean-each-year-37521.
25. Hardesty BD and C Wilcox 15 September 2014. The oceans are full of our plastic – here's what we can do about it. The Conversation https://theconversation.com/the-oceans-are-full-of-our-plastic-heres-what-we-can-do-about-it-31460.
26. Hardesty BD, C Wilcox, TJ Lawson, M Lansdell and T van der Velde. 2014. Understanding the effects of marine debris on wildlife. A Final report for Earthwatch Australia. http://www.csiro.au/Organisation-Structure/Flagships/Wealth-from-Oceans-Flagship/marine-debris.aspx
27. Acampora, H, BD Hardesty, K Townsend and K Erzini 2014. Plastic ingestion by short-tailed shearwaters (*Puffinus tenuirostris*) in northern Australia. Proceedings of the International workshop on fate and impacts of microplastics in marine ecosystems.
28. Hardesty BD, C Wilcox, J Butler and R Gunn. 2013. Exploring sources, impacts and methods for amelioration of ghost nets as a threat to marine species. A final report of the CSIRO and GhostNets Australia Partnership: 2009-2013.
29. Hardesty BD and C Wilcox. 2013. Understanding the effects of marine debris on wildlife: Year 2 Annual Report to Earthwatch Australia.
30. Hardesty BD and C Wilcox 31 Jan 2013. Ghostnets fish on: marine rubbish threatens northern Australian turtles. The Conversation http://theconversation.edu.au/ghostnets-fish-on-marine-rubbish-threatens-northern-australian-turtles-11585.
31. Hardesty BD and C Wilcox. 2012. Understanding the effects of marine debris on wildlife: a report to Earthwatch Australia.
32. JRA Butler, R Gunn, HL Berry, GA Wagey, BD Hardesty, C Wilcox. 2012. Value chain analysis of ghost nets in the Arafura Sea: identifying trans-boundary stakeholders, intervention points and livelihood trade-offs. A report to GhostNets Australia.
33. Hardesty BD and C Wilcox. 2011. Marine debris: biodiversity impacts and potential solutions. The Conversation http://theconversation.edu.au/marine-debris-biodiversity-impacts-and-potential-solutions-2131.
34. Wilcox, C and BD Hardesty. 2011. Cluster Analysis: a novel approach to identify types of derelict nets that comprise ghost nets. Final Report to GhostNets Australia and the Northern Gulf Resource Management Group.
35. Hardesty BD and C Wilcox. 2011. Understanding the types, sources and at-sea distribution of marine debris in Australian Waters. Final report to the Department of Sustainability, Environment, Water, Health, Population and

Communities. http://www.environment.gov.au/marine/publications/understanding-distribution-marine-debris-australia
36. Hardesty, BD, J Reisser, R Sharples and C Wilcox. 2011. Understanding the types, sources and at-sea distribution of marine debris in Australian Waters. Proceedings of the 5th International Marine Debris Conference, Honolulu, HI, USA, 2011.
37. Wilcox, C, BD Hardesty, R Sharples, D Griffin and R. Gunn. 2011. A risk analysis based approach to understanding ghostnet impacts on marine biodiversity. Proceedings of the 5th International Marine Debris Conference, Honolulu, HI, USA, 2011.

Appendix 2: Executive summary "Understanding the effects of marine debris on wildlife: Final report to Earthwatch Australia"

Marine debris is a global environmental issue of increasing concern. Marine ecosystems worldwide are affected by human-made refuse, much of which is plastic. The potential impacts of waste mismanagement are broad and deep. Marine debris comes from both land and sea-based sources and can travel immense distances. It can pose a navigation hazard, smother coral reefs, transport invasive species and negatively affect tourism. It also injures and kills wildlife, can transport chemical contaminants and may pose a threat to human health.

Marine debris includes consumer items such as glass or plastic bottles, cans, bags, balloons, rubber, metal, fibreglass, cigarettes and other manufactured materials that end up in the ocean and along the coast. It also includes fishing gear such as line, ropes, hooks, buoys and other materials lost on or near land, or intentionally or unintentionally discarded at sea.

The Australian government has recognised marine debris as a key threatening process, because of the potential harm it poses to wildlife. In 2003, 'injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris' was listed as a key threatening process under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act). A key threatening process is defined as one that 'threatens or may threaten the survival, abundance or evolutionary development of a native species or ecological community'. Under the EPBC Act, the Australian government implemented the Threat Abatement Plan (TAP) which focuses on strategic approaches to reduce impacts and injuries to marine fauna and ecological communities.

CSIRO's national marine debris project set out to address knowledge gaps identified in the TAP. The project engaged with young Australians while collecting robust, scientific data relevant to the global marine litter problem. To understand the patterns and sources of marine debris and assess the potential harm posed to Australia's marine fauna, our research sought to address four questions:

1) What are the sources, distribution, and ultimate fate of marine debris?

2) What is the exposure of marine wildlife to debris?

3) When wildlife are exposed to debris, what factors determine whether animals ingest or are entangled by debris?

4) What is the effect of ingestion or entanglement on marine wildlife populations?

To address the first question, we carried out a national coastal marine debris survey at sites approximately every 100 km along the Australian coastline. Parts of this work and related research activities were incorporated into TeachWild, a national three-year marine debris research and education program developed by Earthwatch Australia together with CSIRO and Founding Partner Shell. This is the world's largest scale, integrated, rigorous collection of marine debris data.

As part of TeachWild, we engaged with more than 5,500 students, teachers and Shell employees in one-day research and training projects that helped to build knowledge, skills and to change attitudes in issues relating to ocean health. We engaged with more than 150 teachers and Shell employees in immersive, single and multi-day field-based research expeditions led by CSIRO scientists. We also developed curriculum content using marine debris as a teaching tool for science and mathematics to meet the Australian national curriculum guidelines. CSIRO scientists inspired students to explore their world through science in ways that were meaningful and relevant, motivated teachers through innovative learning, and helped increase capacity and networks for educators and citizen scientists, in Australia and beyond. Staff scientists engaged in live-links and video calls that enabled students and Shell employees to ask questions, promoting deeper community engagement. Through this project we connected schools, communities and industry with scientists on a globally important conservation issue through extensive communication, outreach, interviews, webinars, video calls and face-to-face activities. Overall, we reached more than one million Australians, helping to educate them about and increase their understanding of marine debris.

Another key area of deep engagement for CSIRO scientists took place through mentoring and advising the next generation of researchers. CSIRO scientists have been mentors to eight international students who participated in the marine debris project. This included postgraduate students and undergraduates seeking experience in research institutions outside of their home institution as part of their undergraduate or post-graduate education. CSIRO scientists also supervised four Australian honours and PhD students whose research is focused on marine debris issues.

We also developed a public, online, national marine debris database. Here, members of the public can contribute data they collect about local beach litter, following our simple methodology that is freely available online. We also engaged with existing initiatives such as Clean Up Australia, Tangaroa Blue and Surf Rider Foundation, as well as other remarkable NGOs and state based organizations that are cleaning up Australia's beaches. Together, all of these organisations and citizen scientists contribute to the improved understanding of the types, amounts and sources of debris that arrives on Australia's coastline.

Type, source and quantity

We found that within Australia, approximately three-quarters of the rubbish along the coast is plastic. Most is derived from nearby sources, with some likely to be from overseas. In coastal and offshore waters, most floating debris is plastic and the density of plastic ranges from a few thousand pieces of plastic per km^2 to more than 40,000 of pieces of plastic per km^2. Debris is more highly concentrated around major cities, suggesting local source point pollution.

Threats to marine fauna

As the quantity of debris increases in the marine environment, so does the likelihood of impacts from debris to marine fauna. Plastic production rates are intensifying, and the volume of refuse humans release into marine systems is growing at an exponential rate. Litter impacts wildlife directly through entanglement and ingestion and indirectly through chemical affects. We have documented rates of each of these mechanisms through dissections, literature reviews, chemical analyses and modelling.

Ingestion risk to marine turtles

We found that the ingestion of anthropogenic debris by marine turtles has increased since plastic production began in the 1950s. Smaller, oceanic-stage turtles are more likely to ingest debris than coastal foragers, and carnivorous species are less likely to ingest debris than herbivores or gelatinovores. Our findings indicate oceanic leatherback turtles and green turtles are at the greatest risk of both lethal and sub-lethal effects from ingested marine debris. Benthic phase turtles favour soft, clear plastic, supporting the hypothesis that marine turtles ingest debris because it resembles natural prey items such as jellyfish. Most items ingested by turtles are plastic and positively buoyant. We estimated the risk of ingestion across turtle populations at the global scale, and identified regions, such as the north-eastern Indian Ocean, where risks appear to be particularly high.

Ingestion risk to seabirds

We developed a new simple, minimally invasive way of quantifying plastics exposure in seabirds. It can be applied at individual, population and species levels and it has no observed detrimental impacts. We also carried out a global risk analysis of seabirds and marine debris ingestion for nearly 200 species and found that 43% of seabirds and 65% of individuals within a species have plastic in their gut. Our analyses predict that plastics ingestion in seabirds may reach 95% of all species by 2050, given the steady increase of plastics production. We identified high risk regions for seabird impacts, finding a global hotspot in the Tasman Sea between Australia, New Zealand, and the Southern Ocean. In a species-specific study involving TeachWild participants, we found that 67% of short-tailed shearwaters (*Puffinus tenuirostris*) ingested litter. Juvenile birds were more likely to ingest debris than adult birds, and young birds ate more pieces of debris than adults. Birds ate everything from balloons to glow sticks, industrial plastic pellets, rubber, foam and string.

Entanglement risk to turtles and pinnipeds

Entanglement poses a significant risk to marine fauna. Seabirds, turtles, whales, dolphins, dugongs, fish, crabs and crocodiles and numerous other species are killed and maimed through entanglement. We estimate that between 5,000 and 15,000 turtles have become ensnared by derelict fishing nets in the Gulf of Carpentaria region. For pinnipeds in Victoria, the majority of seal entanglements involved plastic twine or rope, and seals become entangled in green items more than in any other colour. In general, young seals are entangled in greater numbers than adults.

Prevention and Recommendations

The most effective way to reduce and mitigate the harmful effects of marine debris is to prevent it from entering the marine environment: cleaning up our oceans is a much less practical solution. To reduce litter inputs requires incorporating an improved understanding of debris at the local, regional and national levels. Improved waste management efforts, targeted education and outreach activities, and technology solutions are also required.

We investigated drivers for releases of debris into the ocean and the potential effectiveness of responses in three contexts. Using our coastal survey data and interviews with more than 40 coastal councils around Australia we investigated the likely drivers for marine debris and effectiveness of local policy responses. We found evidence for two main drivers, general consumer/user behaviour and illegal dumping of refuse. Similarly, we found that local council outreach, which presumably affects user behaviour, and anti-dumping campaigns were both effective in reducing the debris found in coastal areas. We examined the drivers for lost fishing gear and found that they were a mix of overcrowding on fishing grounds, poor crew training, and enforcement evasion. We also evaluated the effectiveness of incentive schemes, such as South Australia's container deposit scheme, in reducing waste lost into the environment. The scheme appears to be very successful, reducing the number of beverage containers, the dominant plastic item in the environment, by a factor of three.

By garnering the information needed to identify sources and hotspots of debris, we can better develop effective solutions to tackle marine debris. For example, fisheries management aimed at reducing losses of fishing gear at sea would undoubtedly result in less wildlife harmed by entanglement and educating the next generation will improve our world for the future. Working together, scientists, industry partners, coastal managers and citizen scientists can make significant strides to reduce marine debris impacts in coastal areas and in the marine environment.

Appendix 3 Input to Department of Environment Threat Abatement Plan

CSIRO Research Related to Australia's Threat Abatement Plan for Impacts of Marine Debris on Vertebrate Marine Life

Chris Wilcox and Britta Denise Hardesty

August, 2015

Background

Marine debris are increasingly recognized as a significant environmental pressure on marine wildlife and ecosystems. Interactions from debris entanglement or ingestion have been noted for nearly species, based on a recent review (Gall and Thompson 2015). Understanding these impacts has been nominated as a priority in the scientific literature by a number of papers (e.g. 7).

CSIRO commenced a major research effort on marine debris, in particular focusing on three aspects of the marine debris issue: understanding sources, evaluating risk to wildlife, and investigating the effectiveness of policy responses, commencing in 2009. This research has involved 4 major research efforts;

1. a collaborative project on derelict fishing gear in collaboration with Ghostnets Australia from 2009-2014;
2. a small scoping project funded by the Department of Environment (SEWPaC) in 2009-2010;
3. a large project involving marine debris generally at the continental scale funded by Shell Australia in collaboration with Earthwatch Australia (2011-2014); and
4. a collaborative working group of international experts funded by the National Center for Ecological Analysis and Synthesis in the United States (20143-2014).

The summaries below are targeted to activities outlined in the Threat Abatement Plan for Marine Debris. However, they do not represent the full range of research on this topic. Many of the references cited below are available publically. For those not available contact Britta Denise Hardesty at CSIRO for access. For each relevant activity outlined in the Threat Abatement Plan, the section from the plan is provided along with the response.

Ongoing Marine Debris Research at CSIRO

CSIRO's marine debris related research program will continue at least through 2017, given current funding. Current funding involves 3 projects, including: 1) a materials flow analysis connecting consumers and industries to plastic lost into the ocean in Australia, 2) a review and analysis of the current state of knowledge of microplastics at the global scale, and identification of future information needs for the United Nations Environment Program, 3) an analysis of coastal clean-up data at the global scale, including design of improved data collection methods for clean-up efforts and determining a global baseline for standing stock of coastal litter. In addition to these three projects, CSIRO and NSW EPA are co-organizing a national litter workshop which includes relevant stakeholders aimed to harmonize data collection methods and identify key priority areas and knowledge gaps for states/territories.

These projects and a linkage grant to which CSIRO contributes (led by Kathy Townsend at UQ and finishing early 2016) will see further results on risk analysis for impacts to sea turtles, an increasing emphasis on design and interpretation of monitoring programs, and the facilitation of data exchange among state and local government bodies to improve the efficacy of existing programs.

CSIRO research and activities relevant to Table 2.1 in the Threat Abatement Plan

1.7	Australian Government agencies in collaboration with state and territory governments to identify appropriate responses and responsibilities for recovery of hazardous debris at sea, notably large derelict fishing nets.	Australian, state and territory governments	1–2 years

CSIRO and Ghostnets Australia published a study which included modelled net pathways, validated against independent data for the Gulf of Carpentaria and surrounding regions (22). This study illustrated the vast majority of nets that are found in the Gulf and surrounding regions pass relatively close to the port of Weipa. This work points to a potential significant cost saving in recovery efforts, if nets can be identified at sea to the northwest of Weipa and then retrieved as they pass close to the port.

Existing Customs surveillance flights pass through this region, and could provide the necessary reporting if targeted. This would reduce both the impacts and the cost of retrieval for nets, as they could be retrieved at sea prior to entering the Gulf and passing through areas with high densities of turtles and dugong. CSIRO and Ghostnets Australia collaborated to track several drifting nets in the Gulf using satellite tracking devices. Together with existing modelling work in the region (22) this information would allow identification of a most cost-effective surveillance location for identifying large drifting nets, and prediction of the timing of arrival of the drifting gear in the region around Weipa to allow the most cost-effective deployment of recovery vessels.

Early interception of these nets is a key management action, as the nets circulate around the margin of the Gulf, passing through areas that support high densities of marine turtles (22). Based on analysis of stranded turtles found in the nets, a second publication by CSIRO and GhostNets Australia staff estimated that the approximately 9,000 nets intercepted to date have caught on the order of 15,000 turtles. The study examined the damage done by particular types of nets, and estimated that large gill nets in particular have very high catch rates of turtles. This finding likely extends to other related species. Given additional nets that have washed ashore in the region, that estimate can be extended to approximately 20,000 turtles.

In 2014, CSIRO, Ghostnets Australia, and Arafura and Timor Seas Ecosystem Action Program (ATSEA) held a series of workshops with fishermen in both Australia and Indonesia, with the goal of identifying the sources of these nets. At the present time it appears that the majority of the nets come from Indonesian waters to the northwest of the Gulf of Carpentaria (2, 22). Discussions with fisheries ministry and industry representatives during the workshops identified a number of potential actions that could reduce the number of lost nets reaching Australia, including development of a voluntary logging program for lost net, financial incentives for net recovery, technical support for better identification of nets and recovery of lost gear, and increased training for fisheries workers (2). These activities vary in cost and complexity. However, some activities such as support for mapping locations where nets are commonly lost or assisting with training for fisheries workers could be readily implemented at relatively low cost.

1.10	DEWHA to support an analysis of financial incentives to encourage return of waste generated at sea to land for appropriate disposal, for example: • fishing gear inventories by port and vessel supported by deposits and bounty initiatives • introduction of regulations relevant to insurance of lost fishing or other gear and/ or insurance levies to support removal of derelict gear	DEWHA	2–4 years

Preliminary results from workshops held in Indonesia with fishermen and fisheries ministry officials suggest that nets have an economic value and are worth recovering if possible (2). Technical support for aggregation of data on locations of lost nets was identified as a valuable contribution by Indonesian fishermen (2). This location information would assist in avoiding the hazard to vessels and gear posed by existing lost net, loss of future nets on at points identified as high risk for snagging, and would also facilitate the possibility of profitable salvage operations. Fishing gear labelling and inventory was also suggested by operators as being a potential solution, supporting a reporting system. Other possible incentives discussed included low interest loan programs for gear, conditional on return of damaged or worn gear. Given that large nets can cost between 5,000 and 30,000 dollars per net, low interest loan programs would provide significant leverage to implement net marking, reduce disposal of repairs at sea, and enhance recovery efforts for lost gear, without requiring extensive fisheries management regulation.

1.12	State, territory and local governments and other relevant bodies to consider providing increased funding for the introduction of improved solid pollutant (particularly litter) control strategies in waterways.	State and territory governments and relevant bodies	2–4 years

New work by CSIRO is examining the connection between State, regional, and local council infrastructure, policy and expenditure on waste management with the density of debris present in the near shore environment in the council area. Preliminary results suggest that council actions can have a significant influence on the amount of debris accumulating in the coastal areas of the council. The study results suggest that outreach programs had a much higher impact that the provision of infrastructure in terms of reducing waste washing up on council coastlines. In particular education programs and anti-illegal dumping campaigns appeared to have benefits. However, particularly targeted types of infrastructure, such as coastal rubbish bins, also significantly reduced plastic reaching the ocean. Based on the results it would be possible to evaluate the cost-effectiveness of local, regional and state initiatives to design an effective and low-cost model policy that could be adopted by local and regional government. This work is ongoing, as detailed in the **Ongoing Research** section of this document.

CSIRO also conducted a national survey of marine debris along the coast of the Australian continent and in the offshore environment (4,18,28). Analysis of this survey data suggests that most marine debris in the Australian region is domestic. Furthermore, debris in the marine environment appears to increase with the local population, suggesting local sources outweigh input from the high seas. Analysis of the data also suggests that areas that have a high population in the region, but relatively isolated coast tend to have high amounts of debris, consistent with illegal dumping being a significant driver of plastic inputs to Australian waters. Taken together, these results suggest that there are opportunities for domestic actions, at the council, region, state, and national levels, to have a significant impact on the debris load in Australia's environment, as most of the debris is from Australian sources.

1.13	State and territory governments to facilitate an analysis of the effectiveness of current litter public awareness and education campaigns to identify gaps and areas for improvement.	State and territory governments	1–2 years

Initial analysis of local policies, facilities and programs suggests that clean-up campaigns are not as effective as education campaigns, and in particular campaigns against illegal dumping. Given analysis suggesting the effectiveness of various measures, currently in progress by CSIRO, a reasonable next step would be to evaluate the cost of various actions at the state, regional and council level to identify the most cost-effective responses to reduce inputs of litter to the marine environment. This analysis will be a significant component of upcoming work on the materials flows project (Project 1 in **Ongoing Research** above), which began in 2015.

1.14	State, territory and Australian governments, in collaboration with appropriate non-government organisations, to develop options for establishing a more consistent and long-term national approach to litter abatement education, particularly for marine-based activities.	Australian, state and territory governments	1–2 years

Analysis of coastal debris in the Australian marine zone suggests that most debris is from land-based activities, not marine activities. This is particularly true near populated centres. Targeting of education campaigns appeared to be one of the most important correlates of reduced debris densities in our analysis of coastal debris patterns. This analysis will be formalized as one component of the upcoming materials flows project (Project 1, **Ongoing Research** section).

Data on animals stranding along the Australian coastline suggests that some types of debris from marine sources, such as monofilament line from recreational fishers, may have particularly high impacts and could be targeted for outreach activities. However, an important consideration in allocating resources is that in general the vast majority of debris is from land-based sources. Active and inactive fishing gear however, despite composing a small volume of the total load of debris, are predicted to have much higher impacts on wildlife than other debris types (5). Based on this, recreational and commercial fishers should likely be targeted in outreach and education activities.

1.15	DEWHA and relevant agencies to examine introducing awareness-raising and outreach programs aimed at relevant groups contributing to marine debris in the Asia-Pacific region	DEWHA and relevant agencies	2–4 years

See comments for 1.7 and 1.10 above.

In addition to those general debris results, a significant portion of fishing related debris in the Gulf of Carpentaria and surrounding regions comes for overseas, in particular from the coastal and offshore regions of Indonesia that border Australia's northern EEZ boundary (15,22). During workshops with fishermen in the region, a number of potential outreach and education activities were identified that could assist in reducing lost gear in the region (2).

For non-fishing related debris, the majority of the material in Australia's marine region appears to be Australian in origin, and from land-based activities in particular. Exceptions to this pattern are areas that are particularly remote, and which have high levels of fishing effort, such as the west coast of Tasmania, where domestic fishing gear dominates the debris in the nearshore region (4,28).

1.16	DEWHA, in collaboration with DFAT, to identify opportunities for exchange visits between coastal (especially Indigenous) communities experiencing the impacts of marine debris and groups in other nations where large proportions of harmful marine debris originate.	DEWHA and DFAT	1–2 years

Ghostnets Australia facilitated several exchanges as part of the program of workshops with Indonesian fisheries officials and fishermen. Environment (DEWHA) co-funded some of these.

1.17	DEWHA, in collaboration with DFAT, to strengthen relations with regional neighbours on marine debris through relevant fora, and develop collaborative project proposals to address the sources and impacts of harmful marine debris.	DEWHA and DFAT	2–4 years

From 2009 to 2014 Ghostnets Australia led a collaborative project in cooperation with CSIRO and ATSEA to develop approaches for reducing lost gear in Indonesia. Through consultation with Indonesian fishermen this project developed a number of potential actions that could be pursued further to reduce loss of fishing gear into the environment and its subsequent transport to Australian waters (2,30). There is some ongoing activity in developing outreach through ATSEA, which is currently being led by Ghostnets Australia with support from DFAT.

2.1	DEWHA in collaboration with state and territory governments and other relevant stakeholders to support the development of nationally consistent, statistically rigorous data collection protocols and survey methods. DEWHA to support the development and management of national mapping of the spatial distribution and concentration of marine debris over time to assess the significance of marine debris and to reduce its occurrence.	DEWHA	1–3 years

CSIRO developed a large project to quantify the amount and distribution of debris in Australia's coastal environment. The project included: 1) development of a statistically robust sampling design at the continental scale; 2) development of a simple, rapid, quantitative survey method; 3) implementation of surveys every 100km along the coastline following this design; 4) development of a database for housing and handling this information; and 5) development of robust statistical tools that could identify both terrestrial and marine sources of debris, and provide a standardized map of the distribution of debris at the national scale. This project was completed in 2014, see reference 28 for full details.

The database developed for this project can accommodate both at sea and terrestrial sampling, along with volunteer clean up data. The survey methods are designed to be useable with a range of participants, including professional staff, primary and secondary schools, and volunteers. The survey methods have been optimized to deliver quantitative and repeatable data, along with all the supporting metadata, in a format that allows for rapid assessment (less than 2 hours per site). These materials, including the database, survey protocols, and a report describing the project outcomes are freely available online.

In combination with these this coastal data, CSIRO implemented a marine debris sampling program throughout Australia's exclusive economic zone, with samples approximately every 80 nautical miles surrounding the continent. This sampling program was implemented based on a statistically robust design to control variation in sampling conditions, along with local and regional heterogeneity. These data have been integrated with other data from around the globe to form a coherent dataset covering all the major oceans, comprised of more than 13,000 samples from multiple researchers. Additional samples are being added to the database as they become available. CSIRO developed a set of statistical tools to standardize the data and create maps of debris densities at the regional, national, and international scale. See reference 28 for full details.

CSIRO and collaborators have produced a number of maps of debris distributions at the national and international scales, with several of these maps incorporated into publications that are in the scientific literature or currently in review (4,7,10,18,28).

Development of a national approach to information collection and management	2.2	State, territory and Australian governments to provide support for community-based coastal and waterway clean-up and monitoring activities.	Australian, state and territory governments	1–2 years

The recent CSIRO marine debris project involved a significant amount of citizen scientist participation. For this process we developed a number of potentially useful materials, including several volunteer friendly survey protocols, and a database front end that was easy for volunteers to use (see 28 for details, materials available at www.csiro.au/Marine-debris). These volunteer oriented materials are designed to mesh directly with the full CSIRO marine debris database, which can incorporate both survey and clean up data, including online data entry forms and reporting materials. The survey methods have been optimized to deliver quantitative and repeatable data, along with all the supporting metadata, in a format that allows for rapid assessment (less than 2 hours per site). These materials are readily available online (www.csiro.au/Marine-debris). Content was also developed to fit into the national science curriculum for students in years 5-10. This material is also freely available online.

2.3	DEWHA in collaboration with state and territory government to facilitate the establishment of a national network of a limited number of permanent marine debris monitoring sites (including within Commonwealth Marine Protected Areas) to promote consistent monitoring and information gathering and exchange, to enable understanding of long-term trends, and to inform adaptive and effective management responses.	DEWHA	1–2 years

While there are a number of coastal sites that could be used as long term monitoring sites, some of which have existing historical data (e.g. Gulf ranger groups, SA NRM), a potentially more useful approach may be to combine direct monitoring at coastal sites with monitoring of seabirds as indicators for debris. There are existing programs in the EU for use of seabirds as monitors for marine debris, including environmental targets for reporting on debris densities and changes in the North Sea (van Franeker 2011).

CSIRO developed a non-invasive method for measuring the amount of plastic in a seabird, based on plastic breakdown products found in oil secreted from seabird's preening gland (13). The advantage of using seabirds is that particular species tend to forage in relatively consistent areas. Species like shearwaters tend to pick up relatively large amounts of debris, and thus could readily be used as bio monitors of debris in the ocean. This would be far less expensive than at-sea surveys from vessels, and likely less expensive than coastal surveys of debris. Sampling debris using seabirds also has the advantage of sampling relatively large areas, which depending on the species chosen could range from hundreds to thousands of square kilometres. Targeting 3 to 5 seabird colonies around Australia, and choosing one or two representative species to work with, could provide relatively low cost and effective monitoring of marine debris. Linking this monitoring to other Key Ecological Features, such as ocean productivity, or threatening processes such as organic and inorganic pollution levels, could provide a useful bio monitoring system for State of the Environment tracking and monitoring Commonwealth Marine Reserves. Importantly, it provides a population level estimate of exposure to plastic debris.

A bio monitor such as seabirds should be paired with direct monitoring sites. One complexity in choosing sites, however, is the need to identify locations that balance responsiveness to change, geographic coverage, and cost. Using the existing CSIRO national survey and statistical methods it would be possible to identify a set of sites that would be useful for monitoring, in terms of providing a sensitive and cost-effective set of sites that will give a national picture of the distribution of debris at sea, and the change in land based inputs. Using the existing survey data, it would also be possible to quantify the capacity of these sites to detect a change of a given magnitude, which would be useful in identifying targets for State of Environment reporting, TAP progress analysis, and as background for recovery plans of species identified as being affected by debris such as Albatross and Petrels, Marine Turtles, Pinnipeds, and Cetaceans.

2.4	DEWHA to support a study on the wind and sea circulation patterns in the Asia-Pacific region as a basis for better understanding the pathways and potential sources and sinks of harmful marine debris of foreign origins in Australian waters.	DEWHA	1–2 years

There are a number of analyses that have been done which can provide information on the sources of debris in Australia. CSIRO provided the Department with a report detailing current modelling at sites distributed along Australia's EEZ (37). Findings from this report suggest that most debris in the Australian marine zone is of Australian origin. More recently, CSIRO and UWA have collaborated to collect data on debris densities ca. every 80 nautical miles around the entire Australian continent (28). A subset of these results have recently been published (18), with analysis of the likely sources for debris observed at sea. In general, the west coast and very northeastern tip of the continent appear to receive material from international sources, while the east coast of the continent appears to primarily receive materials from domestic sources. Ongoing research has examined these patterns at the global scale (7); however, data on the distribution at sea in the Indian Ocean, Southern Ocean, and southwestern Pacific remains relatively sparse (7,28).

CSIRO has collaborated with Ghostnets Australia to evaluate the sources of derelict fishing gear along Australia's northern coast. Of the nearly 15,000 nets recovered to date, it appears that the majority come from neighbouring countries in the Arafura and Timor Seas, with a particular concentration along the international boundary and in the prawn trawling waters to the north of the Gulf (15, 22; Gunn et al. Unpublished Data). CSIRO and Ghostnets Australia cooperated to put satellite tracking devices on several drifting nets in the Gulf, validating that nets circulate in the Gulf clockwise, completing a circuit of the gulf in less than a year.

The CSIRO team has been involved in a collaboration with UNSW researchers and others from the US and EU to develop a global analysis of marine debris sources and distributions. Two publications from this collaboration are particularly relevant to this TAP outcome. A recent paper provided estimates of inputs of plastic into the marine environment for all coastal countries around the globe (10). China and Indonesia were particularly large sources, with the large economics in Asia comprising a substantial portion of the predicted total plastic input to the ocean (10). A second publication, currently in review, synthesizes the existing models of marine debris flows in the ocean (7). This analysis uses these models, in combination with over 13,000 observations of debris from at-sea samples to map the density of debris throughout the world's oceans.

2.5	Australian Government to facilitate a feasibility study on introducing marking of fishing gear so that it may be identified as originating from a specific fishery. The feasibility study will also consider the practical implications of marking fishing gear and the implications of derelict gear being traced back to fisheries operations.	Australian Government	2–4 years

CSIRO has investigated the potential for marking of fishing gear using a number of technologies. Two of the most promising are microdots, which encode information on a small dot that is then incorporated into the gear itself, and chemical marking of the rope used in making the net. Chemical marking of plastics could be widely applicable, in essence providing a bar code that is incorporated into the material itself and thus readable even from small fragments. Both of these technological approaches are feasible, and exist widely in other applications, but have not been used for tracking marine debris. Mapping of fishing gear is currently under investigation by the United Nations Food and Agriculture Organization. A CSIRO representative will attend the next FAO workshop, scheduled for early 2016. The Global Ghost Gear Initiative, an NGO – Industry – Research partnership initiated by World Animal Protection is also exploring the potential for gear marking. CSIRO is a founding-partner in the initiative, providing technical and analytical support.

3.1	State, territory and Australian governments to support expanded and consistent, long-term monitoring, investigation, recording and management of data on vertebrate marine life harmed and killed by the physical and chemical impacts of marine debris. This information will assist the impacts of different types of marine debris on vertebrates to be quantified and characterised. For example: • DEWHA to support monitoring of regurgitated marine debris at albatross and giant petrel breeding colonies (linked with the *Recovery plan for albatrosses and giant petrels* [Environment Australia, 2001]).	Australian, state and territory governments	1–2 years

CSIRO research has focused on two different sets of impacts from marine debris, those resulting from entanglement and those resulting from ingestion. CSIRO entanglement research has been conducted primarily in collaboration with Ghostnets Australia, focusing on derelict fishing gear in

Northern Australia. To date we have been able to identify areas of likely high risk to marine turtles in the Gulf of Carpentaria and surrounding regions, along with estimating the likely sources and paths of drifting nets (15,22,28). More recently we have analysed the characteristics of nets entangling animals to identify particular types of nets that are likely to entangle animals, identify the fisheries they come from, and estimate the total number of turtles killed (15). We estimate that approximately 20,000 marine turtles have been captured in the ADFLG (ghostnets) collected by indigenous rangers in the Gulf of Carpentaria and surrounding regions.

We have also worked with Ghostnets Australia and the ATSEA program to run workshops in Indonesia estimating the distribution of fishing effort by type of fishing, the relative number of vessels, and the frequency with which they lose gear to allow connection of impacts in Australia to fisheries operating across the border (2,24,28). We plan to revisit the analysis of net impacts, to improve the estimate of the number of animals killed.

In terms of monitoring of debris, particularly ingestion and entanglement rates for wildlife, the team at CSIRO have developed a non-invasive method for quantifying the plastic ingested by wildlife using small tissue samples (13). We have trialled this method for seabirds (13), and implemented it to evaluate plastic ingestion at multiple sites around the Australian continent to quantify debris loads in 9 seabird species (2). We have also developed methods suitable for quantifying debris loads with volunteers, and on breeding colonies when seabirds are not present (28). These methods, in particular the fat sampling based method, could provide a low cost monitoring tool for wildlife species, and be used to further understand the sub-lethal impacts of plastic ingestion.

3.2	DEWHA to coordinate marine debris abatement strategies identified in existing marine wildlife recovery plans. For example: • DEWHA to support analysis of the impact of marine debris on the survival and behaviour of marine turtles (linked with the *Recovery plan for marine turtles in Australia*	DEWHA	1–2 years

There are two relevant research projects involving CSIRO, one in collaboration with the University of Queensland and Imperial College, London investigating ingestion of plastics by marine turtles and a second in collaboration with Ghostnets Australia investigating entanglement in drifting gear. In addition, we have several research outputs that attempt to answer similar questions for seabirds. A parallel risk analysis for the threat debris ingestion and entanglement poses to marine mammals has been proposed, although given funding constraints it hasn't been completed to date.

The ingestion work has identified types of plastics ingested, evaluated the role of selection by turtles in ingestion, and identified characteristics of debris which lead to higher ingestion rates (17,23). Turtles are selective of materials, and tend to prefer items that are flexible, and different in colour from the background debris in the ocean. These results suggest that changing the design of consumer items, which constitute the largest portion of debris, might reduce the ingestion rates of turtles.

Complementing these papers on the mechanics of ingestion, we have also conducted a review of ingestion studies to estimate the rates across species and life history stages for all the major turtle population units (20). This study suggests ingestion affects approximately 30% of turtles based on literature reports, and varies by age class, food source, species and other characters. Using these data, together with predicted distributions of plastic debris in the ocean we have developed a spatially explicit risk model for plastic ingestion by turtles which provides estimates of ingestion rates by species, management unit, and location. This work found that approximately 52% of turtles globally have ingestion plastic debris, with this percentage increasing with time. Turtle populations in the Australian region, particularly within the exclusive economic zone of Australia, and in the eastern Indian Ocean and South China Sea were found to have particularly high rates of debris ingestion.

The CSIRO team, in collaboration with University of Queensland and University of Tasmania are currently developing an analysis of the relationship between debris loads in the digestive tract of seabirds and turtles and the likelihood of mortality. Preliminary results for turtles suggest that there is a statistically significant positive relationship. Given that this relationship is borne out, it will be possible to estimate the mortality resulting from debris ingestion. We are collaborating with researchers at the University of Tasmania to conduct a similar analysis, with results expected in the next 12 to 18 months.

In light of the difficulty in directly quantifying impacts to marine wildlife from marine debris, the CSIRO team in collaboration with US researchers based at Ocean Conservancy have developed an expert based system to estimate the entanglement, ingestion, and toxicity impacts to seabirds, turtles, and marine mammals. This analysis provides quantitative estimates of lethal and nonlethal impacts for these three taxa, across the 20 most common debris items in Ocean Conservancy's global coastal clean up data (6).

CSIRO and Ghostnets Australia have been collaborating on developing estimates of the impacts of abandoned fishing gear on marine species, particularly in the northern waters of Australia. Using data collected by Indigenous Rangers, along with a database developed by Ghostnets Australia we have estimated the paths taken by drifting nets, and combined these with estimates of the turtle distribution in the region to create a spatial risk map for entanglement by turtles (22). We extended this analysis to estimate the total number of turtles caught in nets, considering the characteristics of the nets (14). Based on this work we estimate that the nets are concentrated in the Gulf of Carpentaria, with the highest levels of impact in the region northwest of Weipa, in the southwestern corner of the gulf, and along the west coast of the Gulf. We estimate between 5,000 and 15,000 turtles were caught in the ca. 9,000 nets for which we have data (14). Given that there have been a total of 13,000 nets removed as of 2014, it's likely that the total for all the nets is between 10,000 and 30,000 turtles caught (14). Given the wide confidence intervals on the estimates, we plan to revisit this analysis to refine our estimates, conditional on obtaining funding for the work.

In addition to the research results for turtles, CSIRO has recently evaluated the impact of ingestion on seabirds, including conducting a global analysis of the literature on ingestion rates, and using forecast distributions of debris fields and statistical modelling of species to predict ingestion rates for 188 seabird species at the global scale (9). Based on the literature review, of the 135 species studied since 1962, 80 have been found to have ingested debris (59%). These analyses identify three important patterns: 1) the frequency of ingestion by seabirds is increasing significantly, at about 1.5% per year; 2) the discovery of new seabird species impacted by plastic ingestion is increasing at about 0.5% per year; and 3) there is global hotspot for ingestion rates at the boundary between the southern hemisphere temperate oceans and the southern ocean, with the highest expected impact globally in the southern Tasman Sea.

CSIRO Marine Debris Publications

<u>Peer-reviewed Journal Publications</u>

1. Gunn, R. and C. Wilcox. Understanding the sources and causes of ghost nets in northern Australia provide a basis for improved fisheries management in the Arafura Sea, Indonesia. *In preparation* for Journal of Environmental Management
2. Hardesty BD, C Davoust, D Holdsworth, A Revill and C Wilcox. Phthalates detected in live seabirds: the ubiquity of plasticizers in Australian seabirds. *In preparation for* Environmental Toxicology and Chemistry.
3. Roman, L, QA Schuyler, BD Hardesty and KA Townsend. Prevalence and selectivity of anthropogenic debris ingestion in eastern Australian avifauna. *In review.* PLoS One.
4. Hardesty BD, TJ Lawson, T van der Velde, M Lansdell, G Perkins and C Wilcox. Estimating quantities and sources of marine debris at a continental scale. *In review* Frontiers in Ecology and the Environment.
5. Van der Velde, T., Milton, D.A., Lawson, T.J., Lansdell, M., Wilcox, C., Davis, G., Perkins, G., & BD Hardesty. Is citizen science data worth our investment? *In review* Biological Conservation.
6. Wilcox, C. N Mallos, GH Leonard, A Rodriguez and BD Hardesty. Estimating the consequences of marine litter on seabirds, turtles and marine mammals using expert elicitation. *In review* Marine Policy.
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Appendix 4 Marine Debris Fact Sheet

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CSIRO

Marine debris

Sources, distribution and fate of plastic and other refuse – and its impact on ocean and coastal wildlife

Marine debris is a globally recognised environmental issue of increasing concern

Marine ecosystems worldwide are affected by human-made refuse, much of which is plastic.

Marine debris comes from both land and sea-based sources and can travel immense distances. It can pose a navigation hazard, smother coral reefs, transport invasive species and negatively affect tourism. It also injures and kills wildlife, has the potential to transport chemical contaminants, and may pose a threat to human health.

CSIRO has completed a survey of sites approximately every 100 km along the Australian coastline. Parts of this research engaged with thousands of students, teachers and Shell employees and has reached more than one million Australians, helping to educate them about, and increase their understanding of, the problems of marine debris.

What is marine debris?

Marine debris is defined as any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment.

Marine debris includes consumer items such as glass or plastic bottles, cans, bags, balloons, rubber, metal, fibreglass, cigarettes, and other manufactured materials that end up in the ocean and along the coast.

It also includes fishing gear such as line, ropes, hooks, buoys and other materials lost on or near land, or intentionally or unintentionally discarded at sea.

DID YOU KNOW

CSIRO has developed an online national marine debris database where you can contribute data you collect about litter at your local beach. Together, we can contribute to the improved understanding of the types, amounts and sources of debris that arrives on Australia's coastline. See www.cmar.csiro.au/marine-debris

What does CSIRO's research tell us?

CSIRO surveyed coastal sites approximately every 100 km around the continent of Australia. This body of work represents the largest scale, integrated, rigorous data to have been collected anywhere in the world aimed at addressing the marine debris issue.

1. What are the sources, distribution, and ultimate fate of marine debris?

We found that within Australia, approximately three-quarters of the rubbish along the coast is plastic. Most is from Australian sources, not from overseas, with debris concentrated near urban centres. In coastal and offshore waters, most floating debris is plastic. The density of plastic ranges from a few thousand pieces of plastic per square kilometre to more than 40,000 pieces of plastic per square kilometre. Debris is more highly concentrated around major cities, suggesting local sources.

2. What is the exposure of marine wildlife to debris?

Litter impacts wildlife directly through entanglement and ingestion and indirectly through chemical affects. As the quantity of debris increases in the marine environment, so does the likelihood of impacts from debris to marine animals. Plastic production rates are intensifying, and the volume of refuse humans release into marine systems is growing at an exponential rate. Even toothpaste and personal care products can have plastic microbeads in them. These microplastics can be mistakenly eaten by a range of marine species.

3. Why do animals ingest debris, and what is the effect on marine wildlife populations?

Globally, approximately one third of marine turtles have likely ingested debris, and this has increased since plastic production began in the 1950s. Most items eaten by turtles are plastic and positively buoyant. Smaller oceanic turtles are more likely to ingest debris than coastal foragers; herbivores are more likely to ingest debris than carnivorous species; oceanic leatherback turtles and green turtles are at the greatest risk of ingested marine debris effects; and benthic turtles show a strong selectivity for soft, clear plastic that resembles natural prey such as jellyfish.

Around the world, nearly half of all seabird species are likely to ingest debris. Birds eat everything from balloons to glow sticks, industrial plastic pellets, hard bits of plastic, foam, metal hooks and fishing line. CSIRO researchers and colleagues found that 43 per cent of short-tailed shearwaters have plastic in their gut. Young birds were more likely to ingest debris and ate more pieces of debris than adult birds. A global hotspot for seabird impacts exists in the Tasman Sea south of Australia. CSIRO predicts that plastics ingestion in seabirds may reach 95 per cent of all species by 2050, taking into account the steady increase of plastics production.

4. What is the effect on marine wildlife populations that become entangled by debris?

Seabirds, turtles, whales, dolphins, dugongs, fish, crabs and crocodiles and numerous other species are killed and maimed through entanglement. We estimate that between 5,000 and 15,000 turtles have been killed in the Gulf of Carpentaria after becoming ensnared by derelict fishing nets, mostly originating from overseas. For pinnipeds in Victoria, the majority of seal entanglements involved plastic twine or rope, and seals become entangled in green items more than in any other colour. In general, young seals are entangled in greater numbers than adults.

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What can be done?

By garnering the information needed to identify sources and hotspots of debris, we can better develop effective solutions to tackle marine debris.

The most effective way to reduce and mitigate the harmful effects of marine debris is to prevent it from entering the marine environment in the first place. This requires incorporating understanding of debris into local, regional and national decision-making; improved waste management efforts; education and outreach activities; development of technology solutions; anti-dumping campaigns; reducing losses of fishing gear at sea; and incentives to reduce debris, such as South Australia's container deposit scheme (which has reduced the number of beverage containers, the dominant plastic item in the environment, by a factor 3).

Working together, scientists, industry, coastal managers and citizen scientists can make significant strides to reduce marine debris impacts in coastal areas and in the marine environment.

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