Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris

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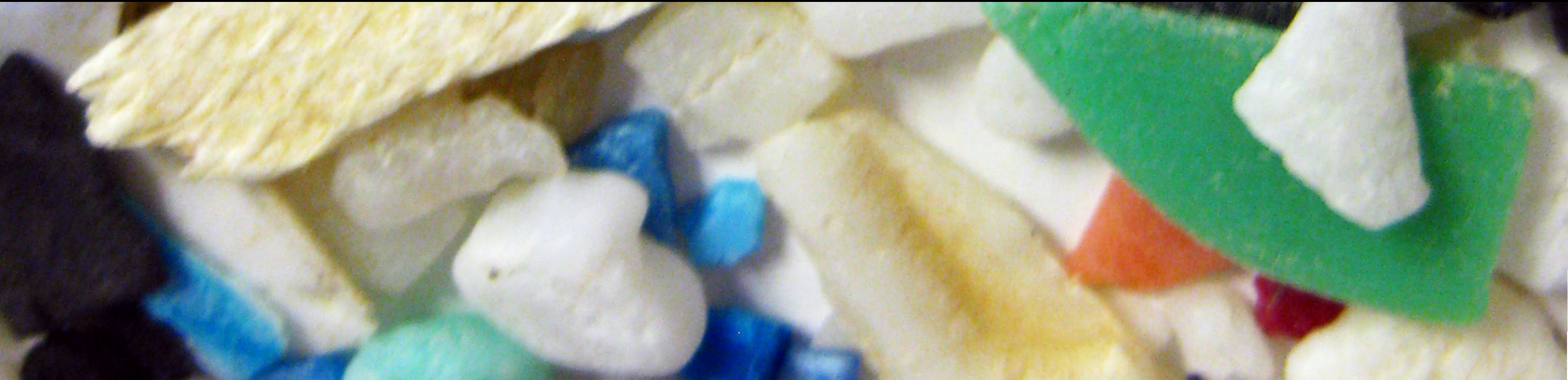

PROCEEDINGS OF THE INTERNATIONAL RESEARCH WORKSHOP ON THE OCCURRENCE, EFFECTS, AND FATE OF MICROPLASTIC MARINE DEBRIS

September 9-11, 2008
University of Washington Tacoma, Tacoma, WA, USA

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PREFACE

Welcome to the proceedings of the first International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris held September 9-11, 2008 on the University of Washington Tacoma campus in Tacoma, Washington, USA. These proceedings include an overall summary of the workshop sessions, the participant points of agreement, and suggested research initiatives to move the science of understanding the impacts of microplastics on the marine environment forward. This invitation only workshop was a joint effort between the University of Washington Tacoma and the NOAA Marine Debris Program.

The purpose of the workshop was to bring together environmental research scientists from around the world to discuss the impacts of microplastic interactions and ingestion to marine species, the connection with contaminant uptake by organisms, and to outline the potential next steps in microplastic research. The workshop format combined presentations, breakout groups, and participant discussions during two days of meetings. Thirty two individuals participated in the workshop, representing academic, industrial, private, policy and governmental sectors. Fourteen oral presentations included research on such broad-ranging topics as the oceanography of the North Pacific, the ingestion of microplastics by marine invertebrates, and persistent organic pollutants in marine plastic debris. All fourteen presentations are included here, with abstracts and slides as deemed appropriate by the presenters.

Sessions were organized to focus on four main research topics: (1) the occurrence of small plastic debris in the marine environment, (2) the impacts of small plastic debris on the marine environment, (3) the impacts of small plastic debris exposure to persistent organic pollutants, and (4) the effect of oceanic microplastics on biogeochemical cycling of persistent organic pollutants. A review paper, currently in preparation for consideration of publication, was distributed to participants before the workshop to capture the overarching themes of these four sessions, and to ensure all participants were equally familiar with each session topic. One final session included three breakout groups: sources and sinks of plastics in the marine environment, effects of microplastic debris on marine organisms, and the role of microplastics in POP cycling and exposure. The workshop closed with presentations from each breakout group that summarized discussions on the state of the science, key research gaps and potential research initiatives. Following the two day workshop was a half day meeting of the Steering Committee consisting of the participant breakout leads, session rapporteurs, and the workshop organizers to help consolidate the information and draft the final workshop proceedings.

Appendices include the workshop agenda, the guiding document for breakout groups, a list of workshop participants and contact information, and a photograph of participants.

These proceedings are meant to be a synopsis of the workshop and its findings. Presenters have sole responsibility for the views and data in their presentations. The content of presentations and summaries from breakout sessions does not necessarily reflect the views of the National Oceanic and Atmospheric Administration nor those of the University of Washington Tacoma.

EXECUTIVE SUMMARY

Summary of the *International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris*

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Executive Summary

Are microplastics a problem in the marine environment? This was the key question investigated at the microplastic marine debris research workshop. Participants examined information on a variety of topics that addressed sources, transport, and possible impacts of microplastic marine debris. When planning this workshop, it was sought to bring together leading scientists investigating microplastics as well as those with expertise in related fields. Very little research directly focusing on sources and levels of microplastics in the marine environment has been published, and even less published research addresses the impacts of microplastics on marine ecosystems. This workshop opened the dialog among scientists in this field and took a comprehensive look at each component of the issue: sources and occurrences of microplastics, impacts of microplastics on the marine environment, and chemistry of microplastics including their ability to sorb and leach contaminants in the marine environment.

I. Workshop Summary

Session I. Occurrence of small plastic debris in the marine environment

Session I presentations covered a broad overview of microplastics in the environment; the fate of plastic debris in the environment; potential approaches to identifying impacts on marine food webs; the oceanography of the North Pacific Ocean; the interaction of oceanography, biology and fisheries; and how these factors may affect movement of microplastics. Additionally, the results of plankton survey cruises in the eastern North Pacific that incidentally captured microplastics (*e.g.*, California Cooperative Oceanic Fisheries Investigations) were discussed (Doyle 2009). These presentations gave an extensive overview of the problem of documenting occurrences, especially in the open ocean. No research has examined microplastics in deep ocean sediments, and most has only – quite literally – scooped the surface of the ocean looking for plastics. Though many plastics are buoyant, many other factors play a role in the “life cycle” of a piece of plastic in the ocean. Sinking may occur due to biofouling, and plastics may eventually settle into sediments. The fouled microplastics may be eaten, the biofilm consumed, and the remaining undigested plastic packaged into fecal matter. Oceanographic factors are very important controls of the movement and weathering of plastic particles, as is the chemical composition and durability of the plastics (Andrady *et al.* 1998; Pichel *et al.* 2007). It is likely that nearly all of the plastic that has ever entered the environment still occurs as polymers and very little or any plastic fully degrades in the marine environment (Andrady 2009). Estimates of amount of macro- and microplastic in the oceans, both in absolute quantities and relative to plankton, are highly uncertain due to the lack of consistent, verified sampling and analytical methods (Carpenter *et al.* 1972; Colton *et al.* 1974; Day and Shaw 1987; Moore *et al.* 2001; Thompson *et al.* 2004). A risk assessment framework was applied to the microplastics issue in an effort to enhance discussion on the best practices to further the science of microplastics (Mearns 2009). This first session framed the complex issues surrounding the occurrence and sources of microplastics for the workshop participants, and set the stage for discussion to identify information gaps and needed studies.

Session II. Impacts of small plastic debris on the marine environment

Session II highlighted the paucity of data linking microplastic debris to demonstrated impacts on the marine environment. Quite a bit of research has focused on larger plastic items that are ingested by seabirds during oceanic foraging trips, but these pieces are greater than 10cm along the longest dimension and too large to be considered “microplastics” (*e.g.,* Auman *et al.* 1997; Baltz and Morejohn 1976; Fry *et al.* 1987; Kenyon and Kridler 1969; Pettit *et al.* 1981; Ryan 1988; van Franeker *et al.* 2004, 2005). Research on northern fulmars, albatross, and other seabirds was presented at the workshop. Some connections were drawn between ingestion of microplastics and seabird death, but overall the impact on entire seabird populations is either unknown or not considered to be large enough to warrant further investigation at this time (Auman 2009; Mallory *et al.* 2006; van Franeker 2009). One presentation given in this session discussed the results of a laboratory study that surveyed the ability of several marine invertebrates to ingest microplastics. The lugworms, amphipods, barnacles, and mussels all were capable of ingesting and passing microplastics through their digestive systems, even though each has a different mode of feeding and particle selection (Browne *et al.* 2008; Thompson *et al.* 2004). Another presentation in this session stressed a comprehensive and scientific approach to the microplastics issue in order to give policymakers the best information possible on the current status of microplastics (Weisman 2009). Data that conclusively demonstrate negative impacts of microplastics on the marine environment are not available. This is probably the largest and most critical gap to fill. Research into collection methods, species impacts, and removal methods should focus on potential microplastics hotspots.

Session III. Impacts of small plastic debris exposure to persistent organic pollutants (POPs)

Session III provided an overview of the interaction of microplastics with persistent organic pollutants (POPs). A synopsis of organic pollutant behavior in the environment was presented, including the process of adding highly sorptive particles to contaminated sediments as a remediation technique (Ghosh 2009). Two presentations detailed the occurrence and potential implications of POPs sorbed to plastics (Takada 2009; Teuten 2009). In some areas, the pollutants sorbed to plastics mirror the concentrations of these pollutants found in mussels from the same areas (Takada 2009). In a laboratory environment, phenanthrene was sorbed from dosed sediments to microplastics and in a separate experiment, ingestion of microplastics was documented in three species of sediment-dwelling invertebrates (Teuten *et al.* 2007; Thompson *et al.* 2004). To date, only a few types of plastic polymers and a few types of organic pollutants have been examined (Endo *et al.* 2005; Karapanagioti and Klontza 2008; Mato *et al.* 2001; Rios *et al.* 2007; Teuten *et al.* 2007). The specificity of pollutant and plastic interactions warrant further research into the ability of plastics to not only sorb contaminants from the environment, but also leach contaminants to the marine environment and to organisms upon ingestion.

Session IV. Effects of marine microplastic debris on the biogeochemical cycling of persistent organic pollutants

Session IV reviewed the global cycling of persistent organic pollutants in marine environments, focusing on the implications of microplastics sorbing POPs and leaching contaminants to the marine environment. Based on available information, it seems unlikely that the amount of microplastics in the marine environment is currently large enough to be an important geochemical reservoir for POPs, as research was presented that pointed to a much stronger binding of organic pollutants to the more abundant black carbon than to plastic polymers (Lohmann 2009). However, depending on the amount of microplastics and their life cycle in the oceans, it is possible that these sorptive properties could influence parts of POPs' biogeochemical cycles. Attention must also be paid to the scale of the system; small scale marine environments may differ from the global perspective. Determining the mobility of sorbed pollutants and of labile plastic components is key to addressing the risk that microplastics pose to food webs and biogeochemical cycles on both regional and global scales.

II. Findings

After the workshop sessions, a Steering Committee, which consisted of the leaders of the breakout groups, members of the NOAA Marine Debris Program, and the meeting coordinators, met to review the information exchanged and discussed at the workshop and to write the Executive Summary. The workshop participants agreed that microplastics may pose problems in the marine environment based on the following: (1)

the documented occurrence of microplastics in the marine environment, (2) the long residence times of these particles (and, therefore, their likely buildup in the future), and (3) their demonstrated ingestion by marine organisms. Microplastics are present in the marine environment, originate from a variety of sources, and are persistent in the marine environment (Andrady *et al.* 1998). Impacts of microplastics to organisms and the environment are largely unknown. The ability for plastics to transport contaminants has been documented, but the specifics of sorption and leaching are not fully understood (Endo *et al.* 2005; Karapanagioti and Klontza 2008; Mato *et al.* 2001; Rios *et al.* 2007; Teuten *et al.* 2007). It is difficult to determine how large an impact microplastics might have as sources or sinks of these pollutants to the oceans. Altogether, the science suggests that microplastics deserve further scrutiny in the laboratory and in the field. Collaborations should be utilized, and research is needed to (1) determine a "life cycle" of microplastics for different marine environments, and (2) assess the ecosystem-level impacts of microplastics on the marine environment. Only then will it be possible for the best science to inform management decisions for the remediation and prevention of microplastic pollution in the marine environment.

Key Issue #1. Sources of microplastics to the marine environment

Points of agreement

Definition of microplastics. The Workshop participants defined microplastics as plastic particles smaller than 5mm.

While there is no requirement for a "lower bound" in size, as a practical matter defining microplastics as those that range between 5mm and 333μm recognizes the common use of 333μm mesh neuston nets commonly used in the field to capture plankton and floating debris. Smaller (1.6μm) particles have been detected, but no standard procedure for sampling these in seawater has been developed (Ng and Obbard 2006). The maximum size was chosen to focus the microplastics discussion on possible ecological effects other than physical blockage of gastrointestinal tracts. Though "micro" infers the need for microscopy to view these plastic pieces, due to the early state of research the Steering Committee chose not to exclude visible components of the small plastic spectrum and thus set the upper limit at 5mm. Perhaps when the science advances, "small plastics" that can be seen without the aid of microscopy will be assigned to a separate category and only microscopic polymer fragments will be included as "microplastics."

Sources of microplastics. An important outcome of the workshop is that there are two main types of sources of microplastics. Borrowing terminology from atmospheric sciences, "primary" microplastic sources are those in which microplastics are intentionally produced either for direct use or as precursors to other products. Examples include pre-production plastic pellets, industrial abrasives, exfoliants, plastics used in rotomilling, and other consumer product uses. “Secondary” microplastics are formed in the environment from breakdown of larger plastic material, especially marine debris. The rate of production of secondary microplastics likely depends on characteristics of the plastic, the extent of weathering, and on the energetics of the local environment.

Key information gaps

The relative importance of primary and secondary sources of microplastics to the marine environment is unknown. It is important to begin addressing this gap in order to mitigate and eventually prevent the input of microplastics into the marine environment, keeping in mind that control strategies will differ by source (e.g., disintegrating plastic debris vs. spillage of pre-production plastic pellets). Obviously, the absolute and relative magnitudes of these source types will vary considerably in space and time.

The physical and chemical composition of primary microplastics and their production volumes has not been cataloged in a way that allows their potential importance to be estimated. Weathering characteristics of primary microplastics, especially release of component chemicals, are largely unstudied.

Predicting the rate of secondary microplastic production is very difficult, as no systematic study of the disintegration processes of microplastics under realistic conditions has been conducted.

At present there are no methods to characterize microplastic particles by source location, although initial efforts to characterize particles by polymer type using Fourier Transform Infrared Spectroscopy (FT-IR) are promising (Thompson *et al.* 2004).

Next steps

Complete an inventory of primary microplastic production and use. This inventory should catalog production by region (*e.g.*, North America), by composition, and by use (*e.g.*, abrasives, consumer products, rotomilling).

Complete an inventory of secondary plastic production and release to the marine environment.

<u>Key Issue #2. Measuring microplastics in the marine environment</u>

Points of agreement

At present, progress is limited by the lack of consistent methods to collect, isolate, identify, and quantify microplastic particles in marine samples (water, sediments, and organisms). Methods to consistently analyze and report data are also required.

Initial measurements of microplastics levels in the marine environment are too sparse to make general statements about spatial distributions or temporal trends.

Key information gaps

Methods to isolate microplastics from surface waters (net tows, filters), sediments, and organisms are desperately needed before further progress can be made in this field. Current methods are tedious and labor-intensive and may be biased towards microplastics that are clearly different from the surrounding natural particles (Thompson *et al.* 2004). These methods likely underestimate levels of smaller and neutrally colored microplastics.

There has not been any attempt to compare or intercalibrate methods used by the very few research groups around the world measuring microplastics in the marine environment.

Next steps

Further evaluate, standardize, and compare sampling and analytical methods among independent laboratories. Conduct an initial investigation in which surface waters, sediments, and native deposit- and filter-feeding organisms are collected from two or more likely "microplastic hot spots" and exchanged between laboratories. Such a study would lead to improved and standardized methods, which could then be expanded to a larger interlaboratory comparison exercise.

Where possible, add microplastic measurements to existing and ongoing plankton surveys, especially in coastal areas.

Key Issue #3. Routes of exposure and potential vulnerabilities

Points of agreement

Studies by R. C. Thompson, University of Plymouth, and colleagues demonstrate that microplastic particles are ingested by deposit-feeding benthos and by filter-feeding mussels, and that microplastics can be assimilated within the mussel (Browne *et al.* 2008; Thompson *et al.* 2004).

Marine organisms that ingest particles of the size range of microplastics are the most vulnerable to potential impacts and should be the focus of initial studies.

Key information gaps

To date, only one study has examined the possible interactions between marine zooplankton and microplastics (Andrady 2009). In a laboratory study presented at the workshop, Andrady and colleagues showed ingestion of 20µm polyethylene fragments by the krill species *Euphasia pacifica*.

To date, no studies have examined microplastic interactions between larval fish or pelagic tunicates, many of which inhabit the sea-surface microlayer, and microplastics. These interactions may be especially important to those species that utilize coastal habitats for spawning.

Next steps

Based on known behaviors, identify marine species or life stages that would likely be most vulnerable to microplastic exposure.

Since there are a very large number of possible combinations of particle-feeding species and microplastic types, focus initial exposure studies on field studies in locations that are likely "microplastic hotspots" and are habitat for vulnerable species and sensitive life stages. Document whether microplastics are ingested by these species under field conditions.

Key Issue #4. Effects of microplastics on marine organisms

Points of agreement

Possible effects include three broad modes of action: (1) physical blockage or damage of feeding appendages or digestive tract, (2) leaching of plastic component chemicals into organisms after digestion, and (3) ingestion and accumulation of sorbed chemicals by the organism. All of these effects require that the microplastic particles be ingested.

Microplastics as defined here (<5mm) are not likely to cause widespread ingestion-related effects on large organisms (*e.g.,* birds, marine mammals), certainly relative to the well-documented impacts of larger marine plastics.

Key information gaps

Dose-response relationships between specific types of microplastics and vulnerable marine species or life stages do not yet exist.

Protocols for conducting realistic exposure experiments of microplastics in laboratory toxicity studies are needed.

Next steps

Scale direct toxicity studies to levels of microplastic particles observed in hotspots, using likely vulnerable organisms as described above.

Key Issue #5. Roles of microplastics on the cycling of persistent organic pollutants (POPs)

Points of agreement

At current levels in the open ocean, microplastics are unlikely to be an important global geochemical reservoir for historically released POPs such as PCB, dioxins, and DDT. It is not clear if microplastics play a larger role as chemical reservoirs on smaller scales.

POPs have a high affinity for plastic in seawater. This is the basis for several POP sampling techniques, including passive sampling. While this high affinity results in elevated POP concentrations on microplastic particles, these POPs may not be readily bioavailable.

Key information gaps

Very little is known about the chemical composition and rates of leaching of integral plastic components in seawater. It is not possible, therefore, to judge whether emission of primary microplastics is a significant source of, for example, plasticizers or flame retardants to the world's oceans.

While microplastics accumulate POPs and some organisms ingest microplastics, the net effect of this on transfer of POPs into marine organisms is unclear. On one hand POP ingestion is increased, but it is not clear under what physiological conditions plastic-associated POPs would be assimilated by marine organisms upon ingestion of plastics.

Next steps

Based on the inventory of primary microplastic production (see Key Issue #1, next steps), conduct studies of integral plastic component leaching in seawater to enable estimates of component loadings to the marine environment.

Systematically study the role of microplastic ingestion in POP exposure (in both the water column and sediment) with a strategically selected series of microplastics (varying in magnitude of affinity for POPs), set of POPs (with varying aqueous solubilities), and organisms (filter feeding and deposit feeding). Interpret results from these studies using existing pharmacokinetic models that account for ingestion rates and assimilation efficiencies.

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ABSTRACTS AND PRESENTATIONS

Keynote Address - How concerned should we be about microplastics?

Dr. RC Thompson, University of Plymouth, Plymouth, UK

Abstract: Microplastics are small fragments of plastic debris. This material has been reported on shorelines and in the water column on a global scale and there are concerns it may present hazards to wildlife and to human health.

Methods to separate and quantify microplastics from environmental samples are time consuming and represent an incomplete estimate of contamination; however these semi-quantitative approaches have successfully identified microplastic as small as 20µm in diameter, have shown that the abundance of this debris has increased over recent decades and that microplastics are widely distributed in the environment. The sources of microplastic debris are most probably fragmentation of larger items of marine litter and the direct release of small pieces of plastic from various cleaning applications.

Plastic products bring many societal benefits and as a consequence, annual global production has increased from 5 million tonnes in the 1950s to over 230 million tonnes today. However, because of their disposable nature substantial quantities of plastic items have been discarded to the environment and so the abundance of microplastic is likely to increase over the next few decades.

Laboratory experiments have shown that microplastics are ingested by filter feeders, deposit feeders and detritivores and there is concern that ingestion of this material could present a physical hazard to wildlife, for example by compromising the ability to feed. In addition, there is evidence, that small fragments of plastic could facilitate the transfer of toxic substances to wildlife. Two routes have been suggested: (1) the release of chemicals incorporated during manufacture as plasticisers, flame retardants and antimicrobials, and (2) the release of persistent organic pollutants (POPs) that have arisen in the environment from other sources and have sorbed to plastic debris in seawater.

Reaching robust, environmentally relevant conclusions about the abundance and the potential impacts of microplastic debris is not a trivial task and this workshop offers a major step toward identifying a suitable research agenda. There is also an important need for parallel research and policy focusing on solutions to established problems associated with the production, usage and disposal of plastics.

Richard C. Thompson, PhD, is a Marine Ecologist specialising in the ecology of shallow water marine habitats. He studied Marine Biology at the University of Newcastle upon Tyne from 1988 to 1991 followed by a PhD on the ecology of intertidal biofilms at the University of Liverpool from 1992 to 1996. He subsequently worked as postdoctoral research fellow at the University of Southampton and since 2001 he has been a lecturer, and is now a Reader, in Marine Ecology at the University of Plymouth. He currently leads the BSc Marine Biology degree programme at Plymouth and lecture in marine ecology and experimental biology. His research has focused on a wide range of ‘natural’ ecological interactions and on anthropogenic disturbance. He supervises a research group of 2 post docs and 8 PhD students. Work by his group has examined: biodiversity and ecosystem function using rockpools as natural mesocosms, trade-offs between food availability and refuge quality, trophic linkages between intertidal and subtidal habitats, the ecology of coastal defenses and marine renewable energy developments. Much of his work over the last decade has focused on marine debris. In 2004 his group published a paper in *Science* describing the distribution and temporal trends in the abundance of microscopic fragments of plastic in the NE Atlantic. They have subsequently been working to establish the environmental consequences of this type of debris. He is currently acting as invited editor of a Theme Issue of 13 papers, for Philosophical Transactions of the Royal Society, focusing entirely on Plastics the Environment and Human Health.

SESSION I: OCCURRENCE OF SMALL PLASTIC DEBRIS IN THE MARINE ENVIRONMENT

Fate of Plastics Debris in the Marine Environment

Dr. Anthony L. Andrady, Research Triangle Institute, Durham, NC, USA

Abstract: Certain classes of plastics, those used in the fabrication of fishing gear and those used in packaging applications are present in quantity in the marine environment. Most of these are non-biodegradable formulations of nylons and polyolefins that are used in netting and ropes. Expanded polystyrene from packaging and floats as well as polyolefins from consumer packaging materials are also commonly present.

The usual factors that facilitate the deterioration of these materials on exposure to land environments, mainly solar UV-B radiation and high temperatures have a limited impact floating plastics debris. This results in markedly retarded degradation of plastics in the oceans. Mineralization of these and their return to the carbon cycle must therefore be a very slow process. The plastic microparticles well known to be present in the oceans, likely originate from both the slow deterioration of the floating or submerged plastics, as well as the fragmentation of plastics degraded to embrittlement in the beach environment. Analysis of the collected particles cannot determine their origin but can only identify the chemical class of the plastic. Also, a significant fraction of the plastic fragments on beach and in water consists of virgin prils that mainly enter the environment during transport. These not being compounded will degrade at a relatively faster rate both on land and at sea.

This discussion will summarize the chemical aspects degradation of the relevant classes of plastics, review the criteria for degradation in these systems and discuss the chemistries for enhancement of plastics degradation. Special emphasis will be on the origins and the fate of polymer microparticles.

Tony Andrady, PhD, is a Senor Research Scientist at the Research Triangle Institute in North Carolina. He is a Material Scientist with a research interest in issues relating to plastics debris in the Marine Environment.

Microplastics as Accumulators and Sources of Persistent Organic Pollutants in Marine Food Webs: How Significant?

Dr. Alan J. Mearns, NOAA Office of Response & Restoration, Seattle, WA

Abstract: It has been nearly 40 years since Carpenter and Smith (1972) first reported the occurrence of plastic spherules in the Atlantic, including confirming the ability of Long Island Sound spherules to accumulate PCBs (Carpenter et al, 1972). Only recently have scientists again started exploring the role of microplastics as accumulators and vectors of Persistent Organic Pollutants (POPs). Microplastics accumulate POPs to part per million concentrations. However, there remain differences of opinion about the significance of microplastics as vectors of POP accumulation in marine wildlife. When birds or juvenile fish ingest microplasics, which is worse to the health of organisms and populations: the undigestible plastic or the POP's? Clearly, reducing microplastic inputs will reduce marine life injuries, regardless of the mode of injury. It remains unclear to what extent microplastics represent a source for food chain POP accumulation compared to other sources, such as marine organisms normal food. A risk assessment approach would help sort out the questions and their significance.

Alan J. Mearns, PhD, is an Ecologist and Senior Staff Scientist with the NOAA Office of Response and Restoration in Seattle, Washington. He holds a PhD in Fisheries from the University of Washington and Master's and Bachelor's degrees in Biology and Zoology from California State University in Long Beach. During the 1970's Alan was Leader of the Biology Division at the Southern California Coastal Water Research Project (SCCWRP) and in the 1980's Ecologist for the MESA Puget Sound Project and Leader of the National Status and Trends Historical Trend Assessment Program which evaluated longterm contaminant trends along the entire US coastline. Since 1989 he has been a member of the NOAA ERD (HazMat) Team supporting NOAA's Scientific Support Coordinators (SSC's) during oil spills and emergency response, including conducting longterm monitoring of recovery from the Exxon Valdez Oil Spill. He is also leader of the Water Environment Research Journal's Annual review of the Effects of Pollutants on Marine Life, which includes marine debris. He has been a science adviser to various national and regional committees involving bioremediation, wastewater discharges, cruise ship pollution, sediment bioassay methods, the San Francisco Estuary Institute (SFEI), the Coastal Response Research Center (CRRC) and is a member of the Science and Technical Committee of the Oil Spill Recovery Institute (OSRI) and EPA's Environmental Technology Verification (ETV) Program. During the past decade Alan has been using 3D trajectory models to support and facilitate consensus evaluation of the effects and benefits of alternative spill response options around the US and in Mexico and the Caribbean.

The oceanography, biology, and fisheries of the North Pacific

Dr. Michael P. Seki, NOAA National Marine Fisheries Service, Honolulu, HI

Abstract: An overview of the oceanography and living resources of the North Pacific Ocean is presented. In particular, physical processes such as large scale ocean circulation patterns and semi-permanent frontal systems that play key roles in facilitating the accumulation of marine debris are highlighted. Seasonal and meso-scale variability of ocean processes give rise to localized “hot spots” of convergence and enhanced biological aggregations. And an examination of the basin-wide Transition Zone Chlorophyll Front depicts a region where surface feeding animals are particularly vulnerable to marine debris accumulation.

Michael P. Seki, PhD, is the Deputy Director of the Pacific Islands Fisheries Science Center located in Honolulu, Hawaii. He is a career government employee having been with NOAA Fisheries since 1980. As a research scientist over the past 27 years, he has conducted studies on marine resources in the Pacific region including seabirds, sea turtles, tropical snappers, oceanic squid, tunas, and billfishes, and has authored or co-authored over 40 scientific papers on topics such as open ocean food webs (ecosystems) and the influence of the physical oceanographic environment on the distribution and abundance patterns of living marine marine resources.

Born and raised in Hawaii, Dr. Seki received his B.S. in biology from the University of Oregon, his M.S. in oceanography from the University of Hawaii, and his Ph.D. in marine environment and resources from Hokkaido University (Graduate School of Fisheries Science); with a dissertation topic focused on how living marine resources in the North Pacific respond to abrupt changes in oceanographic conditions.

Small Plastic Debris and Plankton: Perspectives from NOAA Plankton Sampling Programs in Northeast Pacific Ecosystems

Dr. Miriam Doyle, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA

Abstract: The purpose of this study was to examine the incidence of small particles of plastic in plankton samples collected in Northeast Pacific ecosystems, and to contribute to the development of a standardized protocol for future research into the occurrence and effect of small plastic debris in marine pelagic ecosystems. Zooplankton samples were collected in conjunction with the National Oceanic and Atmospheric Administration's (NOAA) ongoing ecosystem surveys in the Northeast Pacific, during four research cruises off California in spring, summer and fall of 2006, and in January of 2007, and two research cruises in the Southeast Bering Sea in the spring and fall of 2006. Neuston samples were collected during all cruises, and sub-surface samples during the four cruises off California. A total of 593 plankton samples from these research cruises were processed for debris particles. Results from this study indicate that tiny amounts of small plastic debris are present primarily in surface waters of the California Current and Southeast Bering Sea coastal ecosystems. The mean standardized quantity of plastic debris, expressed as mass (mg) and numbers of particles per meter cubed, was very low overall for both sampling areas and all cruises (<1 mg/ m^3, and <0.2 particles/m^3, respectively) but spatial and temporal variability was apparent within the range of values recorded. The plastic particles were assigned to three plastic product types: product fragments, fishing net and line fibers, and industrial pellets; and five size categories: <1 mm, 1-2.5 mm, 2.5-5 mm, 5-10 mm, and >10 mm. Product fragments accounted for the majority of the particles, and most were less than 2.5 mm in size. Although the quantity of plastic particles was extremely low, their ubiquity in the plankton samples and predominance of particles <2.5 mm, implies persistence in these pelagic ecosystems as a result of continuous breakdown from larger plastic debris fragments, and widespread distribution by ocean currents. The estimated biomass of zooplankton was many orders of magnitude higher than the mass of plastic particles, both for average cruise values and among individual samples, implying minimal interaction between small plastic debris and zooplankton organisms in these regions.

This project was supported by a grant from the National Fish and Wildlife Foundation in partnership with the National Oceanic and Atmospheric Administration's Marine Debris Program, and the American Chemistry Council.

Miriam Doyle, PhD, has worked for 17 years at the Alaska Fisheries Science Center in Seattle, USA, on a variety of research projects in the field of early life history ecology of Northeast Pacific fishes, prior to which she studied the ecology of early life stages of fish species in the plankton of the Northeast Atlantic. Through the JISAO Institute at the University of Washington, she works with NOAA scientists at the Alaska Fisheries Science Center and the Pacific Marine Environmental Laboratory to understand the influence of climate and ocean processes on fluctuations in Alaska fish populations.

SESSION II: IMPACT OF SMALL PLASTIC DEBRIS ON THE MARINE ENVIRONMENT

FOOLISH FULMARS AND THEIR CONTRIBUTION TO ECOLOGICAL QUALITY

Dr. Jan A. van Franeker, Wageningen IMARES, Den Berg (Texel), THE NETHERLANDS

& the Save the North Sea Fulmar Study Group

Abstract: Indiscriminate foraging enables the Northern Fulmar *(Fulmarus glacialis)* to successfully exploit variable food resources in changing marine environments. But flexibility can be taken too far. Like most tubenosed seabirds, Fulmars ingest a wide variety of man-made litter. Ingested plastics resist digestion and mechanical breakdown in the stomach and accumulate over time. Unlike gulls, Fulmars normally do not regurgitate indigested stomach contents and need to 'process' them slowly in the digestive system. Ingested materials sometimes cause direct mortality but more importantly, indirect sublethal effects will occur in almost all individuals in many populations. However, the accumulated plastics also represent a convenient monitoring instrument for the litter situation in the offshore environment. Stomach contents integrate probably up to several weeks of 'sampling' of the marine litter situation in their foraging area.

In 2002 the North Sea Ministerial Conference decided to tackle marine problems through the concept of 'Ecological Quality Objectives (EcoQO's)'. An EcoQO provides a monitoring system as well as a target for 'acceptable ecological quality'. For the marine litter issue, an EcoQO based on the amount of plastic in stomachs of beached Fulmars was selected. The preliminary political target for acceptable ecological quality was worded as *"less than 10% of Fulmars having more than 0.1 gram of plastic in the stomach".* Implementation of this 'Fulmar-Litter-EcoQO' started in 2002 in the EU project 'Save the North Sea'. Data show that 40% to 60% of Fulmars in the North Sea currently exceed the critical value of 0.1 gram of plastic in the stomach. In addition of being a valuable policy instrument, the image of 'birds with plastic in their stomach' attracts much public attention and stimulates awareness and changed behaviour among stakeholders. Fulmars are foolish foragers, but by being 'quantifiable fools', they can contribute to improved ecological quality for the benefit of all.

Jan van Franeker, PhD, is a senior scientist at the Ecology department on Texel of the Netherlands Institute for Marine Resources and Ecosystem Studies (IMARES). Van Franeker is a marine biologist and has his main expertise in seabirds and other marine top predators, with a focus on their functioning in polar marine ecosystems, especially the Southern Ocean. SInce 1986 is project leader for the Antarctic Research conducted by IMARES. Throughout his career, pollution issues in relation to marine wildlife have been a recurrent phenomenon. In recent years he has guided important projects on monitoring the ingestion rates of litter by seabirds. Formerly a government research instutute for the Ministry of Agriculture, Nature and Food Quality, IMARES is now a privatised marine research organisation working under the umbrella of Wageningen University and Research (WUR).

Incidence of Marine Debris Ingestion in Seabirds from Midway Atoll and Heard Island

Dr. Heidi J. Auman, University of Tasmania, Hobart, Tasmania, AUSTRALIA

Abstract: The presence of ingested anthropogenic marine debris in seabirds is of growing concern, especially in areas of the earth remote from point sources. Laysan albatross chicks from Midway Atoll, North Pacific Ocean, were assessed for impacts of marine debris ingestion. Masses and incidence of debris in chicks were compared between birds found dead of natural causes and those injured by vehicles. Laysan albatross chicks dead from natural causes had significantly greater masses of plastic debris in their proventriculi and gizzards and had significantly lighter body masses and lower fat indices than injured but otherwise healthy chicks. In a separate study of seabirds from Heard Island in the Southern Indian Ocean, small amounts of ingested marine debris were found in two Antarctic prions and evidence of indirectly ingested debris were found from the casts of sub-Antarctic skuas. Ingested marine debris probably does not cause significant direct mortality in these seabirds, but is likely to cause physiological stress as a result of satiation and mechanical blockages.

Heidi J. Auman, PhD, earned a B.S. in Biology from Alma College, a M.Sc. in Fisheries and Wildlife from Michigan State University, and a Ph.D. in Zoology from the University of Tasmania. She has spent the last 20 years focusing on human impacts in seabirds, specifically in the topics of toxicology, disturbance, plastic debris ingestion, urbanisation and diet. Her research is global in scope with a preference for isolated islands, including those in the North American Great Lakes, subtropical Midway Atoll, subantarctic Heard Island and Tasmania. A popular science communicator, she has demonstrated that our ecological footprint has reached the furthest corners of the Earth, often with disturbing consequences.

Ingestion of microplastics by marine invertebrates

Dr. RC Thompson, University of Plymouth, Plymouth, UK

Abstract: Microplastics are small fragments of plastic debris. This type of material has been reported on a global scale and is present in the water column, on shorelines and in subtidal sediments. Large items of plastic debris are known to have potentially harmful effects on over 260 marine species, principally via ingestion and entanglement. Because of their size microplastics have the potential to be ingested by a much wider range of organisms including relatively small invertebrates.

In laboratory experiments the filter feeder, *Semibalanus balanoides*; the infaunal deposit feeder, *Arenicola marina* and the detritivore, *Orchestia gammarellus* all ingested microplastic fragments (20 - 2000µm diameter) over a period of several days. Subsequent experiments with the common mussel (*Mytilus edulis*) showed that plastic microspheres (3.0 and 9.6 µm) were ingested and within 3 days had translocated from the gut to the haemolymph (circulatory system). These particles were still present in the haemolymph 48 days after transfer to clean conditions, but no adverse biological effects were detected. It is apparent therefore that invertebrates with a range feeding strategies can ingest microplastics and that this debris may be retained in theirbodies.

Ingestion of microplastic could impair feeding in a similar way to that already described for larger items of debris. There is also concern that ingestion of small items of plastic debris could facilitate the transport of toxic chemicals to marine organisms. Our recent experiments support this possibility, but more work will be required to reach firm conclusions. As a precursor we need to establish whether there are particular 'sinks' for the accumulation of microplastic debris and to establish the extent to which organisms are ingesting microplastics in these habitats. Some creatures, such as sea birds, are known to actively select plastic fragments mistaking them for food items at the sea surface. As a consequence of habitat and/or behaviour some organisms may therefore be exposed to greater quantities of microplastics than others. Hence, data on natural levels of exposure are crucial to inform the choice of appropriate test organisms.

Richard C. Thompson, PhD, is a Marine Ecologist specialising in the ecology of shallow water marine habitats. He studied Marine Biology at the University of Newcastle upon Tyne from 1988 to 1991 followed by a PhD on the ecology of intertidal biofilms at the University of Liverpool from 1992 to 1996. He subsequently worked as postdoctoral research fellow at the University of Southampton and since 2001 he has been a lecturer, and is now a Reader, in Marine Ecology at the University of Plymouth. He currently leads the BSc Marine Biology degree programme at Plymouth and lecture in marine ecology and experimental biology. His research has focused on a wide range of 'natural' ecological interactions and on anthropogenic disturbance. He supervises a research group of 2 post docs and 8 PhD students. Work by his group has examined: biodiversity and ecosystem function using rockpools as natural mesocosms, trade-offs between food availability and refuge quality, trophic linkages between intertidal and subtidal habitats, the ecology of coastal defenses and marine renewable energy developments. Much of his work over the last decade has focused on marine debris. In 2004 his group published a paper in *Science* describing the distribution and temporal trends in the abundance of microscopic fragments of plastic in the NE Atlantic. They have subsequently been working to establish the environmental consequences of this type of debris. He is currently acting as invited editor of a Theme Issue of 13 papers, for Philosophical Transactions of the Royal Society, focusing entirely on Plastics the Environment and Human Health.

Translating scientific findings into action: California's response to plastics in the environment

Dr. Stephen B. Weisberg, Southern California Coastal Water Research Project, Costa Mesa, CA, USA

Dominic Gregorio, California State Water Resources Control Board, CA, USA

Abstract: Numerous studies have documented the increasing presence of debris in the marine environment, from derelict floating fishing gear to litter on beaches. In response, California's Ocean Protection Council passed a landmark resolution in 2007 to reduce marine debris, followed by a draft implementation plan in 2008. The implementation plan, as well as actions being undertaken or considered by local jurisdictions, fall into five general strategies: 1) Regulatory controls on the discharge of plastic debris; 2) Public education and behavior modification; 3) Change the packaging strategy; 4) Remove debris from the environment; and 5) Monitor to assess program effectiveness. These strategies reflect effective translation of science into management, but most of the actions focus on reducing the amount of large debris. In part this is because the management actions for large debris are easier to implement, but it also reflects our lesser scientific knowledge about the sources and effects of microdebris. Here we discuss the interface between scientific findings and management action, highlighting the scientific needs for microdebris in that context.

Stephen Weisberg, PhD, is Executive Director of the Southern California Coastal Water Research Project (SCCWRP) where he specializes in the design and implementation of environmental monitoring programs. He Chairs the Southern California Bight Regional Monitoring Steering Committee and is on the Governing Boards of the California Ocean Science Trust and the Southern California Coastal Ocean Observing System. He serves on advisory committees for numerous programs, including the California Ocean Protection Council, California's Clean Beach Task Force the University of Southern California Sea Grant Program, the Alliance for Coastal Technology and the Hollings Laboratory Oceans and Human Health Program. Dr. Weisberg received his undergraduate degree from the University of Michigan and his Ph.D. from the University of Delaware.

SESSION III: IMPACTS OF SMALL PLASTIC DEBRIS EXPOSURE TO PERSISTENT ORGANIC POLLUTANTS

Effect of sorbent particles on the bioaccumulation of persistent organic pollutants in sediments

Dr. Upal Ghosh, University of Maryland Baltimore County, Baltimore, MD, USA

Abstract: Our recent work provides new understanding of contaminant binding through direct microscale determination of contaminant association with sediment particle types. We investigated the roles of different types of natural and anthropogenic organic particulates in impacted sediments (coal, soot, charcoal, wood, coal tar pitch, and humic materials) and explored how predominant association of contaminants with certain types of organic matter may affect overall bioavailability. In our work with sediment from several urban locations across the country, we find that the majority of hydrophobic contaminants such as PAHs and PCBs are strongly bound to carbonaceous particles. We also find that PAHs bound to carbonaceous particles are resistant to desorption, microbial biodegradation, and bioaccumulation by organisms. Our current work extends this understanding by demonstrating how the addition of low-cost sorbents such as activated carbon, may sequester persistent organic contaminants, and reduce contaminant availability, exposure, and accumulation in sediment-dwelling organisms. We propose that addition of activated carbon to PCB contaminated sediment may be an effective in-situ stabilization method to reduce contaminant availability to biota and surrounding water. We are now testing this approach in two pilot-scale technology demonstrations, one in a tidal mudflat, and the other in a river environment. This talk will focus on the role of strong sorbent particles on contaminant bioavailability in sediments and also explore the impact of plastic debris on contaminant bioavailability to marine organisms.

Upal Ghosh, PhD, is an associate professor at the department of Civil and Environmental Engineering, University of Maryland Baltimore County (UMBC). His research explores fundamental process mechanisms that control organic contaminant fate in soils, sediments, and aquatic environments. His research uses multidisciplinary tools to investigate exposure and bioavailability of organic contaminants to organisms. The new understanding is used to develop novel remediation technologies, site-specific risk assessment, and remediation goals. Dr. Ghosh is currently involved in pilot-scale technology demonstrations of in-situ remediation of PCB-impacted sediments. The technology is based on contaminant binding and bioavailability reduction through the amendment of activated carbon tosediments.

Dr. Ghosh has a M.S. and Ph.D. in Civil and Environmental Engineering from the University at Buffalo, and a B.Tech. in Chemical Engineering from the Indian Institute of Technology, Bombay. Before joining UMBC, Dr. Ghosh worked at Carnegie Mellon University as a post doctoral fellow and at Stanford University as a research associate and lecturer.

International Pellet Watch: Global distribution of persistent organic pollutants (POPs) in marine plastics and their potential threat to marine organisms

Hideshige TAKADA, Laboratory of Organic Geochemistry, Tokyo University of Agriculture and Technology, Tokyo, JAPAN

Abstract: Beached resin pellet samples collected at 30 locations from 17 countries were analyzed for PCBs, DDTs, HCHs, PAHs, and hopanes. PCB concentrations in the polyethylene pellets were highest on US coasts (100 - 500 ng/g), followed by western European countries (e.g., U.K. and Netherlands) and Japan (50 - 100 ng/g), whereas lower in tropical Asia, southern Africa and Australia (5 – 50 ng/g). The spatial pattern was well correlated with that of the monitoring results of mussel watch, indicating that concentrations of hydrophobic contaminants in the plastic pellets reflect the pollution status of the coastal environments. DDTs showed high concentrations on the west coast of USA (~300 ng/g) and Vietnam (~200 ng/g). In Vietnam, DDT was predominant over its metabolites (DDE and DDD), suggesting current usage of the pesticide. High concentrations of HCHs were detected in the pellets from southern Africa (~30 ng/g), whereas HCHs showed trace concentrations in the other areas in the world (~ 1 ng/g or lower). This suggests current usage of the pesticide in southern Africa. Hopanes, biomarker of petroleum pollution, were detected in all the pellet samples collected across the world at μg/g level, indicating ubiquitous petroleum pollution. PAHs were significantly detected at several locations and they were rich in alkyl homologs, indicating the dominance of petrogenic origin over pyrogenic one. We also analyzed plastic fragments (i.e. scraps of consumer products) from the central gyre of the Pacific and a Japanese coast for the organic micropollutants. In addition to the hydrophobic organic pollutants such as PCBs and PAHs, additive-derived chemicals such as bishphenol A and nonylphenols were detected in the plastic fragments. Higher concentrations (20 – 40 ng/g) of brominated flame retardants, PBDEs, were detected in the plastic fragments from the central gyre than the Japanese coast. They were rich in BDE183 which is the major component of Octa BDEs, indicating contribution of the additives. To examine potential transfer of the plastic-associated contaminants to sea birds which ingest the marine plastics, a feeding experiment was conducted and contaminated plastic resin pellets were fed to Streaked Shearwater chicks. Analysis of PCBs in preen gland oil excreted from the sea bird suggested that transfer of lower-chlorinated congeners from the plastics to the sea bird.

Hideshige TAKADA, PhD, is an organic geochemist studing the behaviors of organic micropollutants in aquatic environments. He was born in Tokyo, Japan, in 1959. He obtained a PhD from Tokyo Metropolitan University in 1989, and then studied at Woods Hole Oceanographic Institution with Dr. John Farrington from 1990-1991. He is a professor in the Laboratory of Organic Geochemistry (LOG) in Tokyo University of Agriculture and Technology. His lab discovered a range of organic micropollutants in marine plastics in 2001. Since then they have been conducting several researches on organic micropollutants in environmental plastics including "International Pellet Watch."

Microplastic-pollutant interactions and their implications in contaminant transport to organisms

Dr. Emma Teuten, University of Edinburgh, Edinburgh, UK

Abstract: Uptake of hydrophobic organic contaminants (HOCs) onto plastic debris followed by transport of the sorbed contaminants to organisms has been discussed in the literature since the 1970s. While it has been unequivocally demonstrated that contaminants concentrate on plastics in the environment, little evidence exists supporting their subsequent transfer to animals. This is probably due partly to the complexity of designing experiments to effectively investigate such transfer.

On-going work at the University of Plymouth has attempted to address this issue. Transfer of plastic-bound contaminants to a typical benthic organism (lugworm; *Arenicola marina*) was modelled using equilibrium partitioning. The model results suggested that addition of plastic to the sediment would decrease the contaminant tissue concentration in lugworms. This is due to the high affinity of plastics for HOCs allowing them to act as "scavengers", thus removing contaminants from the environment and reducing the exposure of benthic organisms. However, this mechanism can only apply for plastics that are relatively "clean" and uncontaminated. Since plastics readily sorb HOCs from the environment, they are unlikely to remain clean for long. Plastics are known to accumulate on the strandline, and float in the sea-surface microlayer, where contaminant concentrations are often higher than in the bulk water. Fouling of the plastics can cause them to sink, carrying their contaminant load into the sediment, where it may ultimately increase the contaminant body burden of sediment dwelling organisms. Preliminary *in vivo* trials have demonstrated transfer of a selection of HOCs from plastics to lugworms.

Uptake of contaminants by organisms occurs by inhalation, dermal sorption and ingestion, dependant upon the organism and the physicochemical properties of the contaminant. For many organisms ingestion is the most likely exposure route for plastic-mediated uptake of contaminants. More than 180 species have been documented to ingest plastic debris, and a positive correlation between the mass of ingested plastic and the PCB concentration in birds has been observed. Since plastics are known to accumulate PCBs in the environment, this correlation supports plastic-mediated transfer of contaminants to higher organisms.

Emma Teuten, PhD, completed her PhD in organic chemistry at the University of Missouri in 2002 and then received a Dreyfus Postdoctoral Fellowship to conduct environmental chemistry at Woods Hole Oceanographic Institution. Her work there focused on the origin of halogenated organic contaminants in marine mammals. Following that she returned to the UK and did another postdoc at the University of Plymouth, where she investigated transport of contaminants to benthic organisms by microscopic fragments. She is currently working as a Research Fellow in Environmental Engineering at the University of Edinburgh, where she is looking into the potential for plastics to be used as sorbents in the removal of contaminants from the environment.

SESSION IV: EFFECT OF OCEANIC SMALL PLASTIC DEBRIS ON BIOGEOCHEMICAL CYCLING OF POPS

Role of microplastics on transport and fate of POPs

Dr. Rainer Lohmann, University of Rhode Island, Providence, RI, USA

Abstract: Results from recent ocean cruises covering the Arctic (2004), Atlantic (2006) and Pacific (2007) Ocean are presented for different POPs. Polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) were simultaneously measured in air and surface seawater between 49° N and 25° S in the open Atlantic Ocean. Broad latitudinal trends were observed with the lowest PAH and PCB air concentration in the South Atlantic and the highest off the west coast of Africa. The unexpectedly high concentrations off NW Africa were discussed assessing the possible contribution of the emerging oil industry along the African shore, the role of biomass burning and natural sources of PAHs. Correlations of PAHs' partial pressures versus inverse temperature were not significant, in contrast to results for PCBs from the same transect. This could have been due to the importance of ongoing primary sources for PAHs combined with shorter atmospheric life-times. Ratios for anthracene and phenanthrene were <0.3 in the remote tropical Atlantic, suggesting net volatilization. PCB concentrations were highest in Europe and the lowest in the Arctic. Fractionation was observed for PCBs in seawater with the relative abundance of PCB 28 and 52 increasing and that of the heavier congeners decreasing with latitude. Comparison with other data from cruises in the Atlantic and Arctic Ocean since 1990 indicate little change in PCB air concentrations. On average, deposition dominates over volatilization for PCBs in the Arctic region with a strong increase in the middle of the transect near the marginal ice zone (78-79 °N), possibly caused by ice melting. During a 2006/2007 cruise on the Pacific, gas-phase PCBs were highest in the Northern Hemisphere (NH), and decreased towards the equator. In the remote South Pacific, concentrations declined to <10 pg/m^3 for individual PCBs. In the surface water, concentrations of PCBs decreased from >2 pg/L per congener in the NH to ~1 pg/L in the S-Pacific. Dissolved PCBs in the S-Pacific gyre were higher than those reported from the S-Atlantic, possibly due to the extremely low biological productivity and removal fluxes from the S-Pacific gyre's surface waters.

Rainer Lohmann, PhD, received his PhD in Environmental Chemistry from Lancaster University, England (UK) in 2000. He then joined the Massachusetts Institute of Technology as a postdoctoral fellow, and moved to the Research Center for Ocean Margins (Bremen, Germany) as a fellow for most of 2004. Since November 2004 he has been Assistant Professor in Oceanography at the University of Rhode Island's Graduate School of Oceanography. His current research interests are: the black carbon cycle and its effects on the (bio)availability of organic pollutants, the global fate of POPs and the use of passive samplers to measure the activities of organic compounds in air, water and sediment.

Consequences and challenges of microplastics in the world's oceans

Dr. Joel Baker, University of Washington Tacoma, Tacoma, WA, USA

Abstract: Producing industrial intermediates and consumer products that are persistent in the environment inevitably leads to their global distribution throughout the world's oceans. The re is abundant evidence and numerous examples of this, including the well-told story of the 'global distillation' of semivolatile organic chemicals (*e.g.*, the 'dirty dozen' POPs). Materials susceptible to global transport are those that resist degradation and are poorly removed from mobile reservoirs (*i.e.*, the atmosphere and surface ocean water). Due to their chemical stability and near neutral buoyancy, it appears that microplastics meet these criteria, as supported by the increasing number reports documenting microplastics in remote marine environments. It is also now clear that microplastics may enter marine food webs, primarily through inadvertent ingestion, that components of the plastic may leach into seawater, and that other chemical contaminants can adsorb to microplastics. While parts of the story are emerging, the overall impact and consequences of marine microplastics has not yet been articulated. Significant scientific uncertainty remains, especially surrounding the potential biological impacts and the role of microplastics in controlling chemical contaminant exposure and cycling. For example, one might argue that microplastics scavenge pollutants from seawater into highly concentrated, easily ingested packages, resulting in enhanced exposure to marine organisms. Conversely, this 'packaging' can be viewed as a competitive 'protection', where the microplastic-bound pollutants are sequestered in a non-bioavailable form. Assessing the risk of marine microplastics depends on resolving these uncertainties.

Joel Baker, PhD holds the Port of Tacoma Chair in Environmental Science at the University of Washington Tacoma. He earned a B.S. degree in Environmental Chemistry from the State University of New York in Syracuse, and M.S. (1985) and Ph.D. (1988) degrees in Civil and Environmental Engineering at the University of Minnesota. Between 1988 and 2007, he was a member of the faculty of the University of Maryland Center for Environmental Science's Chesapeake Biological Laboratory. Dr. Baker's lab studies the transport of organic contaminants in the atmosphere and in surface waters, specifically atmospheric transport and deposition of organic chemicals, aerosol particle chemistry, the dynamics of contaminant transport in estuaries, and the exposure and transfer of bioaccumulative chemicals in aquatic food webs. He has co-authored over eighty papers on contaminant cycling in the Great Lakes, the Chesapeake Bay and coastal waters, and edited *Atmospheric Deposition of Contaminants to the Great Lakes and Coastal Waters* (SETAC Press, 1997). He was the lead author on a scientific review of PCBs in the Hudson River, a contributing author to the Pew Oceans Commission report *Marine Pollution in the United States*, and a member of the national Research Council's Committee on Oil in the Sea, chaired the New York/New Jersey Harbor Contaminant Assessment and Reduction Program's Model Evaluation Group, advised the European Commission on water quality modeling, and served on the Board of Directors of the Society of Environmental Toxicology and Chemistry. Dr. Baker is the Science Director of the Center for Urban Waters in Tacoma, WA and recently elected as chair of the Puget Sound Partnership Science Panel.

APPENDICES

APPENDIX A: WORKSHOP AGENDA

Tuesday, 9 September 2008

CARWEIN AUDITORIUM, KEYSTONE BUILDING, UNIVERSITY OF WASHINGTON TACOMA

08:30 Coffee and Registration

09:00 Opening remarks – *Dr. Pat Spakes*, Chancellor, University of Washington Tacoma, *Dr. Joel Baker*, University of Washington Tacoma, *Doug Helton,* National Oceanic and Atmospheric Administration, Marine Debris Program

09:15 Keynote Address – How concerned should we be about microplastics?
Dr. RC Thompson, University of Plymouth, Plymouth, UK

10:15 Break

SESSION I: Occurrence of small plastic debris in the marine environment

10:30 Fate of Plastics Debris in the Marine Environment
Dr. Anthony Andrady, Research Triangle Institute, Durham, NC, USA

11:15 Microplastics as accumulators and sources of persistent organic pollutants in marine food webs: how significant?
Dr. Alan Mearns, NOAA Office of Response & Restoration, Seattle, WA

12:00 Lunch

13:00 The oceanography, biology, and fisheries of the North Pacific
Dr. Mike Seki, NOAA National Marine Fisheries Service, Honolulu, HI, USA

13:45 Small Plastic Debris and Plankton: Perspectives from NOAA Plankton Sampling Programs in Northeast Pacific Ecosystems
Dr. Miriam Doyle, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA, USA

SESSION II: Impact of small plastic debris on the marine environment

14:30 Foolish Fulmars and their contribution to ecological quality
Dr. Jan A. van Franeker, Wageningen IMARES, Den Berg (Texel), THE NETHERLANDS

15:15 Break

15:30 Incidence of marine debris ingestion in seabirds from Midway Atoll and Heard Island
Dr. Heidi J. Auman, University of Tasmania, Hobart, Tasmania, AUSTRALIA

16:15 Ingestion of microplastics by marine invertebrates
Dr. Richard Thompson, University of Plymouth, Plymouth, UK

17:00 Translating scientific findings into action: California's response to plastics in the environment
Dr. Stephen Weisberg, Southern California Coastal Water Research Project, Costa Mesa, CA, USA

17:45 Adjourn – *Dr. Joel Baker*

18:30 Reception and Dinner
The Tacoma Club, Wells Fargo Plaza, 1201 Pacific Avenue, 16th floor

Wednesday, 10 September 2008

CARWEIN AUDITORIUM, KEYSTONE BUILDING, UNIVERSITY OF WASHINGTON TACOMA

08:00 Opening remarks – *Dr. Joel Baker*

Session III: Impacts of small plastic debris exposure to persistent organic pollutants

08:15 Effect of sorbent particulate amendments on PCB bioavailability in sediments
Dr. Upal Ghosh, University of Maryland Baltimore County, Baltimore, MD, USA

09:00 International Pellet Watch: Global distribution of persistent organic pollutants (POPs) in marine plastics and their potential threat to marine organisms
Dr. Hideshige Takada, Tokyo University of Agriculture and Technology, Tokyo, JAPAN

9:45 Microplastic-pollutant interactions and their implications in contaminant transport to organisms
Dr. Emma Teuten, University of Edinburgh, Edinburgh, UK

Session IV: Effect of oceanic small plastic debris on biogeochemical cycling of POPs

10:30 Role of microplastics on transport and fate of POPs
Dr. Rainer Lohmann, University of Rhode Island, Providence, RI, USA

11:15 Wrap-up: Consequences and challenges of microplastics in the world's oceans
Dr. Joel Baker, University of Washington Tacoma, Tacoma, WA, USA

12:00 Lunch Media Availability – Tacoma Room

Session V: Breakout Groups

1:00 Introduce breakout sessions
A. Sources (accumulation) and sinks (uptake) of plastics in the marine environment (GWP 212)
B. Importance of physical impacts (ingestion) vs. other impacts of microplastic debris (GWP 216)
C. Overall accumulation of microplastics in organisms, potential to bioaccumulate POPs (GWP 220)

1:30 Breakout groups discuss their perspectives on major questions

15:00 Break

15:30 Reconvene to discuss breakout group reports (Carwein Auditorium)

16:15 Discussion of future research initiatives

17:00 Closing Remarks and Adjourn Workshop – *Dr. Joel Baker*

Thursday, 11 September 2008

Session VI: Preparation of Workshop Proceedings (Cherry Parkes 103)

8:30 - 12:00 Steering Committee only

APPENDIX B: CHARGE TO BREAKOUT GROUPS

<u>Session V: Breakout Groups</u>

A. Sources and sinks of plastics in the marine environment

Lead*: Anthony Andrady
Rappateur: Nir Barnea
Participants: Miriam Doyle, Michael Seki, Dave Foley, Dominic Gregorio, Pete Dinger, Marcus Eriksen, Joseph Greene
Location: GWP 212

B. Effects of microplastic debris on marine organisms

Lead*: Richard Thompson
Rappateur: Kris McElwee
Participants: Heidi Auman, Jan van Franeker, Ashley Greene, LeeAnn Woodward, Beth Phillips, Doug Helton
Location: GWP 216

C. Role of microplastics in POP cycling and exposure

Lead*: Rainer Lohmann
Rappateur: Amy Merten
Participants: Alan Mearns, Shige Takada, Emma Teuten, Tara Conrad, Benjamin Applegate, Aja Reyes, Fung-chi Ko, Stan Phillippe
Location: GWP 220

<u>Charge to breakout groups</u>

1. Review white paper for any major omissions of published literature.

2. Identify key gaps in our current knowledge. Are there any products, techniques, or technologies required that are not currently available?

3. Describe potential research projects and best methods to achieve filling the gaps in research.

*The lead should be prepared to present the breakout group's collective thoughts to the workshop participants.

APPENDIX C: WORKSHOP PARTICIPANTS

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Appendix D: Group Photograph

International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris. Photo taken on the University of Washington Tacoma campus, 9 September 2008.

<u>From left:</u> D. Gregorio, E. Teuten, M. Eriksen, C. Morishige, B. Applegate, D. Foley, M. Doyle, E. Phillips, S. Weisberg, C. Arthur, H. Takada, R. Lohmann, U. Ghosh, R. Thompson, J. van Franeker, S. Phillippe, P. Dinger, J. Greene, M. Seki, F. Ko, A. Mearns, K. McElwee, J. Baker, N. Barnea, L. Woodward, A. Merten, D. Helton, H. Auman, A. Greene, A. Reyes

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