

Investigating the Accumulation of Plastic Debris in the North Pacific Gyre

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BACKGROUND AND EARLY STUDIES

The accumulation of plastic debris in marine environments has been observed and documented for at least the past four decades. The production of synthetic polymer plastics increased rapidly after the 1940s and by the early 1970s the first scientific literature appeared reporting on plastic particles at the surface of the Atlantic (Carpenter and Smith, 1972) and the Central North Pacific (Venrick *et al.*, 1973). Reporting in the journal *Science*, Carpenter and Smith (1972) examined the western Sargasso Sea in the Atlantic and extrapolated from a series of surface neuston tows made across a span of nearly 1300 km. They reported encountering large numbers of visible plastic objects as well as concentrations of smaller particles caught in the nets ranging from 1 to 62 particles, yielding estimates of between 47 and 12,080 particles km⁻² with an average of 3,537 particles km⁻². While the estimates in this early study were based on a small number of tows, the authors also noted encountering a wide variety of types of particles including small plastic pellets and rough edge particles. Carpenter and Smith (1972) pointed to dumping of waste from major cities as an important source of materials that were subsequently subjected to weathering and mechanical breakdown in the ocean. They also noted that while biological effects were unknown, many of the plastics contain considerable quantities of polychlorinated biphenyls (PCBs) as plasticizers and that these plasticizer materials were likely lost into the surrounding seawater during weathering and might be incorporated into marine algae and animals.

The following year, Venrick *et al.* (1973) reported in the journal *Nature* a short communication on visible plastic debris observed in the Central North Pacific between 31°00' N, 155°0' W and 34°0' N, 145°0' W. During an unusual combination of clear warm weather and calm seas that “tempted the scientific personnel to spend their leisure time on the bow of the ship,” a log of floating debris was recorded and a large number of plastic debris items were counted. In this case no net samples were taken and the report only includes visible items at the sea surface. The reported plastic items were mainly bottles and fragments

some of which were colonized by algae and invertebrates. Venrick *et al.* (1973) posed the question whether the increased prevalence of these “micro-arks” might alter the distribution of organisms and, or, attract local pelagic organisms.

The study of marine debris has advanced considerably since the 1970s. However, these early studies are noteworthy for several reasons. First, although not directly commented upon at the time, both studies were conducted in likely convergence zones within oceanic gyres. These gyre areas would subsequently be identified as major areas of debris accumulation. In fact, the physical processes of convergence in gyres now provides a paradigm for conceptualizing the larger plastics debris problem. Second, both reports expressed concerns that increasing production and inappropriate disposal of plastics into the marine environment could lead to a dramatic increase in the extent and severity of the debris problem. We now know that these concerns were, in fact, well founded as the scope and extent of the marine debris problem has increased markedly in recent decades. Third, both reports describe a new recognition that even the vast spatial scale of open ocean ecosystems were within the influence of human pollution originating on land. Venrick *et al.* (1973) specifically expressed alarm that disposable items were found littering one of the most remote parts of the ocean surface.

In the decades since the early 1970s a significant body of research has developed around the science, policy, and public awareness of plastic marine debris. As emphasized by Law *et al.* (2010) it is now widely evident that plastic debris is a major anthropogenic contaminant in the world oceans. The impacts of plastic marine debris include direct effects such as feeding interference and entanglement of marine animals (e.g., Gregory, 2009), consumption of materials by organisms (Laist, 1987; Thompson *et al.*, 2004), as a pathway of plasticizer contaminants into marine environments and potentially into organism and food webs (Mato, 2001; Teuten *et al.*, 2007), and in facilitating transport and dispersal of colonizing macro and microbial species (Derraik, 2002; Law *et al.*, 2010). It is again interesting to note that all of these impacts were anticipated in the 1970s and that as the scale of plastic production has increased these anticipated potential environmental impacts have become realities. It is also now known, that in addition to post consumer waste materials, preproduction plastic pellets are a significant source of the plastic materials found in the marine environment and that these can absorb and transport chemical pollutants (Mato, 2001; Endo *et al.*, 2005). The observations of plastic materials on beaches also include large, repeated deposition of debris from external sources. Modeling and technological advances are now providing insight into the rates of delivery of plastic debris to beaches in the Western Pacific (Kako *et al.*, 2010).

In addition, there is now significant global-scale, popular interest in the problems posed by plastic marine debris. These interest can be seen both in scientific publications on the topic and in coverage in mainstream media. The work of C. Moore and colleagues through the Algalita Marine Research Foundation (<http://www.algalita.org/>) has been instrumental in providing compelling observational evidence of the nature and scale of the plastic debris in the North Central Pacific and in framing many of the relevant scientific questions (Moore

et al., 2001; Moore, 2008). This is an example of the important roles that outreach and advocacy groups can play both in initiating and fostering scientific investigations of environmental problems and in delivering compelling images and information to the public and media outlets. This role in gathering compelling observational evidence before more traditional scientific research activities garner funding for costly at-sea activities is particularly important. Additional groups such as Project Kaisei (<http://www.projectkaisei.org/>), The Sea Education Association (<http://www.sea.edu/>), Five Gyres (<http://www.5gyres.org/>), and the Plastiki Expedition (<http://www.theplastiki.com/>) are now active in bringing awareness to plastic debris issues and far greater attention at local to global scales than ever before. The proliferation of coverage of plastic debris research in wide-distribution media outlets such as the New York Times, Cable News Network, British Broadcasting Company, and smaller local media outlets in many countries all reflect and stimulate the growing concerns regarding plastic marine debris.

THE SCRIPPS ENVIRONMENTAL ACCUMULATION OF PLASTICS EXPEDITION

In 2009 a research cruise to the eastern portion of the North Pacific Gyre was organized in partnership between Scripps Institution of Oceanography and Project Kaisei. The scientific effort was led by a group of graduate students at Scripps with financial support provided by the University of California Ship Fund and Project Kaisei. J. Leichter served as faculty advisor for the project and the cruise. The cruise was aboard the 52 m Research Vessel *New Horizon* and the trip was dubbed the *Scripps Environmental Accumulation of Plastics Expedition* (SEAPLEX). The goals of this three-week effort were to travel to the eastern portion of the North Pacific Gyre and to sample both surface and subsurface waters and biota in an area previously described and predicted on the basis of surface convergence as a zone of significant plastic accumulation (Moore *et al.*, 2001; IPRC Climate, 2008). This study area was chosen with the intention of bringing quantitative oceanographic tools available on a ship with heavy winch capabilities to an area previously described as a zone of plastic debris accumulation. The primary research tools were surface plankton nets towed for 15 minute intervals at stations spaced continuously along the cruise track, subsurface plankton collections via oblique water column tows from the surface to 50 m depth, and mid water trawls to maximum depths of 500 to 800 m to capture pelagic fishes for later analysis of gut contents. Hydrographic sampling was also conducted via a CTD Rosette with bottle sampling capability. The primary focus was on quantifying the distribution of small plastic particles. In addition, methods were adapted from visual survey techniques used for marine bird and mammal research in order to quantify larger plastic materials along the cruise track during daylight hours. The cruise track, which originated in San Diego, California and concluded in Newport, Oregon is shown in Fig. 1. The primary sampling region for plastic debris was the area bounded by 32°0' N, 130°0' W and 33°0' N, 140°0' W.

The primary observations of the SEAPLEX cruise were a continuous presence of small plastic particles in the range of 1 to 10 mm across a linear cruise track of approximately 2,800 km. The straight-line distance from the locations of the

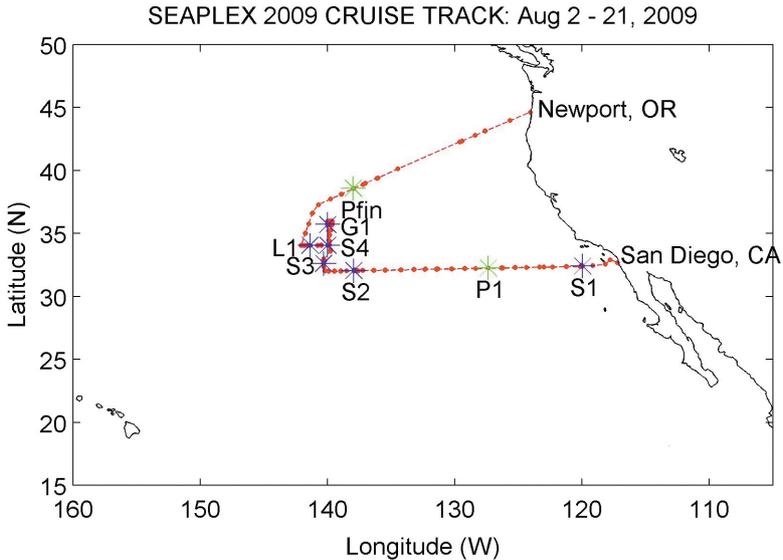


Fig. 1. Chart of the SEAPLEX cruise track. The cruise started at San Diego, California and ended in Newport, Oregon, USA. P1 and P_{fin} indicate the first and last stations at which visually evident plastic particles were found in surface net samples. S1 to S4 and G1 and L1 indicate areas of intensive plastic and hydrographic sampling.

first to the last stations with visually identified plastic particles was approximately 1,200 km. Plastic particles were found in over 100 consecutive surface tows over approximately 8 days of sampling in the region (M. Goldstein, unpubl. data). Examples of the small materials found are shown in Fig. 2. Rather than fundamentally novel, these initial results are largely confirmatory of other prior sampling (e.g., by Algalita Marine Research Foundation, and by the Sea Education Association). It is, however, significant to note that these observations present another independent set of measures that extends our knowledge of the consistency of observations across time. In addition, this new sampling provided a level of replication larger than previously attempted. The very large spatial scale and consistency of observations of plastics debris accumulation in the North Pacific Gyre underscore two important aspects of scaling for this system. One of the fundamental issues regarding the plastic debris field in the North Pacific Gyre is that we know very little about the underlying length scales or the scales of internal patchiness. From the perspective of observational oceanographic research these topics also offer opportunities to focus further efforts.

The cruise visual observations also included large numbers of identifiable and fragmented objects at the surface, often in clusters or micro-aggregations. Identifiable objects included large numbers of plastic drinking and detergent bottles, as well as floats and fishing gear (Fig. 3). The aggregations of material



Fig. 2. Examples of plastic micro debris (objects <1 cm in size) and a pelagic squid captured in a surface neuston sample in the North Pacific Gyre.

were suggestive of local mechanisms such as wind convergence and, or, surface manifestations of internal waves in concentrating debris. However, specific measurements relevant to such mechanisms were not made and the observations were in general purely qualitative. Numerous small aggregations of tangled line and parts of fishing nets were also observed. These observations suggest that the mechanical interaction of surface waves and, or, currents with objects such as line may result in an effective entanglement mechanism such that accumulations of these debris grow in size and shape. Perhaps some element of this aggregating mechanism might be relevant to designing a mechanical system that could aid in efforts to collect plastic particles at sea. The results also include a small number of mid water Myctophid fishes with plastics particles found within their gut contents (P. Davison, unpubl. data). Although these fish represent only a few percent of the total number of fish caught in mid water tows over the course of the cruise, they point to the potential that vertically migrating mid water fishes that ascend to shallow depths at night may encounter and ingest plastic materials at or near the surface. This may be an additional pathway by which surface contamination can be transported to depth. Takahashi *et al.* (2000) found high levels of organochlorine and butylin residues in Myctophid fishes collected in the western North Pacific and noted that vertical migration behavior may significantly impact



Fig. 3. Examples of macro debris (object >10 cm in size) captured during the SEAPLEX cruise.

patterns of pollutant loading among species.

In addition to generating valuable datasets from which new scientific questions can be formulated, the SEAPLEX project also became a focus of considerable media coverage. This was due in large part to the efforts of the Scripps Communications Office and Project Kaisei devoting effort to making initial contacts within the media community and in presenting a range of visual images that were able to capture a sense of the environment and the plastic contamination. One distinct aspect of communicating the issue of plastics debris

is that there are clear images of familiar and tangible objects out of place in some of the most remote locations of the ocean. Thus, compared for example with problems that cannot be as easily seen, such as the buildup of the colorless, odorless gas, carbon dioxide in the atmosphere, the visual images of plastic debris can bring to media producers and consumers an immediate, and emotional reaction and level of concern. In this time when mass media communications are dominated by visual modes, it is perhaps not surprising that issues of marine plastic debris seem to resonate widely.

SCIENTIFIC OPPORTUNITIES

The study of plastic accumulation in the North Pacific Gyre presents a number of scientific opportunities. Primary among these are opportunities for modeling the dispersal pathways of buoyant materials at the sea surface. As such, this fits into well-developed subdisciplines in oceanography associated with the construction and deployment of Lagrangian drifters and analysis of the resulting data, as well as the construction of numerical circulation models. The models of Maximenko and Niiler (Maximenko *et al.*, 2009) present a global assessment of convergence zones within the major ocean basin gyres based on data gathered over several decades of drifter deployments. This work presents a compelling case for the likelihood of plastic accumulations in all of the ocean gyres. Efforts to sample regions in addition to the North Pacific and North Atlantic are likely to be important in furthering understanding of the scale of plastics debris and the underlying mechanisms of aggregation. Opportunities also exist to use deterministic models of ocean circulation to examine possible pathways of transport and aggregation of buoyant materials. Particularly significant in this respect would be developing the conceptual framework to model sources of materials reaching the large ocean gyres. Here the modeling framework may build upon probabilistic and Bayesian approaches. One conceptual view for such a model would be to ask the question: *Given the observation of plastic debris in an area, what is the probability weighting of potential point sources contributing to the debris field?* Key pieces of observational data that may drive model development are better understanding of the length scales and patchiness of plastic debris aggregations, knowledge of the size and age distribution of debris materials, temporal variability in debris aggregation, and understanding of the depth distribution of debris in surface waters. Innovative sampling schemes for these data must be designed and may be most likely to succeed where they are adapted to low cost and can be accomplished from sailing vessels.

SUMMARY AND CONCLUSIONS

Plastic marine debris is clearly one component of the human impact on the oceans at a global scale. Direct, at-sea observations are a key component of scientific understanding of this problem, and are critical to successful modeling efforts. Clearly the scale of this problem is such that modeling is also a critical component of understanding the underlying physical processes and sources of

material reaching ocean gyres. At-sea observations also play an important role in generating accurate visual representations of interest to media with global reach. The level of public concern and interest in the topic of plastic marine debris suggests research involvement through both by private and government support is likely to expand. Successful solutions to the problems posed by marine plastic debris are clearly complex, and likely to involve: 1) Significant alterations to the production, use, handling, and disposal of materials at all stages from preproduction to post consumer and industrial waste streams. It appears that drink and detergent bottles, and plastic materials associated with industrial scale fishing should be areas of particular concern. 2) Greatly expanded attention to capturing plastic materials before they are lost into the marine environment. 3) Development of innovative technologies to capture debris materials and reuse schemes for plastics removed from the sea. The large scale of this problem and significant need for information from a variety of areas presents opportunities for progress in the fields of applied observational oceanography, as well as social and environmental policy.

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