



Inter-annual variation in the density of anthropogenic debris in the Tasman Sea



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ABSTRACT

An increasing number of studies highlight the risk of plastic pollution in the marine environment. However, systematic longitudinal data on the distribution and abundance of plastic debris remain sparse. Here we present the results of a two-year study of plastic pollution within the Tasman Sea, contrasted with a further year of data from the same region, in order to document how the density of debris varies across years in this area. Surface net tows were collected between Hobart, Tasmania and Sydney, Australia during the spring of 2013 and 2014 and compared with a subset of data from autumn 2012 from the same region. Substantial inter-annual variation in mean plastic abundance was observed over the three year period, ranging from to 248.04–3711.64 pieces km⁻², confirming the need for multiple years of sampling to fully estimate the extent of, and trends in, plastic pollution.

1. Introduction

The majority of plastics are synthetic polymers derived from petrochemicals (ACCESD, 2013). Due to the lightweight, versatile and durable properties of plastic materials, the demand for it has increased exponentially over the past six decades, resulting in > 322 million metric tonnes (MT) of plastic being produced worldwide in 2015 (PlasticsEurope, 2016). Though substantial, this is considered an underestimate of total global plastic production because this figure does not include synthetic fibres made from polyethylene terephthalate (PET) and polypropylene (PP), which accounted for an additional 40 million MT of global plastic production in 2009 (Engelhardt, 2009). Mass production of plastic materials, paired with inefficient disposal systems and lack of environmental awareness, has resulted in plastic being the dominant form of anthropogenic marine debris (Eriksen et al., 2013a).

Plastics enter the ocean from populated areas through both natural and man-made processes, including via wind, rivers, tides, wastewater outflows and illegal at-sea dumping (Derraik, 2002; Nollkaemper, 1994). From here many plastics float, fragment into smaller pieces via chemical and mechanical degradation (i.e., ultraviolet light, microbial action and wind and wave stress; Andrady et al., 1993) and can either exit the system onto coastlines and beaches or migrate along surface

currents, accumulating in subtropical gyres (Eriksen et al., 2013b; Law et al., 2014; Thiel et al., 2013).

Although the total quantity of plastic waste entering the ocean is largely unknown, Jambeck et al. (2015) estimate that in 2010, 275 million MT of plastic waste was produced by 192 coastal countries (93% of the global human population), of which between 4.8 and 12.7 million MT (1.7–4.6%) entered the ocean. These items fragment, resulting in microplastic particles (fragments < 5 mm) that are orders of magnitude more numerous than the initial piece of debris (Eriksen et al., 2014). The most recent global estimate of marine plastics, which accounted for this stepwise fragmentation of plastics, suggests that there are currently 5.25 trillion plastic particles weighing 243,978 MT floating in the world's oceans (Eriksen et al., 2014). Though substantial, this figure is likely an underestimate of global marine plastic pollution because of the conservative methods used (e.g., lack of sampling in waters > 5 m depth) and due to a limited dataset. However, if current production and consumption rates coupled with a rise in demand for plastics continues, MacArthur et al. (2016) suggest that by 2050 the oceans will contain more plastic than fish (by mass).

Synthetic plastic debris is now ubiquitous in marine environments, having been documented in all oceanic zones (including the surface and mixed layer), deep sea habitats, under Arctic ice sheets, and on remote islands (Barnes et al., 2009; Obbard et al., 2014; Schlining et al., 2013).

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Though pervasive in the world's oceans, current knowledge suggests that the southern hemisphere contains less buoyant marine plastic than the northern hemisphere, with models by Eriksen et al. (2014) estimating that southern hemisphere oceans contain around 44% of the total particle count and mass of plastic. Of this, the Indian Ocean contains a greater amount of synthetic debris than the South Pacific and South Atlantic combined (Eriksen et al., 2014), most likely due to the comparatively sparsely populated areas of coastline combined with a lower input from shipping activities. Recent research into plastic debris in the surface waters surrounding Australia and nearby Pacific islands (Reisser et al., 2013) suggests that this region is significantly contaminated with plastic, particularly microplastics. In fact, Reisser et al. (2013) found the waters around Australia to be similarly polluted as those in the Caribbean Sea and Gulf of Maine.

Though current published data on buoyant marine plastics provides an invaluable baseline, crucial follow-up data are lacking, but are needed to support legislation towards addressing reductions in plastic pollution inputs. Thus, repeat surveys are required over longer time periods in order to explore trends in the plastic pollution issue. This study provides much-needed follow-up data for the Tasman Sea by sampling over a two year period within this region and using these samples in conjunction with a subset of data from Reisser et al. (2013; see Table S1 & Fig. S1). We examine the abundance and characteristics of plastic pollution (e.g., colour, polymer type) along the south-east coastline of Australia and offer inter-annual and –seasonal comparisons with existing data. We present novel data from inshore (harbour) areas along the lower eastern seaboard of Australia and examine the resulting plastic loads in relation to data from surveys in nearby offshore areas.

2. Methods

2.1. Study site

This study was conducted in the south western Tasman Sea, a dynamic portion of the large temperate body of water located in the south west Pacific, and bounded by Australia, New Zealand and Antarctica (Fig. 1). The region provides habitat for a myriad of marine species and is dominated by a high energy surface current – the East Australian Current (EAC) – which runs parallel to the east coast of Australia and forms the western boundary of the South Pacific subtropical gyre (Everett et al., 2012). Surface net tows of the Tasman Sea and its associated inshore areas were completed in 2013 between August 18 to October 2 and in 2014 from September 14 to October 4 as the vessel *Yukon* sailed north along the eastern coastline of Australia. Both voyages began in the Derwent Estuary, Tasmania and stopped at various locations en route to Sydney, New South Wales, collecting samples when conditions permitted (more below). Due to the nature of the voyage (a citizen science-based project), the vessel stayed close to the coastline in case of emergency.

2.2. Sample collection

Volume reduced samples were collected at the air-sea interface via a neuston trawl (0.2 × 0.6 m mouth, 333 µm mesh) that was positioned out of the boat's wake via a spinnaker pole. The contents of the collecting bag (cod end) were transferred into labelled jars and fixed in dilute ethanol. Wave height was observed by both the skipper and two trained observers, from which the sea state was calculated using the Beaufort scale (Beer, 1996).

Optimal trawl duration was 60 min, however mean duration was 46 min in 2013 and 53 min in 2014 due to various factors that affected the trawl period, including fouling of the net. Boat speed varied from 0.309–1.800 m s⁻¹ and 1.029–2.006 m s⁻¹ over 2013 and 2014, respectively. Trawl distance was measured via GPS co-ordinates. In order to attain a high level of confidence in our data, surface net tows with incorrect latitude and longitude co-ordinates and samples in which the

net was fouled were discarded from the dataset. In total, 18 samples were kept from 2013 (9 discarded) and 9 samples from 2014 (10 discarded).

2.3. Sample processing

In the lab, the contents of each sample jar were rinsed into petri dishes and analysed under a dissecting microscope to separate synthetic polymers from organic materials. Plastic fragments were rinsed and sorted through stacked Tyler sieves into four size classes: small micro- (0.33–0.99 mm), large micro- (1.00–4.74 mm), meso- (4.75–200 mm), and macro- (> 200 mm). The contents of each plastic size class were transferred to individual petri dishes, dried, categorized by type (fragment, industrial pellet, line, thin film, foam, and other) following van Franeker et al. (2011) and then weighed to the nearest 0.0001 g using an electronic balance. The 'other' category consisted of particles that could not be classified into the preceding categories but were still plastics/plastic derivatives (e.g., latex balloons, balloon strings, cigarette butts, etc). The colour of each fragment was also noted and classified into eight broad categories as outlined in Provencher et al. (2017) in order to determine the colour of plastics that were most prevalent in this region and thus accessible to biota that forage from the sea surface. The total area sampled in each trawling event was calculated by multiplying the distance travelled by the width of the opening of the trawl. This area was then transformed so that particle abundance and weight per km² could be calculated. Abundances from this study were used in conjunction with six particle counts recorded within the same sampling region in 2012 by Reisser et al. (2013; see Table S1 & Fig. S1).

2.4. Polymer identification

Fourier transform infrared spectroscopy (FT-IR; range: 375–4000 cm⁻¹) was conducted using a Bruker Alpha (OPUS, v. 6.5) spectrometer fitted with a platinum Attenuated Total Reflectance (ATR) module, to identify the parent polymer composition of the contents of each trawl sample. Polymer type was determined by performing a similarity search against a database (based on common resin codes) of known polymer spectra.

2.5. Environmental factors

Annual average sea surface temperature for the Tasman Sea (2013 and 2014) was extracted from the MODIS Aqua satellite data sets provided by the Ocean Biology Processing Group (NASA; <https://oceancolor.gsfc.nasa.gov/>; (Brown and Minnett, 1999)) using the Marine Geospatial Ecology Tools (MGET) in ArcGIS 10.4 (Roberts et al., 2010). Eddies in the same area and during the sampling period were derived from the gridded multi-mission Sea Level Anomalies (MSLA) altimeter dataset also using MGET. The Ssalto/Duacs altimeter products were produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS; Pujol et al., 2016; <http://www.marine.copernicus.eu>).

3. Results

3.1. Overall trends across both years

In both locations and over the entire sampling period (2013 and 2014), 20/27 trawls (74%) contained plastic (range = 0–5578 items, median = 2, mean ± SD = 217.4 ± 1071; Fig. 1) resulting in a total of 5871 pieces of plastic from all categories and size classes. The combined mass of all synthetic material was 6.19 g, with a large portion of individual pieces being from the two micro-size classes. The thin film, fragment, and other categories accounted for 96% of the total weight. Foam (small and large micro-) comprised the majority of particles recorded over the two years (namely in inshore areas), however

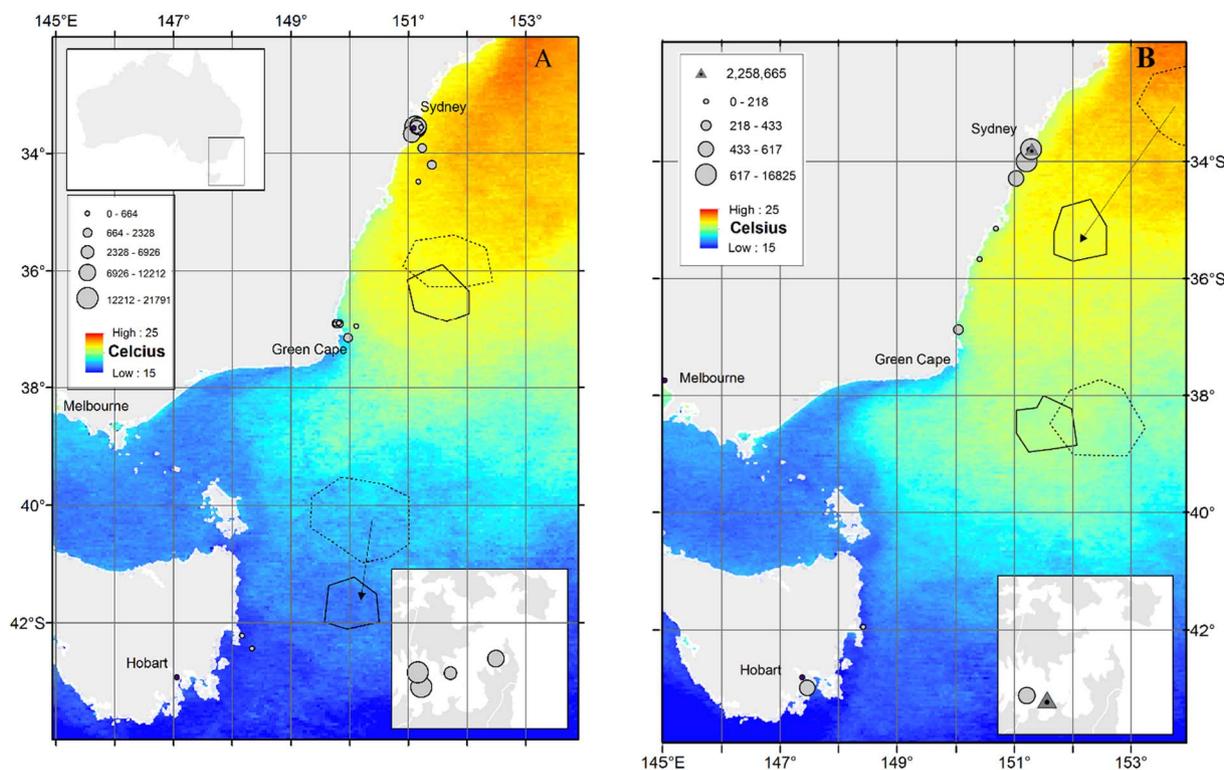


Fig. 1. Location of the 27 neuston net samples that were collected within the Tasman Sea off eastern Australia in the spring of 2013 (A) and 2014 (B). Graduated symbols indicate the abundance of plastic particles (pieces km^{-2}) recorded at each site. The sampling locations are superimposed over the annual average sea surface temperature for the corresponding sampling year. The polygon outlines represent the progression of warm, anticyclonic eddies from the start of the sampling period (dotted lines) to the end of the sampling period (solid lines). Inset map (bottom right of both panels) shows the location of samples collected within Sydney Harbour.

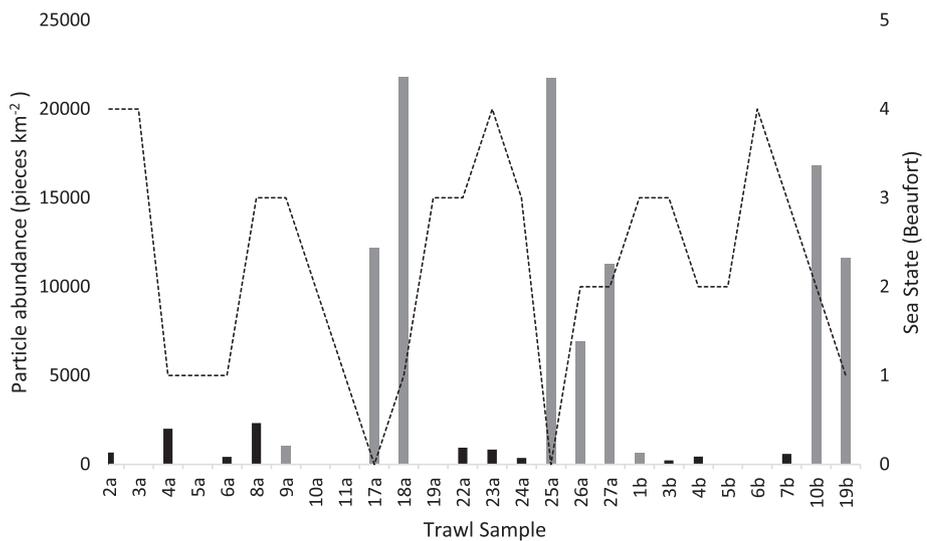


Fig. 2. Particle abundance (bar) and sea state (dashed line) at 27 sampling sites within the Tasman Sea. An ‘a’ and ‘b’ denotes samples from 2013 and 2014, respectively. Grey bars coincide with inshore trawling locations and black bars correspond to offshore locations. Net tows labelled according to the samples retained for analysis, hence numbers are not consecutive. N.b. Due to the high particle abundance of sample 18b (2,258,665 pieces km^{-2}) and thus impracticality of reporting this number, this data point is not shown here.

due to its low density, it comprised only 2.7% (0.168 g) of the total mass. Due to the patchy distribution of debris and a relatively low sample size, no clear relationship could be determined between particle abundance and sea state (Fig. 2).

3.2. Density of inshore (harbour) debris

In the 2013 harbour samples, 227 pieces of plastic were found in six out of seven (85%) net tows (range = 0–71 items, median = 31, mean \pm SD = 32.4 ± 27.7), weighing a total of 4.69 g. In 2014, 5620 synthetic particles were found in 100% of the harbour trawl samples (n = 4; range = 2–5578 items, median = 20, mean \pm SD = 1405 ± 2782). The average abundance in 2013

harbour tows was 10,719.6 pieces km^{-2} and the average weight density during this same year was 216 g km^{-2} . In the second year of sampling, the average harbour abundance was 571,931.8 particles km^{-2} and the average weight density was 160.9 g km^{-2} .

3.3. Colour and types of inshore (harbour) debris

The majority of plastic particles recovered from harbour areas over both years of sampling were either white or transparent in colour ($n_{2013} = 110, 48\%$; $n_{2014} = 5581, 99\%$; (Table S2)). Overall, a range of plastic type, size classes, and categories were present in harbour samples in both 2013 and 2014 (Tables 1 and S2). While polyethylene (PE) was common in both years, in 2014 it was significantly less common

Table 1

Polymer types present in neuston net samples collected from the Tasman Sea in the Austral spring of 2013 and 2014. Other polymer types included polyvinyl alcohol, polymethyl methacrylate, nylon and plastic derivatives such as cellulose acetate (cigarette filters) and latex balloons.

	Inshore		Offshore	
	2013	2014	2013	2014
Polyethylene	114	37	9	1
Polypropylene	73	27	6	1
Polystyrene	30	5555	2	0
Other polymers	10	1	2	3
Total	227	5620	19	5

than polystyrene (PS) due to an abundance of small foam balls in one harbour sample, the result of that net tow passing through a windrow (see Discussion section).

3.4. Density of offshore debris

Overall, considerably less plastic pollution was found in offshore areas than in inshore areas. Over the 2013 sampling period, 7 out of 11 (64%) of offshore trawls contained a total of 19 pieces of plastic (range = 0–6 items, median = 2, mean \pm SD = 1.73 \pm 1.85) that weighed 0.137 g. In 2014, five plastic particles were found in 3 out of 5 (60%) offshore net tows (range = 0–2, median = 1, mean \pm SD = 1.0 \pm 1.0), weighing a total of 0.0273 g. The average abundance and weight density for 2013 was 685 pieces km⁻² and 4.17 g⁻², respectively, and in 2014 these figures were 248 pieces km⁻² and 1.19 g km⁻².

3.5. Colour and types of offshore debris

White/transparent ($n_{2013} = 8$, 42%; $n_{2014} = 3/60\%$) and blue ($n_{2013} = 6$, 32%; $n_{2014} = 2$, 40%) accounted for the majority of plastics, by colour, recorded in offshore trawls. In 2013, the colour of plastic in offshore samples was somewhat more variable, including black ($n = 2$, 11%), green ($n = 2$, 11%) and red-pink ($n = 1$, 5%). Plastic type also varied over the two years of sampling, however fragments were the most commonly observed item ($n_{2013} = 9$; $n_{2014} = 2$) and pieces from the 'other' category (e.g., rubber) were not observed in either year.

3.6. Environmental factors

The annual average sea surface temperature shows that the warmer waters of the EAC penetrate further into the Tasman Sea off the coast of Tasmania in 2014 (Fig. 1B). Also, data extracted from the altimeter dataset showed that two warm anticyclonic eddies were present in the Tasman Sea during the sampling period. In 2013, both eddies appear to be slow moving, lingering off the coast of the south-east Australian mainland and the east coast of Tasmania (Fig. 1A). In 2014, a fast moving eddy appears to move rapidly along the east coast adjacent to Sydney (Fig. 1A & B).

4. Discussion

Greater abundances of plastic debris were found in harbour areas compared to offshore waters, with the majority (98.5%) of plastics observed being microplastics (< 4.75 cm). These results are consistent with other similar studies conducted in coastal areas that are close to centres of industrial activity (Collignon et al., 2012; Dubaish and Liebezeit, 2013; Isobe et al., 2014). Within Sydney Harbour, the largest population centre along Australia's eastern seaboard, 100% of trawls contained an average of 384,227 pieces of plastic km⁻², which is

within the same order of magnitude as the density of microplastics reported for the Mediterranean Sea (116,000 pieces km⁻²; Collignon et al., 2012), suggesting the two water bodies are similarly polluted with microplastics.

Once in the ocean, plastic particles can either sink or float and become dispersed over long distances, or can exit the system onto coastlines or the seabed (Thiel et al., 2013). Prevailing winds and surface currents influence the drift behaviour of buoyant marine plastics (Eriksen et al., 2014; Reisser et al., 2013). Computer models indicate floating debris can take a variety of routes depending on the hydrodynamics of different areas (Reisser et al., 2013), with plastics converging along surface currents and accumulating to form hotspots or windrows (Eriksen et al., 2013b), the largest of which are the subtropical gyres. The presence of a small-scale windrow is thought to have contributed to the high particle count of a single Sydney Harbour sample collected in 2014.

The inter-annual variability of currents, eddies, and wind patterns have been shown to influence the overall distribution of marine plastics (Law et al., 2014; Thiel et al., 2013; Welden and Lusher, 2017). In the Tasman Sea, the southward penetration of the warmer waters of the EAC has increased over the past 60 years (Ridgway, 2007). The EAC varies in width (15–100 km), can be 200–500 m deep, and flow at speeds of up to four knots (Suthers et al., 2011). Along the coast, the EAC is influenced by a range of factors, including coastal and oceanic processes, changes in the continental shelf, and seasonal fluctuations. Though there appears to be no clear pattern between plastic distribution and the EAC, more investigation is required to fully understand the effect of the EAC variation on the inter-annual distribution of plastics.

The synthetic materials found offshore during this study mainly comprised small and large micro-plastics (68%), consistent with the only other study from this region (Reisser et al., 2013) with these items likely originating from the breakdown of larger plastic items. The majority of these particles were fragments (45.8%), though plastics from all categories were observed. Synthetic materials retrieved from harbour trawls had, overall, greater numbers of plastics from all categories. Likewise, a greater diversity of polymer types were observed in harbour samples than from offshore waters, a result of both proximity to the source and differential rates of biofouling. PE and PP are the most buoyant polymer types and are consistently found floating in offshore environments (Cózar et al., 2014; Moret-Ferguson et al., 2010; Reisser et al., 2013). A variety of colours were recorded in both harbour and offshore samples, with white comprising the majority of items (97%).

While lower than in harbour areas, plastic pollution was moderately high along the coast of south east Australia, with 63% of all samples containing plastic. Moderate inter-annual variation was observed over our two years of sampling with a higher mean plastic abundance observed in 2013 (685.1 pieces km⁻²) compared to 2014 (248.0 pieces km⁻²). Likewise, the values recorded in our study vary considerably (up to an order of magnitude less) when compared to the Tasman Sea subset of Reisser et al.'s (2013) data (Table S1 & Fig. S1), providing evidence of inter-annual and -seasonal variability. It is interesting that our values are lower than those obtained in 2012 by Reisser et al. (2013), despite increasing inputs and fragmentation of buoyant plastics in the marine environment.

While these data provide insights into variability between years/seasons, the analysis of much larger datasets suggests spatial or temporal variability in plastic concentration can contribute to significant differences in summary statistics calculated over short time periods (Law et al., 2014). For the Tasman Sea, seasonal shifts in major currents (i.e., the EAC), as well as changes in water surface turbulence due to the wind, likely introduce substantial inter-annual and -seasonal variation, and these cannot be properly assessed with datasets that are limited in duration or scope. To overcome some of these challenges, we encourage the use of highly trained citizen scientists to assist with long-term data collection, with an emphasis on repeat sampling in areas where some baseline data exists.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.marpolbul.2017.07.010>.

References

- ACCESD, 2013. Plastic Resins in the United States. American Chemistry Council, Economics & Statistics Department.
- Andrady, A.L., Pegram, J.E., Song, Y., 1993. Studies on enhanced degradable plastics. II. Weathering of enhanced photodegradable polyethylenes under marine and freshwater floating exposure. *J. Environ. Polym. Degrad.* 1, 117–126.
- Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. *Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci.* 364, 1985–1998.
- Beer, T., 1996. *Environmental Oceanography*, 2nd edition. (Boca Raton, Florida).
- Brown, O.B., Minnett, P.J., 1999. MODIS Infrared Sea Surface Temperature Algorithm Theoretical Basis Document.
- Collignon, A., Hecq, J.H., Glagani, F., Voisin, P., Collard, F., Goffart, A., 2012. Neustonic microplastic and zooplankton in the North Western Mediterranean Sea. *Mar. Pollut. Bull.* 64, 861–864.
- Cózar, A., Echevarría, F., González-Gordillo, J.I., Irigoien, X., Úbeda, B., Hernández-León, S., Palma, Á.T., Navarro, S., García-de-Lomas, J., Ruiz, A., Fernández-de-Puelles, M.L., Duarte, C.M., 2014. Plastic debris in the open ocean. *Proc. Natl. Acad. Sci.* 111, 10239–10244.
- Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. *Mar. Pollut. Bull.* 44, 842–852.
- Dubaish, F., Liebezeit, G., 2013. Suspended microplastics and black carbon particles in the Jade system, southern North Sea. *Water Air Soil Pollut.* 224, 1352.
- Engelhardt, A., 2009. *The Fiber Year 2008/09: A World Survey on Textile and Nonwovens Industry*. Oerlikon Textiles, Pfäffikon, Switzerland.
- Eriksen, M., Mason, S., Wilson, S., Box, C., Zellers, A., Edwards, W., Farley, H., Amato, S., 2013a. Microplastic pollution in the surface waters of the Laurentian Great Lakes. *Mar. Pollut. Bull.* 77, 177–182.
- Eriksen, M., Maximenko, N., Thiel, M., Cummins, A., Lattin, G., Wilson, S., Hafner, J., Zellers, A., Rifman, S., 2013b. Plastic pollution in the South Pacific subtropical gyre. *Mar. Pollut. Bull.* 68, 71–76.
- Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borror, J.C., Galgani, F., Ryan, P.G., Reisser, J., 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PLoS One* 9, e111913.
- Everett, J.D., Baird, M.E., Oke, P.R., Suthers, I.M., 2012. An avenue of eddies: quantifying the biophysical properties of mesoscale eddies in the Tasman Sea. *Geophys. Res. Lett.* 39, L16608.
- Isobe, A., Kubo, K., Tamura, Y., Kako, S., Nakashima, E., Fujii, N., 2014. Selective transport of microplastics and mesoplastics by drifting in coastal waters. *Mar. Pollut. Bull.* 89, 324–330.
- Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. *Science* 347, 768–771.
- Law, K.L., Morét-Ferguson, S.E., Goodwin, D.S., Zettler, E.R., DeForce, E., Kukulka, T., Proskurowski, G., 2014. Distribution of surface plastic debris in the eastern Pacific Ocean from an 11-year data set. *Environ. Sci. Technol. Lett.* 48, 4732–4738.
- MacArthur, E., Waughray, D., Stuchtey, M.R., 2016. The new plastics economy: Rethinking the future of plastics. In: *World Economic Forum, Switzerland*. (p. 35 pp).
- Moret-Ferguson, S., Law, K.L., Proskurowski, G., Murphy, E.K., Peacock, E.E., Reddy, C.M., 2010. The size, mass, and composition of plastic debris in the western North Atlantic Ocean. *Mar. Pollut. Bull.* 60, 1873–1878.
- Nollkaemper, A., 1994. Land-based discharges of marine debris - from local to global regulation. *Mar. Pollut. Bull.* 28, 649–652.
- Obbard, R.W., Sadri, S., Wong, Y.Q., Khitun, A.A., Baker, I., Thompson, R.C., 2014. Global warming releases microplastic legacy frozen in Arctic Sea ice. *Earth's Future* 2, 315–320.
- PlasticsEurope, 2016. *Plastics - the Facts 2016: An Analysis of European Plastics Production, Demand and Waste Data*. PlasticsEurope Market Research Group, Brussels, Belgium.
- Provencher, J.F., Bond, A.L., Avery-Gomm, S., Borrelle, S.B., Brave Rebolledo, E.L., Hammer, S., Kühn, S., Lavers, J.L., Mallory, M.L., Trevail, A.M., van Franeker, J.A., 2017. Quantifying ingested debris in marine megafauna: a review and recommendations for standardization. *Anal. Methods* 9, 1454–1469.
- Pujol, M.-I., Faugère, Y., Taburet, G., Dupuy, S., Pelloquin, C., Ablain, M., Picot, N., 2016. DUACS DT2014: the new multi-mission altimeter data set reprocessed over 20 years. *Ocean Sci.* 12, 1067–1090.
- Reisser, J., Shaw, J., Wilcox, C., Hardesty, B.D., Proietti, M., Thums, M., Pattiaratchi, C., 2013. Marine plastic pollution in waters around Australia: characteristics, concentrations, and pathways. *PLoS One* 8, e80466.
- Ridgway, K.R., 2007. Long-term trend and decadal variability of the southward penetration of the East Australian Current. *Geophys. Res. Lett.* 34, L13613.
- Roberts, J.J., Best, B.D., Dunn, D.C., Trembl, E.A., Halpin, P.N., 2010. Marine Geospatial Ecology Tools: an integrated framework for ecological geoprocessing with ArcGIS, Python, R, MATLAB, and C++. *Environ. Model. Softw.* 25, 1197–1207.
- Schlining, K., von Thun, S., Kuhn, L., Schlining, B., Lundsten, L., Jacobsen Stout, N., Chaney, L., Connor, J., 2013. Debris in the deep: using a 22-year video annotation database to survey marine litter in Monterey Canyon, central California, USA. *Deep Sea Res. Part 1 Oceanogr. Res. Pap.* 79, 96–105.
- Suthers, I.M., Young, J.W., Baird, M.E., Roughan, M., Everett, J.D., Brassington, G.B., Byrne, M., Condie, S.A., Hartog, J.R., Hassler, C.S., Hobday, A.J., Holbrook, N.J., Malcolm, H.A., Oke, P.R., Thompson, P.A., Ridgway, K.R., 2011. The strengthening East Australian Current, its eddies and biological effects — an introduction and overview. *Deep Sea Res. Part 2 Top. Stud. Oceanogr.* 58, 538–546.
- Thiel, M., Hinojosa, I.A., Miranda, L., Pantoja, J.F., Rivadeneira, M.M., Vásquez, N., 2013. Anthropogenic marine debris in the coastal environment: a multi-year comparison between coastal waters and local shores. *Mar. Pollut. Bull.* 71, 307–316.
- van Franeker, J.A., Blaize, C., Danielsen, J., Fairclough, K., Gollan, J., Guse, N., Hansen, P.L., Heubeck, M., Jensen, J.K., Le Guillou, G., Olsen, B., Olsen, K.O., Pedersen, J., Stienen, E.W., Turner, D.M., 2011. Monitoring plastic ingestion by the Northern Fulmar *Fulmarus glacialis* in the North Sea. *Environ. Pollut.* 159, 2609–2615.
- Welden, N.A.C., Lusher, A.L., 2017. Impacts of changing ocean circulation on the distribution of marine microplastic litter. *Integr. Environ. Assess. Manag.* 13, 483–487.