Editorial: Plastic Pollution: An Ocean Emergency

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The oceans have become one giant refuse bin for all manner of plastics. Environmental and health concerns associated with plastic pollution are a long recognised international problem (Carpenter & Smith 1972). Whilst approximately 10% of all solid waste is plastic (Heap 2009), up to 80% of the waste that accumulates on land, shorelines, the ocean surface, or seabed is plastic (Barnes et al. 2009).

Plastics have an array of unique properties: they are inexpensive, lightweight, strong, durable, corrosion resistant, and with high thermal and electrical insulation properties. This versatility has revolutionised our life and not least made information technology and electrical goods far more readily available than would have been possible otherwise. They have also contributed to our health and safety (e.g., clean distribution of water and breakthrough medical devices), and have led to substantial energy savings in transportation. Unsurprisingly, with an ever expanding population and our standard of living continuously improving, plastic production has increased from 0.5 to 260 million tonnes per year since 1950 (Heap 2009), accounting today for approximately 8% of world oil production (Thompson et al. 2009b). Almost all aspects of our daily life involve plastics in some form or another: from hair dryers to shoes, to the car we drive and the wrap around lunch sandwiches. A scary thought considering that in the 1960s, less than 1% of our waste was plastic.

The key problem with plastic however is that a major portion of plastic produced each year is used to make disposable packaging items or other short-lived products that are permanently discarded within a year of manufacture (Hopewell et al. 2009). Well over a billion single-use plastic bags are given out for free every day.

Around 0.2 to 0.3% of plastic production eventually ends up in the ocean (Andrady & Neal 2009). Two of plastics' most touted advantages, their light weight and durability, also make plastic items a significant environmental hazard once seaborne. Close to half of plastics are buoyant and remain so until they become waterlogged or amass too much epibiota to float. Plastics don't biodegrade. Through photodegradation and abrasion plastics only break into smaller and smaller pieces so "that they can be consumed by the smallest marine life at the base of the food web," according to a report by the United Nations Environment Programme (UNEP 2009). Saline marine environments and the cooling effect of the sea mean that degradation requires very long exposure times. Persistence of plastic debris is poignantly illustrated in the account that plastic swallowed by an albatross had originated from a plane shot down 60 years prior some 9,600 km away (Weiss et al. 2006).

Plastics' buoyancy also means they can be easily carried by ocean currents and transported across ocean basins, their contamination stretching from the shorelines to the deepest parts of the sea, from the poles to the Equator and the most remote of islands. Between 1996 and 2006, NOAA recovered 511 tonnes of fishing gear from the reefs of the Northwest Hawaiian Island Marine National Monument (NWHI-MNM), one of the largest marine conservation areas in the world (Pichel et al. 2007). Stewart Island's Mason Bay, located at almost 47° S, is a spectacular, remote and isolated, ca.10 km sandy beach that is open to the Southern Ocean, facing into the Roaring Forties. The beach is fouled with 2 to 3 tonnes of plastic pollution, mostly fisheries-related items due to intense fishing in close and offshore waters (Barnes et al. 2009). Most of these items are from New Zealand sources. A more minor, but significant, component comes from Korea and Japan; other sources include Argentina, Australia, Belgium, Chile, France, Norway, Poland, Russia, Spain, South Africa, and the United Kingdom (Barnes et al. 2009).

Although most plastic floats on the sea surface, there are an increasing number of reports of sunken plastic debris settling to the sea floor at all depths. A disturbing note is Oshima's (2000, p. 73 in Gregory 2009) report of numerous white plastic shopping bags suspended upside down and freely drifting past a deep-sea submersible at depths of 2,000 m, looking like an assembly of ghosts.

Impacts on ocean wildlife. The bodies of almost all marine species, ranging in size from plankton to marine mammals, and including some of the wildest and most vulnerable species on the planet – animals that make nearly their entire living far from humans – now contain plastic. Sixty percent of 6,136 surface plankton net tows conducted in the western North Atlantic Ocean and Caribbean Sea from 1986 to 2008 contained buoyant plastic pieces, typically millimetres in size (Law et al. 2010). Plastics turn up in bird nests, are worn by hermit crabs instead of shells, and are present in sea turtle, whale and albatross stomachs (Mrosovsky et al. 2009). Over 260 species, including invertebrates, turtles, fish, seabirds and mammals, have been reported to ingest or become entangled in plastic debris, resulting in impaired movement and feeding, reduced reproductive output, lacerations, ulcers, and death (Derraik 2002; Laist 1997).

Entanglement in discarded or lost plastic netting, rope and monofilament lines from commercial fishing is one of the more visible impacts of plastic pollution (Laist 1997). Recent sightings include pods of endangered humpback whales travelling northwards with a mass of tangled rope in tow (e.g., crayfish pot and buoy with marker pole and flag) (Gregory 2009). Lost and abandoned or derelict fishing gear can also continue to capture fish and other species for lengthy periods of time, ("ghost fishing") (Brown & Macfadyen 2007; Goñi 1998).

Ingestion of plastic items occurs much more frequently than entanglement (e.g., Laist 1997; Robards et al. 1997). At sea, plastic bags may often be mistaken for jellyfish, whilst on shorelines seabirds have been seen to pick at plastic items the same way they pick at cuttlefish bones. In the North Sea, almost all Northern Fulmars (*Fulmarus glacialis*) contain some plastic. Monitoring of plastic loads in seabirds showed increases in plastic ingestion from the 1960s to the 1980s, but have stabilized or decreased more recently (Ryan et al. 2009). On the other hand, microscopic fragments, in some locations outweighing surface zooplankton, revealed a significant increase in abundance when samples from the 1960s and 1970s were compared with the 1980s and 1990s (Barnes et al. 2009). When ingested, such small particles can also be taken up from the gut into other body tissues. Ingestion of plastic can lead to wounds (internal and external); impairment of feeding capacity; blockage of digestive tract followed by satiation and starvation; and general debilitation often leading to death. Plasticizers and organic contaminants that typically sorb and concentrate on plastics at levels far superior to the surrounding marine environment have been shown to affect both development and reproduction in a wide range of marine organisms. Molluscs and crustaceans appear to be particularly sensitive to these compounds (Oehlmann et al. 2009). Being an important food item for many species, plastics ingested by invertebrates then have the potential to transfer toxic substances up the food chain (Teuten et al. 2009). The mechanisms by which ingestion lead to illness and death can often only be surmised because the animals are at sea unobserved or are found ashore dead.

Once fouled with marine life or sediment, plastic items sink to the seafloor contaminating the seabed. Deployment of a remotely operated vehicle submarine in the Fram Strait (Arctic) revealed 0.2 to 0.9 pieces of plastic per km at Hausgarten (2,500 m) (Galgani & Lecornu 2004 in (Barnes et al. 2009)). On dives between 5,500 and 6,770 m, 15 items of debris were observed, of which 13 were plastic (Barnes et al. 2009). The presence of plastic at shallow and greater depths may harm sediment wildlife such as worms, sessile filter feeders, deposit feeders and detritivores, all known to accidentally ingest plastics.

The hard surfaces of pelagic plastics also provide an attractive and alternative substrate to natural floating debris (e.g., seeds, pumice, and wood) for a number of opportunistic colonizers. The increasing availability of these synthetic and non-biodegradable materials in marine debris may increase the dispersal and prospects for invasions by non-indigenous species (Gregory 2009).

Impacts on sea turtles. All sea turtle species are particularly prone and may be seriously harmed by ‘feeding on’ anthropogenic marine debris, particularly plastics (Carr 1987) (e.g., Hawaiian Islands, (Balazs 1985); Texas coast (Shaver 1991); coastal Florida, (Bjorndal et al. 1994); Azores (Barreiros & Barcelos 2001); Western Mediterranean, (Tomás et al. 2002); Paraíba, (Mascarenhas et al. 2004) and Rio Grande do Sul, (Bugoni et al. 2001/, see below) Brazil). Of particular concern are floating plastic bags that might be mistaken for jellyfish, and discarded fishing gear in which sea turtles get entangled, or pieces of which they ingest (Mrosovsky et al. 2009). Laboratory experiments demonstrated that green and loggerhead turtles actively target and consume plastics whether it be small pieces intermixed with food items, or single 1- to 10-cm^2 sheets (Lutz 1990). Sublethal impacts of plastics on sea turtles can be substantial, yet mortality resulting from interactions with plastic debris is much more difficult to quantify.

Ingestion. Plastic ingestion by sea turtles is a relatively common occurrence, albeit often in small quantities. However, even in small quantities, plastics can kill sea turtles due to obstruction of the oesophagus or perforation of the bowel for example. Relief of gastrointestinal (GI) obstruction of a green turtle off Melbourne beach, Florida, resulted in the animal defecating 74 foreign objects over a period of a month, including four types of latex balloons, five different types of string, nine different types of soft plastic, four different types of hard plastic, a piece of carpet-like material, and two 2 to 4 mm tar balls (Stamper et al. 2009).

Fishing line can be particularly dangerous, when, during normal intestinal function, different parts of the digestive tract pull at different ends of the line. This can result in the gut gathering along the length of the line preventing digesta from passing through the tract (Bjorndal et al. 1994). Plastic ingestion may also indirectly lead to death of an animal through nutrient dilution, i.e., plastic pieces displacing food in the gut (and reducing the surface available for absorption). Typical consequences include decreased growth rates, longer developmental periods at sizes most vulnerable to predation, depleted energy reserves, and lower reproductive output and survivorship of animals (McCauley & Bjorndal 1999). The latter is likely to be an important threat to smaller individuals with a lower ability to increase intake to meet their energetic requirements than larger animals.

Young pelagic sea turtles typically associate with “floating islands” of drifting seaweeds such as *Sargassum*. Floating plastics, tar from terrestrial and oceanic (ship) sources and lost fishing gear are drawn by advection into the same drift lines (Carpenter & Smith 1972; Pichel et al. 2007; Wong et al. 1974). As young sea turtles indiscriminately feed on pelagic material, high occurrences of plastic are common in the digestive tract of these small sea turtles, often contributing to their mortality (Witherington & Witherington 2002).

As plastics can accumulate in multiple segments of the gut, stomach lavages underestimate the incidence of ingestion.

Entanglement. Entanglement in woven plastic sacks, fishing nets, ropes or lines, can prevent sea turtles from diving to feed or from surfacing to breathe. Nets and lines can also amputate limbs, severely reducing an animal’s mobility. Notes on selected studies:

Fifty turtles (23 out of 38 juvenile greens, one out of 10 adult loggerheads and one out of two adult leatherbacks) out of the 92 turtles found dead stranded on the shorelines of Rio Grande do Sul State, Brazil, had ingested considerable amount of anthropogenic debris. Most of this debris consisted of plastic bags and ropes, causing severe lesions and/or obstruction of the digestive tract, linked to the death of four green turtles (Bugoni et al. 2001).

Of 51 sea turtle carcasses that washed ashore in Florida, 25 had ingested debris, which included plastic pieces and fishing lines. The death of at least two animals was attributed to ingestion of monofilament line (Bjorndal et al. 1994).

Forty one of 54 turtles illegally captured by fishermen in Spain had plastic debris in their digestive tract (Tomás et al. 2002).

Necropsy records of 408 leatherback turtles, spanning 123 years (1885 - 2007), were studied for the presence or absence of plastic in the GI tract. Plastic was reported in 34% of these cases, with a marked increase over time (Mrosovsky et al. 2009).

Hope and the future of plastic in the ocean. "There is a role for individuals, via appropriate use and disposal, particularly recycling; for industry adopting green chemistry, material reduction, and by designing products for reuse and/or end-of-life recyclability; and for governments and policymakers by setting standards and targets, by defining appropriate product labelling to inform and incentivize change, and by funding relevant academic research and technological developments." (Thompson et al. 2009a).

Re-design. The past decades have proven that there is no stopping the ingenious human mind. Therefore, the development of materials derived from renewable natural resources, with similar functionalities to that of oil-based products, needs to be supported/ subsidised. The use of such materials should particularly be encouraged for packaging applications. There is some hope: the Green Chemistry Initiative (Boughton 2009), signed by California Governor Schwarzenegger in 2008, directs the Department of Toxic Substances Control to reduce toxics going into our oceans, including those from plastics, with biodegradable, non-toxic substitutes.

Remove. Beach and ocean cleanups are a great way to raise awareness and to collect data on abundance and trends of debris on shorelines. However, alone they will not solve the problem. At some locations around the world cleaning plastic from the coast amounts to little more than relocation of the items from the beach to inland dumpsites where they pose different problems to the environment and may even find their way back to the ocean when storms or flooding occur. Of concern are high profile "beach cleanups" that serve to mask the severity of the plastic pollution problem with a feel-good event. The most well-run cleanup efforts combine the removal of trash with proper disposal and follow-up educational efforts on how to reduce the production of single-use disposable plastics. When people see and touch plastic pollution they are most open to such behavioural changes.

Reduce, Reuse, Recycle. There is considerable scope for reuse of plastics utilised for the transport of goods, and for potential re-use or re-manufacture of plastic components in goods such as vehicles and electronic equipment (Hopewell et al. 2009). Provided with adequate incentives, industry could be led to use plastic "waste" as raw instead of virgin material, which currently is often cheaper. At much smaller scales users should be encouraged to reuse plastic bags and other plastic goods as much as possible. Although globally only a small proportion of plastics get recycled, mechanical recycling has been increasing at 7% per year in Western Europe (Thompson et al. 2009a). Public support for recycling is high in some countries (57% in the UK and 80% in Australia (Hopewell et al. 2009)). Still, reduction, simplification, and streamlining of everyday packaging, together with clearer labelling could lead to greater separation of materials by users. This would in turn reduce labour associated with sorting costs, currently one of the main impediments to recycling programmes' efficiency, and maximise the amount that gets recycled, e.g., The Netherlands and Germany.

However, the most efficient and cost-effective solution is to refuse single-use plastic in the first place, and drastically reduce the use disposable plastic and subsequent release of plastics into the environment. Some simple and immediate actions include:

- o Avoiding plastic-bottled beverages;
- o Buying products with minimal or reusable packaging;
- o Buying in bulk whenever possible to reduce packaging;
- o Buying used items;
- o Seeking out reusable shopping bags like those made from renewable sources (e.g., natural fibres) and always bringing it along;
- o For coffee and or tea – bring your own mug;
- o For food – bring your own container.

Personal actions can advance social change, yet policy actions are oft where the most significant advances are found. For example, Ireland, Eritrea, Rwanda, China, South Africa, Bangladesh, Thailand and Taiwan, have banned or taxed plastic bags. In July 2009, the southern Australian town of Bundanoon became the first community in the world to pass a law banning PET bottles (Malkin 2009). Bans on polystyrene, bottled water and plastic bags are being inplemented by communities, businesses and universities around the world, and these trends are expected to continue. At the international level, the United Nations Environment Programme is calling for a worldwide ban on plastic bags.

Continued research on the impacts of plastic on the ocean environment and human health is likely to conclude the problem is worse than currently understood. Plastic production and pollution continues to increase at most locations. The symptom of this growing crisis can be seen inside and on sea turtles as well as their oceanic and terrestrial habitats. Bold initiatives that directly confront the source of plastic pollution, redesign packaging and rethink the very idea of "throwaway culture" are urgently required (e.g., Plastic PollutionCoalition.org). Sea turtle researchers and conservationists have a unique role to play in this cultural evolution, as we have watched the havoc the surge of plastic has caused first hand.

ANDRADY, A.L. & M.A. NEAL. 2009. Applications and societal benefits of plastics. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 1977-1984.

BALAZS, G.H. 1985. Sea turtles and debris: Ingestion and entanglement. Marine Turtle Newsletter 32: 8-9.

BARNES, D.K.A., F. GALGANI, R.C. THOMPSON & M. BARLAZ. 2009. Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 1985-1998.

BARREIROS, J.P. & J. BARCELOS. 2001. Plastic Ingestion by a Leatherback Turtle Dermochelys coriacea from the Azores (NE Atlantic). Marine Pollution Bulletin 42: 1196-1197.

BJORNDAL, K.A., A.B. BOLTEN & C.J. LAGUEUX. 1994. Ingestion of marine debris by juvenile sea turtles in coastal Florida habitats. Marine Pollution Bulletin 28: 154-158.

BOUGHTON, B. 2009. California's Green Chemistry Initiative. 2009 IEEE International Symposium on Sustainable Systems and Technology. pp 72.

BROWN, J. & G. MACFADYEN. 2007. Ghost fishing in European waters: Impacts and management responses. Marine Policy 31: 488-504.

BUGONI, L., L. KRAUSE & M. VIRGÍNIA PETRY. 2001. Marine debris and human impacts on sea turtles in southern Brazil. Marine Pollution Bulletin 42: 1330-1334.

CARPENTER, E.J. & K.L. SMITH, JR. 1972. Plastics on the Sargasso Sea surface. Science 175: 1240-1241.

CARR, A. 1987. New perspectives on the pelagic stage of sea turtle development. Conservation Biology 1: 103-121.

DERRAIK, J.G.B. 2002. The pollution of the marine environment by plastic debris: a review. Marine Pollution Bulletin 44: 842-852.

GOÑI, R. 1998. Ecosystem effects of marine fisheries: an overview. Ocean & Coastal Management 40: 37-64.

GREGORY, M.R. 2009. Environmental implications of plastic debris in marine settings - entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 2013-2025.

HEAP, B. 2009. Preface. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 1971-1971.

HOPEWELL, J., R. DVORAK & E. KOSIOR. 2009. Plastics recycling: challenges and opportunities. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 2115-2126.

LAIST, D.W. 1997. Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: J.M. Coe & D.B. Rogers (Eds.). Marine Debris: Sources, Impacts, and Solutions. Springer-Verlag, New York, pp. 99-140.

LAW, K.L., S. MORET-FERGUSON, N.A. MAXIMENKO, G. PROSKUROWSKI, E.E. PEACOCK, J. HAFNER & C.M. REDDY. 2010. Plastic accumulation in the North Atlantic subtropical gyre. Science 329: 1185-1188.

LUTZ, P.L. 1990. Studies on the ingestion of plastic and latex by sea turtles. In: R.S. Shomura & M.L. Godfrey (Ed.). Second International Conference on Marine Debris. U.S. Department of Commerce, NOAA Technical Memo NOAA-NMFS-SWFSC-154, pp. 719-735.

MALKIN, B. 2009. Australian town bans bottled water. Telegraph (London) Newspaper (www.telegraph.co.uk/news/worldnews/australiaandthepacific/australia/5778162/Australian-town-bans-bottled-water.html)

MASCARENHAS, R., R. SANTOS & D. ZEPPELINI. 2004. Plastic debris ingestion by sea turtle in Paraíba, Brazil. Marine Pollution Bulletin 49: 354-355.

MCCAULEY, S.J. & K.A. BJORNDAL. 1999. Conservation implications of dietary dilution from debris ingestion: Sublethal effects in post-hatchling loggerhead sea turtles. Conservation Biology 13: 925-929.

MROSOVSKY, N., G.D. RYAN & M.C. JAMES. 2009. Leatherback turtles: The menace of plastic. Marine Pollution Bulletin 58: 287-289.

OEHLMANN, J.R., U. SCHULTE-OEHLMANN, W. KLOAS, O. JAGNYTSCH, I. LUTZ, K.O. KUSK, L. WOLLENBERGER, E.M. SANTOS, G.C. PAULL, K.J.W. VAN LOOK & C.R. TYLER. 2009. A critical analysis of the biological impacts of plasticizers on wildlife. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 2047-2062.

PICHEL, W.G., J.H. CHURNSIDE, T.S. VEENSTRA, D.G. FOLEY, K.S. FRIEDMAN, R.E. BRAINARD, J.B. NICOLL, Q. ZHENG & P. CLEMENTE-COLÓN. 2007. Marine debris collects within the North Pacific Subtropical Convergence Zone. Marine Pollution Bulletin 54: 1207-1211.

ROBARDS, M.D., P.J. GOULD & J.F. PIATT. 1997. The highest global concentrations and increased abundance of oceanic plastic debris in the North Pacific: evidence from seabirds. In: J.M. Coe & D.B. Rogers (Eds.). Marine Debris: Sources, Impacts, and Solutions. Springer-Verlag, New York, pp. 71-80.

RYAN, P.G., C.J. MOORE, J.A. VAN FRANEKER & C.L. MOLONEY. 2009. Monitoring the abundance of plastic debris in the marine environment. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 1999-2012.

SHAVER, D.J. 1991. Feeding ecology of wild and head-started Kemp's Ridley sea turtles in south Texas waters. Journal of Herpetology 25: 327-334.

STAMPER, M.A., C.W. SPICER, D.L. NEIFFER, K.S. MATHEWS & G.J. FLEMING. 2009. Morbidity in a juvenile green sea turtle (*Chelonia mydas*) due to ocean-borne plastic. Journal of Zoo and Wildlife Medicine 40: 196-198.

TEUTEN, E.L., J.M. SAQUING, D.R.U. KNAPPE, M.A. BARLAZ, S. JONSSON, A. BJÖRN, S.J. ROWLAND, R.C. THOMPSON, T.S. GALLOWAY, R. YAMASHITA, D. OCHI, Y. WATANUKI, C. MOORE, P.H. VIET, T.S. TANA, M. PRUDENTE, R. BOONYATUMANOND, M.P. ZAKARIA, K. AKKHAVONG, Y. OGATA, H. HIRAI, S. IWASA, K. MIZUKAWA, Y. HAGINO, A. IMAMURA, M. SAHA & H. TAKADA. 2009. Transport and release of chemicals from plastics to the environment and to wildlife. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 2027-2045.

THOMPSON, R.C., C.J. MOORE, F.S. VOM SAAL & S.H. SWAN. 2009a. Plastics, the environment and human health: current consensus and future trends. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 2153-2166.

THOMPSON, R.C., S.H. SWAN, C.J. MOORE & F.S. VOM SAAL. 2009b. Our plastic age. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 1973-1976.

TOMÁS, J., R. GUITART, R. MATEO & J.A. RAGA. 2002. Marine debris ingestion in loggerhead sea turtles, Caretta caretta, from the Western Mediterranean. Marine Pollution Bulletin 44: 211-216.

UNEP. 2009. Marine Litter: A Global Challenge. In: (Ed.). UNEP, Nairobi, Kenya. pp. 232.

WEISS, K.R., U.L. MCFARLING & R. LOOMIS. 2006. Plague of plastic chokes the seas. In: (Ed.). Los Angeles Times. pp.

WITHERINGTON & B. WITHERINGTON. 2002. Ecology of neonate loggerhead turtles inhabiting lines of downwelling near a Gulf Stream front. Marine Biology 140: 843-853.

WONG, C.S., D.R. GREEN & W.J. CRETNEY. 1974. Quantitative tar and plastic waste distributions in the Pacific Ocean. Nature 247: 30-32.