Proceedings of the Second Research Workshop on Microplastic Marine Debris

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PROCEEDINGS OF THE SECOND RESEARCH WORKSHOP ON MICROPLASTIC DEBRIS

November 5-6, 2010
University of Washington Tacoma, Tacoma, WA, USA

Courtney Arthur[1] and Joel Baker[2] (eds.)

[1] National Oceanic and Atmospheric Administration
Office of Response and Restoration
Marine Debris Program
Silver Spring, MD 20910, USA
and
I.M. Systems Group
Rockville, MD 20852, USA

[2] The Center for Urban Waters
University of Washington Tacoma
Tacoma, WA 98402, USA

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For copies of this document, please contact:
NOAA Marine Debris Program
N/ORR, SSMC-4
1305 East-West Highway
Silver Spring, MD 20910

www.MarineDebris.noaa.gov

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Preface

Welcome to the proceedings from the *Second Research Workshop on Microplastic Marine Debris*. The following quote from the proceedings of the 2008 *International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Debris* underscores the two main reasons for hosting a second workshop:

> 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. (Arthur *et al.*, 2009)

The science of microplastics has expanded in the two years between the first and second microplastics workshops hosted by NOAA and the University of Washington, yet the risk of microplastic particles to marine systems is still unclear.

The second workshop was intended to update microplastics science and take steps toward clarifying the risks of microplastics. Life cycles and impacts are important elements of the larger picture and are critical to an improved understanding of the risk of ecological harm from microplastics. This topic is inherently inter-disciplinary and attracts interest from scientists, policymakers, and public citizens. While these characteristics ensure a wide audience, they also create a complex environment for setting research agendas.

In this case risk assessment science provides a simplified backdrop for synthesizing data from various disciplines. The framework used in environmental risk assessment – defining known parameters of source, stressors, effects, and impacts – is simple and unbiased. This backdrop was used to synthesize known information and brainstorm additional information needed to begin a risk assessment. The workshop conveners agreed that – though microplastics have the potential for marine impacts –the magnitude of this threat is unknown. Thus, applying risk assessment techniques to microplastic pollution is both timely and critical.

To better address the threat, this second, invitation-only workshop convened approximately 40 scientists from various fields of research to update the state of the science through presentations and posters in sessions focused on the topics of measurement and occurrence of microplastics, effects of microplastics, and engineering and risk assessment principles. Four working groups were formed to lead participants through a risk assessment exercise. Major gaps were identified, most of which involved tying microplastic presence to measured effects and impacts on the environment and organisms.

This proceedings document is meant to guide the reader through main points of agreement and to outline key information gaps that were revealed. Additional research is needed to produce estimates of risk. As microplastics continue to be an emerging concern for scientists and the public, obtaining unbiased risk estimates is the best approach to inform management efforts.

Courtney Arthur Silver Spring, Maryland

Executive Summary

Summary of the Second Research Workshop on Microplastic Marine Debris

Courtney Arthur[1] and Joel Baker[2]

[1] National Oceanic and Atmospheric Administration, Marine Debris Program; and I. M. Systems Group
[2] University of Washington Tacoma, Center for Urban Waters

What risk do microplastics[1] pose to the marine environment? In order to answer this question, the current state of knowledge must be synthesized and assessed for important gaps. The *Second Research Workshop on Microplastic Marine Debris* brought together a diverse group of participants to share updated information on the measurement, occurrence, and effects of microplastics. In order to make meaningful progress on assessing the risk of microplastics to marine environments, the workshop was structured to begin the development of a conceptual model for an environmental risk assessment. By identifying knowns and unknowns in a conceptual model framework of sources, stressors, effects, and impacts, this workshop took concrete steps toward answering the question, "What risk do microplastics pose to the marine environment?"

I. Workshop Summary

A. Technical Sessions

The first session of speaker presentations discussed the issue of measurement and occurrence of microplastics in the environment. Without robust methods of measurement, it is not possible to obtain reliable estimates of occurrence and compare these estimates at large spatial scales. Study designs that facilitate global comparison are desired given the fluidity and connectedness of marine systems. Measurement of abundance is also needed before impacts to marine organisms can be quantified – it is necessary to accurately quantify the dose in order to measure the effect (Foster 2011). When available, sophisticated techniques such as flow cytometry may be useful in quantifying particles, and may be increasingly important when investigating nano-scale particles (Andrady 2011). Methods from the University of Washington described in Foster (2011) report thorough and relatively simple procedures for obtaining a gravimetric calculation. Microplastics abundance in some samples was as high as 10% by mass of suspended solids in water, with a mean in Puget Sound waters of approximately 1.8% showing temporal and spatial variation (Foster 2011; Baker et al. 2011). In the Atlantic Ocean, the Sea Education Association has shown correspondence between increased plastic concentration and converging surface currents, which could make plastics an unintended but useful tracer of large-scale current patterns (Law et al. 2011). There is not a strong trend in the concentration of surface water plastics in the North

[1] Microplastics are defined here as plastic particles smaller than 5mm (Arthur *et al*., 2009).

Atlantic over a 22 year time period despite increases in plastic production during this time, indicating that loss through fragmentation, sedimentation, ingestion, and deposition may be significant and should be quantified (Law et al. 2011). In order to facilitate global, regional, and local comparisons of quantity, mapping applications can be used to graphically display location and concentration data, which are important for risk assessment (Merten 2011).

The second session focused on potential stressors and effects of microplastics in the environment. Takada (2011) observed large variation in organic pollutant (eg, PCBs, PAHs) per pellet and fragment sampled, which the authors suggest is due to slow sorptive processes. This variation is important when assessing the risks associated with individual particles. Other presentations described ongoing experiments designed to determine the partitioning behavior of PCBs and additive-derived chemicals to common plastic polymers (Beckingham and Ghosh 2011; Kennish et al. 2011). A new study is assessing the toxicity of POP-dosed plastics in a feeding exposure experiment using Japanese medaka, *Oryzias latipes* (Rochman 2011). This session underscored that research in this field, while expanding, is still in the early stages especially regarding studies that determine the effects of microplastics and sorbed chemicals on the environment and organisms.

The final oral presentation was a brief engineering primer describing the basics of plastic behavior and degradation in the environment. The discussion reviewed the definitions and differences between “bio-based” and “bio-degradable” plastic polymers (Narayan 2011). A key message was that most biodegradable polymers are engineered to degrade in very specific composting conditions, and are thus not very likely to degrade in cold oceanic conditions. This could lead to an increase in fragmented plastic particles over time if inputs remain constant.

B. Working Groups

One purpose of this workshop was to delineate the sources, stressors, effects, and impacts of microplastics in various marine habitats. This combined information is needed to fully understand the environmental risk posed by small plastics. Here we focus on marine systems due to a number of concerns, including but not limited to stewardship of trust resources, the potential for harmful impacts, the resistance of plastics to degradation in marine waters, and the consideration that marine waters are often an unintended endpoint for solid pollution.

Each working group produced a list of known and potential microplastic sources, stressors, effects, and impacts for a single habitat. Considered habitats were marine gyres, coastal waters, estuaries, and urban waters. Working groups were asked to rank sources, stressors, effects, and impacts according to the following certainty levels: plausible, with enough data; plausible, with little supporting data; plausible, with no supporting data; and not mechanistically plausible. Very few groups determined any sources, stressors, effects, or impacts that were not mechanistically plausible. Rankings required subjective judgments that were not completely vetted for accuracy; thus, section II of this document was informed but not strictly guided by the ranked lists of sources, stressors, effects, and impacts.

Lists of sources, stressors, effects, and impacts were augmented by discussion among all workshop participants. There was high uncertainty surrounding many of the potential sources, stressors, effects, and impacts. Working groups disagreed about some certainty rankings but listed generally similar sources, stressors, effects, and impacts. Disagreement likely occurred due to the small body of microplastics research and the difficulty in evaluating the amount of supporting data. For example, it is difficult to determine how much information is needed to list "storm water" as a source of microplastics; there are few documented occurrences of this, but knowledge of storm water controls leads to the conclusion that this is a very likely source. Due to the small body of available research, the synthesis provided in section II combines all habitat types to highlight major trends. Complete notes are provided in Appendix B. It is expected that further research will improve the ability to rank the sources, stressors, effects, and impacts of microplastics.

II. Findings

While some new research has been completed since the *International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris*, many of the key information gaps are still present. Participants agreed that most of the progress in this field of research has focused on standardizing terminology and framing the issues (Arthur *et al.* 2009; Thompson *et al.* 2009; GESAMP 2010), developing new methods for assessing quantities of microplastics in the environment (Foster 2011; Andrady 2011), and energizing larger scientific and public audiences that are keen to address the issue. Interestingly, breakout groups had the most certainty when discussing sources of microplastics. The list of impacts of microplastic marine debris was relatively short and was overwhelmingly concentrated in the "plausible, with no supporting data" category (Appendix B). Some of these impacts are key to determining the overall risk of microplastics to marine systems, and include specific impacts on biodiversity, organism health, and fisheries. Research should focus on the information gaps documented in these proceedings to move towards completed conceptual models for environmental risk assessments.

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

Points of agreement

There are many potential sources of microplastics. Given the connectivity of marine ecosystems and the potential for long-range transport of microplastics, a complete source list must encompass all land- and ocean-based sources. All listed sources (see Appendix B) are plausible, but most have not been quantified. It is difficult to procure data on the quantity and frequency of microplastic inputs to the marine ecosystems. Although sources of microplastics are better known than stressors, effects, and impacts, there are still quite a few information gaps.

Major sources were categorized as waste management, ocean dumping, effluent, and litter from land. Waste management is a broad category and includes specifics such as urban runoff, rural and agricultural runoff, storm water debris, fragments of debris already in the environment, and aquaculture debris. Dumping includes intentional and accidental releases. Groups distinguished litter from dumping by qualifying that litter was mainly from land whereas dumping occurred offshore. Effluents from waste water treatment facilities could contain microplastics, depending on the filtering processes.

To fully characterize microplastic inputs, it is necessary to have a very good understanding of larger plastic inputs to marine systems, as these pieces will be subjected to degradation processes and will eventually break into micro-scale particles. Better knowledge of the rates of fragmentation and degradation of larger plastic pieces to microplastics is also required. Knowledge of realistic degradation timeframes will allow estimation of the quantity of larger plastics that can be expected to fragment into microplastics on an appropriate temporal scale.

Information gaps

All of the potential sources of microplastics listed in this document are plausible mechanistically. However, the quantification of different source contributions to the marine debris problem has been investigated for decades without much traction. The difficulty is two-fold. Monitoring programs, if they are in place, cannot distinguish the mechanism(s) by which a microplastic particle arrived at a coastal beach (Cheshire *et al.* 2009; Takada 2006). Secondly, there is little practical way to estimate accidental and illegal dumping activities that take place offshore versus debris that originates on land (Criddle *et al.* 2008). Given the number of times that sources relating to poor waste management were mentioned by working groups, research that delineates the inputs of microplastics from runoff is an important information gap to fill. Each habitat working group cited effluents in some manner; the ubiquity of that concern identifies effluent concentrations as another important knowledge gap.

Key Issue #2. Stressors caused by microplastics

Points of agreement

Workshop participants were most concerned with the potential for microplastics to sorb organic pollutants in the environment and to release these and other additive chemicals to the marine environment and organisms. Another stressor mentioned by all breakout groups was the potential for microplastics to serve as additional substrate for invasive or harmful species transport. Other stressors discussed include a wide range of potential physical stressors of microplastics on marine environments and habitats, as well as the physical stress of plastics on organisms, mainly due to ingestion. Examples of physical stressors on the environment include the shifting physical properties of sediments, changes to biogeochemical cycles, and decreased light penetration to the photic zone.

Information gaps

A few studies have examined the ability of microplastics to cause stress to marine systems (Endo *et al*. 2005; Browne *et al*. 2008; Teuten *et al*. 2009; Gouin *et al.* 2011). To date, most studies on the potential for microplastics to act as chemical stressors have focused on only one chemical or one polymer. Research has confirmed that plastics can serve as a vector for chemicals to certain marine environments, and that plastics can serve to introduce “rafting” organisms to new areas. However, the *extent* of these stressors has largely not been quantified for marine environments.

Key Issue #3. Effects of microplastics

Points of agreement

Groups agreed that there is potential for microplastics to have demonstrable effects on marine systems. However, there are little or no available data that verify and quantify these potential effects. Discussions centered on broad ecosystem-level effects, such as changes to habitat and community structure, biomagnification of microplastics resulting in enhanced uptake of sorbed chemicals, and changes to organism behavior and function. Although each of these topics is important, biomagnification was mentioned the most as a topic that has not been sufficiently quantified and merits further research due to the implications for potential fisheries and human health effects.

Information gaps

As noted above, the effects of microplastics are largely assumed but undocumented. In other words, we do not yet understand how – and if – the potential stressors listed here are having quantifiable effects on marine systems. It is important to note that the term "effect" is neutral; effects may be positive, negative, or a combination. Studies are needed that quantify the presence or absence of specific, measurable effects on the marine environment. Some effects listed as having enough data (see Appendix B) refer to either larger plastic debris or specifically to chemicals that may be associated with microplastics (*e.g.*, Derraik 2002; Gregory 2009; Talsness et al. 2009). Studies have not yet tied *microplastics* to any measurable effect on the environment or organisms.

Key Issue #4. Impacts of microplastics

Points of agreement

Participants agreed that virtually every plausible impact of microplastics lacks supporting data. Here, "impact" can be thought of as the combination of effects to a number of assessment endpoints (*e.g.*, valued ecosystem services) under management consideration. Many of the possible impacts, such as declines in fisheries due to mortality, declines in beach use due to habitat degradation, and degraded water quality are inherently difficult to quantify. These potential impacts will need to be assessed on local and regional scales, as appropriate; these location-specific assessments will be useful for risk assessment purposes, as impacts will likely vary based on a variety of environmental factors and conditions. At present, no studies exist that quantify the impacts that microplastics have on marine ecosystems.

Information gaps

Determination of all key stressors and effects must occur before impacts are quantified. Since the topic of microplastics is an emerging field, there is very little information on the environmental impacts of these particles. This is to be expected. As information on key stressors and effects is compiled, cumulative and location-specific impacts may be determined.

III. Next Steps

The diverse group of scientists at this workshop discussed and brainstormed the sources of microplastic particles, and the stressors, effects, and impacts that could possibly be attributed to this type of marine debris. In order to provide risk estimates for localities and/or watersheds, much more information is needed to elucidate the impact of microplastic particles. Future research should focus on the information gaps outlined in this document with a special focus on the effects of microplastics, as this piece of the puzzle is crucial to predicting risk and developing a better understanding of the potential environmental hazards posed by synthetic polymers. To summarize some of the main dialog at the meeting, it was widely agreed that determining the contributions of microplastics from effluents and runoff would be a reasonable next step to address microplastics sources. Sorption and the potential chemical interactions caused by microplastics, and the extent to which this could vary on spatial scales, was discussed as a potentially crucial stressor. The potential for biomagnification of particles, and the subsequent food web implications, was identified as an important gap in understanding the effects of microplastics. Lastly, the impacts of microplastics are a combination of the effects measured on endpoints that are important to society – for example, on an ecosystem service. Cumulative impacts integrate effects, and thus are difficult to study without a better understanding of effects and stressors. For this reason, short-term research should focus on quantifying source contributions from effluents and runoff, developing research into the stressors of microplastics, especially relating to chemical sorption, and assessing the potential for biomagnification of microplastic particles and associated chemicals.

Though there are many gaps in this emerging field of research, it is undeniable that the dialog on microplastic debris has increased in the past several years. Microplastic particles have become elevated in the public mind as a concern, and it is important that scientists provide the best information possible regarding the potential hazards and solutions. Forward movement in state of the science over the past few years is encouraging; for example, robust methods were developed to accurately measure particle abundance and composition, and there is a growing body of high-quality research completed by an increasing pool of partners with common goals. Standardized procedures and partnerships are valuable tools to elucidate the risks of microplastic particles and to develop solutions for this topic of emerging concern.

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Abstracts

Session 1: Measurement and occurrence of microplastics in the environment.

Presentation.

Measuring microplastics in the marine environment

Gregory D. Foster

Department of Chemistry and Biochemistry, George Mason University, Fairfax, VA

It has been widely reported that plastic debris is abundant in world's oceans. Most of the debris reported to date is of large size (macroplastic) and is visible as floating material on the ocean surface. Large plastic debris fragments into smaller bits, which may be hazardous to microscopic marine life. What are the health implications of microplastics debris to marine organisms? This emerging question has not been addressed because there are not reliable methods to quantify small plastic debris in marine environments. The goal of our study is to develop standarized sampling and quantification methods to document the abundance of microplastics in seawater and in marine sediments. These methods are designed to be robust, reproducible among laboratories, relatively simple, and able to be incorporated into existing marine monitoring programs. Specifically, we aim to develop methods compatible with on-going plankton and sediment quality surveys. Methods have been developed to quantify microplastics (size range from 5 mm to 0.33 mm) in the marine environment to determine their abundance and distribution in water, sediments and beach sands. The analysis method involves a peroxide oxidation followed by gravimetric analysis. The method has been used to measure microplastics in marine samples, primarily in the Puget Sound (Washington) region. The initial measurements have shown that microplastics can occur at concentrations as high as ~10 percent by mass in suspended solids in water.

Session 1: Measurement and occurrence of microplastics in the environment.

Presentation.

Concentration of Marine Microplastics in the Puget Sound

Joel E. Baker[1], Gregory Foster[2], Julie Masura[1], and Christopher LaRocque[1]
[1]Center for Urban Waters, University of Washington Tacoma, 1900 Commerce Street, Tacoma, WA
[2]Department of Chemistry and Biochemistry, George Mason University, Fairfax, VA

Marine microplastic debris are particles composed of plastic polymers with dimensions between 0.33 and 5 mm. Early reports of pre-production resin pellets in Northwest Atlantic waters suggested losses during manufacturing or shipping may supply plastics to the oceans. Since those initial studies in the 1970's there have been very few reports of microplastics in the oceans. Recently, we have developed standarized protocols to sample and analyze microplastic particles in surface waters, sediments, and beach sands. The goal of our study is to make the first systematic characterization of microplastics in the Puget Sound estuary. Nets with 0.33 mm mesh size were towed horizontally through surface waters using standard plankton sampling conditions and tow durations in several locations throughout the Puget Sound, ranging from highly urbanized, stormwater-dominated embayments to relatively unimpacted open waters. Samples were oxidized with hydrogen peroxide to remove marine carbon. Samples from nearshore that contained more recalitrant terrestrial carbon were oxidized with a sulfuric acid/potassium dichromate solution. After oxidation, inorganic solids were separated from the plastic by density gradient and the remaining solids were isolated and weighed to determine the total quantity of microplastic mass. Concentrations of solid material collected from Puget Sound surface waters in the 0.33 to 5 mm size range vary widely from 1.5×10^{-5} to 0.11 g/m^3, and the geometric mean plastic content of this material is 1.8% (range 0.008 to 27% plastic). Strong temporal and spatial gradients indicate a significant source from urban stormwater.

Session 1: Measurement and occurrence of microplastics in the environment.

Presentation.

Plastic Marine Debris in the Atlantic Ocean and Caribbean Sea

Kara Lavender Law[1], Skye Morét-Ferguson[1],Giora Proskurowski[1,2], Nikolai A. Maximenko[3], Christopher M. Reddy[4], Emily Peacock[4], Jan Hafner[3]

[1]Sea Education Association, Woods Hole, MA; [2]University of Washington, Seattle, WA; [3]University of Hawaii, Honolulu, HI; [4]Woods Hole Oceanographic Institution, Woods Hole, MA USA

Undergraduate students and faculty scientists at Sea Education Association (SEA) have measured floating plastic debris for more than 20 years in the western North Atlantic Ocean and the Caribbean Sea as part of the SEA Semester program. Since 1986, more than 100,000 pieces of pre- and post-consumer plastic pieces have been collected between Newfoundland and Venezuela and from the U.S. east coast to 40°W. Comparison to oceanographic data shows a remarkable correspondence between the high plastic concentration and the large-scale converging surface currents that act to concentrate and retain floating debris in the western subtropical gyre. This striking relationship also illustrates how floating debris acts as a valuable tracer of large-scale surface current patterns.

An analysis of temporal trends in plastic concentration from 1986-2008 showed no strong trend in plastic concentration in the Atlantic accumulation region during a time of strongly increasing global plastic production and discarded plastic in the U.S. municipal waste stream. Loss terms likely include fragmentation, sedimentation, ingestion, and shore deposition, although none can be sufficiently quantified at this time.

Observed plastic pieces were typically fragments millimeters in size that were irregularly-shaped, weathered, and from unidentifiable sources, with the exception of fishing line and industrial resin pellets. Laboratory analysis revealed that more than 98% were less dense than seawater, with properties consistent with high and low density polyethylene and polypropylene. Other common consumer plastics denser than seawater were not observed. Observations suggest that the material density of plastic marine debris increases over time, perhaps due to bioaccumulation or to chemical degradation.

Session 1: Measurement and occurrence of microplastics in the environment.

Presentation.

Approaches towards solving the problem of microplastics in the environment at IVM

Heather Leslie, Dick Vethaak, Nicolien van der Grijp, Roy Brouwer, Bert van Hattum, Michiel van Drunen, Frans Berkhout, Jacob de Boer

IVM INSTITUTE FOR ENVIRONMENTAL STUDIES

In the Netherlands, the 'plastic soup' problem has been receiving growing attention from government bodies, scientists, NGOs, the plastics industry, architects, artists and the media. The Dutch government has urged UNEP and the EU Environment Council to put plastic soup on the political agenda. In addition to the concern for large plastic debris, microplastics are an important parameter in the implementation phase of the EU Marine Strategy Framework Directive 2008/56 (MSFD), which builds upon work performed in the OSPAR program. Creating sound policies for tackling the microplastics issue depends to a great extent on access to relevant scientific information. Broadly speaking, few specific and targeted approaches have been developed for this emerging issue, although there are a range of approaches by state and non-state actors at different geographical levels that may have a positive impact on, for example, the composition of plastics, plastic waste reduction, effective environmental monitoring. To study this challenging environmental problem, IVM has formed an interdisciplinary research team lead by Prof. Dr. Jacob de Boer in which chemists, ecotoxicologists, economists, policy experts, environmental law experts and others are involved. The aim is to come to understand and contribute to solutions to the microplastics problem by combining and linking approaches from different disciplines. Elements include: evaluating the extent of microplastic pollution and its ecological impact in the environment, identifying the relationships between microplastics and human welfare, investigating ecosystem services (provisioning, regulating, cultural and supporting services) that are affected by microplastics, exploring options and costs of mitigation, conducting legal and institutional analyses, studying how the problem is perceived and framed by different actors, facilitating participatory dialogues (which can include exercises such as backcasting), and analysing governance mechanisms and political strategies to solve this problem. IVM aims to work with its partners to remove knowledge barriers and produce the necessary supporting information to both state and non-state actors to enable them to act effectively towards taking plastic soup off the global menu.

Session 1: Measurement and occurrence of microplastics in the environment.

Presentation.

Web-mapping applications to improve data sharing and communication for micro-plastic transport

Amy A. Merten

National Oceanic and Atmospheric Administration, Office of Response and Restoration, Seattle, WA

The presentation will use the Deepwater Horizon Oil Spill as a case study for applying open source web-mapping technology to provide a common platform for data sharing, visualization, and decision-making. ERMA® - the Environmental Response Management Application - currently provides the Common Operational Picture for decision-makers responding to the Deepwater Horizon disaster and provides the public access to real-time information on the spill progress and access to data sets. The presentation will highlight data types and tools that are relevant for marine debris micro-plastic mapping, transport, and data sharing.

ERMA is a website that incorporates static base layers along with real-time streams of data (*e.g.*, weather, tides, ship tracking data, etc.) into a fast, user-friendly Geographic Information System (GIS) that is accessible to multiple locations. ERMA enables a user to quickly and securely upload, manipulate, export, and display spatially referenced datasets, resulting in high impact and fine resolution visualization of integrated data for solving complex environmental response and resource issues. ERMA was jointly developed by the University of New Hampshire and NOAA's Office of Response and Restoration. For more information, see http://gomex.erma.noaa.gov.

Session 1: Measurement and occurrence of microplastics in the environment.

Presentation.

Plastic Debris and Toxin Releases in Oceans off of California's Coast

Joseph P. Greene

Department of Mechanical Engineering and Sustainable Manufacturing, California State University, Chico

Plastics comprised the majority of collected waste in worldwide beach cleanups in 2006, 2007 and 2008. In California, the five most common plastic debris items on beaches are cigarette filters, food wrappers and containers, beverage caps and lids, bags, and food service items, *e.g.*, cups, plates, and cutlery. The majority of plastic items are made from four common plastics; polyethylene, polypropylene, polystyrene, and PET, accounting for 75% of the plastic debris. Pre-production plastic pellets also account for significant amounts of plastic in the oceans from storm run-off of industrial areas. The fate of plastics in the oceans can lead to fragmentation and result in slurry of plastic particles that can degrade and release toxic chemicals such as phthalates, flame retardants, BPA, antimony oxide, heavy metal inks, and styrene monomer as the plastics break down. Plastics can accumulate toxins floating in the oceans from persistent organic pollutants (POPs). POPs can include DDT, hexachlorobenzene, polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons, among others.

Session 1: Measurement and occurrence of microplastics in the environment.

Presentation.

Using flow cytometry to detect micro- and nano-scale polymer particles

Anthony L. Andrady

Department of Chemical and Biomolecular Engineering, North Carolina State University, Raleigh, NC 27695

A need exists to reliably quantify the microplastics in the marine environment. Fluorescence techniques that use a lipophilic dye might be successfully used to detect these using optical microscopy. Flow cytometry can be used to observe the dyed microplastics easily and might even allow quantification. However, the nanoscale particles that are generated along with microparticles also need to be eventually quantified. The potential introduction of nanoscale polymer particles into the marine environment can have potential adverse effects on marine organisms. These smaller particles need to be reliably quantified as well.

Session 1: Measurement and occurrence of microplastics in the environment.

Poster.

Marine Litter around the UK

T. Maes[1], M. Nicolaus[2]

[1]Cefas / EQT; [2]Cefas

Marine pollution represents one of the most significant environmental problems facing mankind. Over the past decades quantities and types of marine litter went up dramatically following the trends in use. The accumulation of synthetic debris in marine and coastal environments is a result of the intensive and continuous release of highly persistent materials. The distribution and abundance of marine litter on the seabed has been investigated on the back of existing trawling cruises around the UK, more specific the ICES International Bottom Trawl Surveys (IBTS) , the UK Clean Safe Environmental Monitoring Programme (CSEMP) and recently also on an ICES stock assessment survey (Q1SW) over a time period from 1992 up till 2010. This study is one of the first valuable contributions to assess the different types and quantities of offshore marine litter in North European waters and may eventually be used to determine where possible harm from marine litter may arise. It clearly shows the distribution and accumulation patterns in North European waters, particularly around the UK. There is a considerable geographical variation in abundance, ranging from 0 to 3224 pieces of debris per km2. In most stations sampled, plastic (mainly bags and bottles) accounted for a very high percentage (more than 38%) of total number of debris, and accumulation of specific debris was commonly observed. In general the results indicated widespread distribution of marine litter on the seabed of the North Sea, especially plastics.

Session 1: Measurement and occurrence of microplastics in the environment.

Poster.

Microplastic Accumulation on Sandy Puget Sound/Northwest Straits Beaches – A multi-partner, citizen science study lead by the Port Townsend Marine Science Center

Jen Kingfisher

Marine Program Educator, Port Townsend Marine Science Center

DESCRIPTION: Port Townsend Marine Science Center staff and volunteers, along with partnering community groups have biannually sampled beach sediments from sandy beaches around Puget Sound and the Northwest Straits since 2008. At each beach, three 7.5 liter samples of sediment were collected, sieved to create two size classes (a 1-5 mm , and a >5 mm), and then sorted for marine debris. The debris was further sorted by type, counted, and weighed. Each beach was assigned geomorphological characteristics such as fetch length, drift cell properties, obstructions and size of backshores. While our results showed high variability, they suggest that beaches with obstructions and long south fetches are important characteristics in debris accumulation.

Session 1: Measurement and occurrence of microplastics in the environment.

Poster.

Testing standardized field methods for analysis of marine debris on shorelines and in coastal surface waters

Sherry M. Lippiatt, Sarah E. Opfer, Courtney D. Arthur, and Lisa M. DiPinto

National Oceanic and Atmospheric Administration, Marine Debris Program

The issue of marine debris was first recognized a half-century ago, yet a comprehensive assessment of man-made persistent debris on shorelines and in coastal waters does not exist. Scientific monitoring of marine debris is necessary in order to understand the source, distribution, abundance, movement, and impact of debris on national and global scales. Standard monitoring methods allow for the comparison of the spatial distribution and temporal variability of debris at a given location as well as regional characterization according to land use. The NOAA Marine Debris Program has developed standardized, statistically valid methodologies for monitoring the abundance and density of debris on shorelines and in coastal surface waters. Information presented will include preliminary sampling efforts as well as refined methodologies. On rocky or sandy shorelines approximately 100 m in length, a subset of five meter-wide transects from water's edge to the back of the shoreline are visually sampled for macro-debris (> 2.5 cm) and surface sand samples are collected for micro-debris (≤ 5 mm) analysis. Associated surface water trawls include at least three 0.5 nautical mile-long transects using a 0.333 mm manta net. Net contents are sieved through a 5 mm screen onto the 0.333 mm net to isolate the micro-debris fraction (0.333 mm < x < 5 mm). Shoreline and pelagic macro-debris samples are assessed based on material category (*i.e.* plastic, metal, glass, etc.). Micro-debris samples are stored for future analysis while extraction methodologies are being developed. These methodologies are necessary for developing an ecological risk assessment for marine debris, as well as measuring the spatial distribution and temporal variability over large scales.

Session 1: Measurement and occurrence of microplastics in the environment.

Poster.

The Impact of Wind Stress on the Concentration of Plastic Debris in the Open Ocean

Giora Proskurowski[1,2*], Kara L. Lavender Law[1], and Skye Moret-Ferguson[1,2], and Christopher M. Reddy[2]

Millimeter-sized plastic debris in the world's oceans is subject to the physics of mixing in the surface boundary layer. While the density of plastic debris is generally less than the density of seawater, the resulting upward buoyancy force can readily be overcome by turbulent mixing due to wind forcing and surface heat loss. The extension of this logic suggests that as the wind stress increases, plastic debris can be mixed downwards meters to 10's of meters to the base of the boundary layer. As a fraction of the total plastic debris is likely mixed down into the water column under many environmental conditions, surface layer (neuston) net tows (*e.g.* Sameoto, Manta, MARMAP) that sample the upper ~20 cm cannot account for all the plastic mixed throughout the surface boundary layer.

On an annual basis since 2003, the Sea Education Association (SEA) has conducted plastic marine debris research on a cruise-track from Hawaii to the west coast of North America. These expeditions occur in the early summer (May-June-July), and typically include twice daily neuston net tows over the course of the month-long expedition. Coincident with each sample tow are continuous shipboard measurements of true wind speed, air temperature, surface water temperature, and hourly measurements of relative humidity. Results show persistent high concentrations of plastic debris in two areas, within a band north of Hawaii between 26-28°N, and within a large region of east and north of Hawaii between 33-40°N and 136-155°W. Preliminary results clearly show that the highest measured plastic concentrations correspond with wind speeds of less than 15 knots. The results from a handful of experimental sampling efforts where a surface net and a net submerged 3-5 meters below the surface were towed simultaneously showed that up plastic concentrations below the neuston layer are up to 25% of the surface concentrations. A basic understanding of the relationship between wind stress and the distribution of plastic debris dispersed throughout the boundary layer is important in determining the total plastic debris in the world's oceans, as the true amount is undoubtedly higher than the value calculated from neuston tow observations.

Session 2: Effects of microplastics on the environment.

Presentation.

Organic pollutants in plastic fragments and resin pellets.

Hideshige Takada

Tokyo University of Agriculture and Technology, Tokyo, JAPAN

Analytical results on hydrophobic organic pollutants (*e.g.*, PCBs, PAHs) and additive-derived pollutants (*e.g.*, nonylphenol, PBDEs) in plastic fragments collected from open ocean (*e.g.*, central pacific gyre), remote coast (*e.g.*, Costa Rica), and urban coast (*e.g.*, Los Angeles, Tokyo) will be presented. Plastic resin pellets were also analyzed for the remote and urban beaches. A good correlation was observed in PCB concentrations between plastic fragments and the pellets. This indicates that International Pellet Watch tells us potential chemical risk associated with marine plastic fragments. Both for the plastic fragments and pellets, large piece-to-piece variations in the concentrations of the hydrophobic pollutants were observed. Sporadic high concentrations of the hydrophobic pollutants were detected among the fragments and pellets from the individual locations. This variation can be ascribed partially to slow sorption/desorption processes. This is unique and different from the case of sediment particles (*i.e.*, conventional vector of transport of POPs). Slow sorption/desorption and non-uniform distributions of organic contaminants (*i.e.*, sporadic high concentrations of hydrophobic organic pollutants) should be taken into risk assessment of hydrophobic pollutants transported by marine plastics. Detection of additive-derived chemicals (*e.g.*, nonylphenol and PBDEs) in the open ocean plastic fragment is another point to be considered on the risk assessment. Normally such additive-derived chemicals are not transferred to higher-trophic-level-organisms (*e.g.*, seabirds) through marine food web due to metabolism. On the other hand, marine plastics can bring the additive-derived chemicals directly to the higher predators.

Session 2: Effects of microplastics on the environment.

Presentation.

Polychlorinated biphenyl partitioning in common plastics and comparison of levels in water, marine plastic debris, and fish lipids in the Chesapeake Bay

Barbara Beckingham and Upal Ghosh

Department of Civil & Environmental Engineering, University of Maryland Baltimore County

Plastics are known to accumulate hydrophobic organic compounds from the water phase. Therefore, marine plastic debris may pose a potential harm to aquatic ecosystems as these materials are weathered into smaller fragments and accumulate environmental contaminants of concern while in circulation. Microscopic plastic particles have been found to be widespread in pelagic and sediment environments since the 1970's and are known through field or laboratory observations to be ingested by many different classes of aquatic organisms, including deposit- and filter-feeding invertebrates. Recent research has identified a potential hazard to aquatic ecosystems from the transport and exposure of toxic chemicals associated with plastic debris; however, significant gaps exist in understanding the extent of this potential risk.

In the present study, we measure the solid-water partitioning of ~50 PCB congeners, ranging from di to hexa-chlorinated, to common marine debris materials, including polypropylene (PP), polyethylene (PE) and polyethylene terephthalate (PET). Solid-water PCB partitioning coefficients for each plastic followed a linear relationship with K_{ow}. Values for PP and PE were similar, and were also on the same order of magnitude as partitioning coefficients cited in the literature for zooplankton and phytoplankton. Partitioning coefficients for PET were ~2 log units lower than those measured for the other plastics; however, this may reflect under-equilibration or analytical artifact. We also report the contaminant load on plastic pellets collected from the shoreline on the upper reaches of Chesapeake Bay and the Inner Harbor of Baltimore, MD, and relate the PCB concentrations found on pellets in Baltimore to measured aqueous concentration and to tissue concentration of white perch collected by a fish monitoring program by using the calculated partitioning coefficients and literature lipid partitioning relationships.

Ongoing work is investigating the partitioning behavior of PCBs to other common plastic materials, such as nylon fishing line, the abundance of various pesticides on collected plastic pellets and the digestive bioavailability of contaminants associated with plastics.

Session 2: Effects of microplastics on the environment.

Presentation.

Marine Plastic Debris: A Source of Toxins in Marine Animals

John M. Kennish[1, 2], Shareen Ali[2], Ben Applegate[2] and Birgit Hagedorn[2]

[1]Department of Chemistry; [2]Applied Science, Engineering and Technology Laboratory (ASET), University of Alaska Anchorage 3211 Providence Drive Anchorage AK 99508.

This study is designed to provide basic knowledge for evaluating the toxicity of plastics in marine wildlife which result from the adsorption of toxic substances from marine debris. Additionally, the exposure to additives present in the plastics after ingestion by marine organisms is being investigated. While some plasticizers have already been found in the marine environment, the connection between plastic debris ingestion and toxic levels in marine organism has not been investigated. We are performing leaching and adsorption-desorption experiments using solvents that mimic digestive system of marine organisms. The experiments are setup in vitro under controlled conditions and are adequate to evaluate sorption-desorption and dissolution equilibrium and kinetics of the toxic substances sorbed and bound in plastic debris.

For the analysis of the sorption kinetics of PAHs, we have chosen to use a flow through column experiment. This system consists of a reservoir of artificial seawater containing phenanthrene, a liquid chromatography pump system, column cooling compartment, and column containing our plastic of interest, a flow through fluorescence detector, and a fraction collector. Cleaned plastic resin powder was loaded as slurry into a liquid chromatography column. We saturated the flow through system with our phenanthrene – artificial seawater solution by recirculation with the column removed, paying close attention to the concentration of phenanthrene in our reservoir and adding additional phenanthrene as needed to maintain our concentration. After the system had equilibrated, the column was reconnected to the system and maintained at 10°C in the thermostatically controlled column compartment. The feeding solution was pumped through the thermostated column at a flow rate of 0.5 ml/min using the HPLC pump. The outflow was monitored with a fluorescence flow through detector and fractions were collected every 30 minutes using a fraction collector. The concentration of phenanthrene in the fractions was analyzed using a fluorescence spectrometer. We are currently running the first plastic, unplasticized PVC (uPVC). Plastics with sorbed compounds will be prepared using the information determined by the sorption kinetics.

Desorption kinetics of the sorbed compounds for the four plastic types by Instant Ocean, simulated gastric and intestinal fluid solutions will be determined by adding the prepared plastic resin pellets to the simulated solutions and agitate at constant temperature.

Marine tissue samples are homogenized and spiked with surrogate standards and extracted using pressurized fluid extraction. A solid phase dispersive method was used to separate the phthalates from interfering substances with good recovery. Analysis of the phthalates is being completed using LC MS/MS equipped with an atmospheric pressure photo ionization source (APPI). Analysis of clams, halibut, salmon and marine birds resulted in the observation of low part per billion concentrations in most samples.

Session 2: Effects of microplastics on the environment.

Presentation.

Occurrence of Small Plastic Debris in San Diego Beaches and Their POP Content and Toxicity Assessment

Eunha Hoh
Graduate School of Public Health, San Diego State University, San Diego, CA

A preliminary study was conducted in order to gain insight into the marine debris issue that exists in the San Diego area including examination of the abundance as well as the presence of persistent organic pollutant (POP) content of small plastic debris found on local beaches. Results of this study will be presented as a main subject. In addition, preliminary toxicity data of dietary exposure experiment of plastics with the Japanese fish, medaka, will be introduced.

Session 2: Effects of microplastics on the environment.

Presentation.

Novel Techniques and Methods for Characterization of Environmental Pre-Production Resin Pellets

Neal, A.[1*], Randall, M. [2,6*], Raymond, E.[3], Figueroa, D.[4], Gonsior, M.[2], Gassel, M.[5], Coleman, H.[4], Argyropoulos, N.[2], Hume, C.[6], Steuerman, D. [7], Leftwich, B.[8]

[1]Blue Ocean Sciences; [2]Jet Propulsion Laboratory – Caltech/NASA; [3]Monterey Bay Aquarium Research Institute;[4] Bren School of Environmental Science and Management, University of California, Santa Barbara; [5]California Environmental Protection Agency, Office of Environmental Health Hazard ; [6]Project Kaisei; [7]Department of Chemistry, University of Victoria; [8]University of California at Santa Barbara, Department of Archeology

Marine debris is a multi-faceted problem that includes interactions with everything from environmental toxins, the world's carbon cycling systems, ocean surface chemistry, fine minerals deposition, and nano-particles. However, research on this significant environmental pollution problem has not been able to keep up with the scope of the issue. On the S/V Kaisei cruise in 2009 we covered over 3,000 nautical miles and sampled over 102,000 m3 of the first 15cm of the water column to investigate marine debris accumulation, distribution, physical characteristics, and ecological consequences of marine debris concentrated in the Subtropical Convergence Zone of the North Pacific Gyre. Here we will present data on the material degradation and the associated biofilm lattice on the environmental pre-production resin pellets collected on the S/V Kaisei cruise. We will demonstrate how the use of established and novel techniques of Fourier transform infrared spectroscopy (FT-IR), scanning transmission electron microscopy (STEM), environmental scanning electron microscopy (ESEM), and gas chromatography-mass spectrometry (GC-MS), Spectroscopic Organic Analysis, and ArcGIS mapping systems can be utilized to study possible mechanisms of material weathering of synthetic polymers in deep ocean environments and identification of POP's association with them. These new techniques are highly transferable to many studies on material biofilm interactions in the environment.

Session 2: Effects of microplastics on the environment.

Presentation.

Lone Ranger Mission: Testing The Latest Advances of Marine Debris Monitoring Techniques, New Methodologies, and Environmental Sensing Technologies

Andrea Neal[1*], Raymond, E.[2*], Randall E. Mielke[3], Figueroa, D.[4], Gonsior, M.[1]; Coleman, H.[5]; Stam,C.[2], Nadeau, J.[6], Lane, A.[7], Bhartia, R.[3,8], Sheavly, S.[9]

[1]Blue Ocean Sciences; [2]Monterey Bay Aquarium Research Institute; [3]Jet Propulsion Laboratory – Caltech/NASA; [4] Bren School of Environmental Science and Management, University of California, Santa Barbara; [5]PACMARA ; [6]Department of Biomedical Engineering, McGill University; [7]PDSi, inc, [8]University of Southern California, Environmental Studies and Earth Sciences; [9] Sheavly Consultants

In January 2011, the Blue Ocean Sciences (BOS) team and our National Aeronautics and Space Administration (NASA) partners crossed the Atlantic on The Schmidt Foundation Research Group R/V Lone Ranger to explore the North Atlantic Gyre, and the Sargasso Sea, exploring approximately 3,000 nautical miles of critical ocean environments. Marine debris is a multifaceted problem that includes interactions with everything from environmental toxins, the world's carbon cycling systems, ocean surface chemistry, fine minerals deposition, and nanoparticles.

However, research on this significant environmental pollution problem has not been able to keep up with the scope of the issue since some of the first studies published in Science in 1972 by Edward Carpenter. During the Lone Ranger Mission, eight senior level scientists from NASA and BOS tested out the latest advances in remote sensing systems, imaging technologies, and monitoring methodologies, and compared these to traditional sampling techniques. These studies will help in the development of our understanding of marine debris interactions and development of new techniques for assessment of marine debris accumulation.

Session 2: Effects of microplastics on the environment.

Poster.

"Trash is not food!: consequences of ingestion of marine plastic debris deployed in the San Diego Bay to a medaka fish model, *Oryzias latipes*"

Chelsea Rochman

Joint Doctoral Program in Marine Ecology/Ecotoxicology, SDSU/UC Davis

Marine plastic debris (MPD) has not only become a serious environmental issue, but a largely popular topic of discussion in recent years. One of the 'so what?' questions often raised is, "how is this plastic debris harming marine organisms?". Unfortunately, beyond mechanical effects, the answer is often "we don't know." MPD not only carries toxins such as BPAs and phthalates from the manufacturing process, but also adsorbs and accumulates Persistent Organic Pollutants such as PCBs, organochlorine pesticides, and PAHs among others present in surrounding waters. It is currently known that many marine organisms do ingest plastic debris; therefore, we aimed to better understand how MPD accumulates chemicals from the ocean and the consequences of ingestion of MPD by fish. Based on previous field data analysis, we selected low-density polyethylene plastic which had been deployed in the San Diego Bay for three months for dietary exposure experiments with adult Japanese medaka (*Oryzias latipes)*. Fish will be exposed to diet spiked with 10% plastic for 28 days and tested for several toxic endpoints including: mortality, weight loss, histopathology, immunohistochemistry, and body burden. Results of adsorption of POPs across plastic type and at different locations in the San Diego Bay as well as the effects of marine plastic debris to medaka will be presented.

Session 3: Other Perspectives.

Presentation.

Understanding Biodegradable Plastics

Ramani Narayan (narayan@msu.edu)

University Distinguished Professor, Chemical Engineering & Materials Science, Michigan State University
East Lansing, MI

Plastics are ubiquitous. Starting from a mere 1.5 million metric tons resin production in 1950, it has grown to 270 million metric tons by 2008 and is expected to grow at a rate of 9% per annum, as India, China, and the African continent begin to discover the benefits and advantages that plastics offer. Single use disposable packaging and consumer products constitute about 30-40% of plastics usage and consequently being released into the environment in increasing numbers. Contamination of the world's oceans by light weight plastics has become a major issue and the subject of this workshop. The plastic debris presents a physical hazard to wildlife including seabirds, fish and turtles. More importantly, the break down of these plastics into small and even microscopic fragments of plastic potentially results in the absorption and concentration of toxic chemicals present in the environment that eventually get transported up the food chain [Theme issue of Plastics, the Environment, & Human Health; Phil. Trans. Royal. Soc. (Biology) July 27, 2009, 364 (1526)]

Biodegradability is a measure of the ability of microorganisms present in the disposal environment to utilize carbon substrates for energy to drive its life process. It is a property attribute that can be engineered into plastics to provide for an environmentally responsible end-of-life option in select biological disposal systems like composting, and anaerobic digestion. This is particularly important and valuable attribute for single use, disposable, short-life products like packaging and consumer articles as it allows for the complete, safe and efficacious removal of plastic from the environmental compartment. Unfortunately, there is a growing number of misleading, deceptive, and scientifically unsubstantiated biodegradability claims proliferating in the marketplace. Evidence of degradation, fragmentation or partial biodegradation is used to claim that the plastic substrates will not accumulate or persist in the environment. Degradation/fragmentation or partial biodegradation is not an option as it can have potentially serious environmental and human health consequences. Documenting complete biodegradation (microbial assimilation) of the plastic substrate in the targeted disposal environment (like composting) within a specified and measurable period is necessary to ensure safe and complete removal from the environmental compartment.

Biobased plastics based on renewable bio carbon feedstock offer the intrinsic value proposition of a reduced carbon footprint and in complete harmony with the rates and time scale of the natural biological carbon cycle. Being biobased, does not automatically qualify them as biodegradable and end-of-life solutions including biodegradability needs to be evaluated and clearly identified.

We will review fundamental principles underlying biodegradability and degradability of polymer materials in the environment, and describe the harmonized International Standards that are in place to ensure complete and effective removal. The value proposition for biobased plastics and its biodegradability option in the context of marine debris will be examined.

Appendices

Appendix A: Workshop Agenda

AGENDA
Thursday, 4 November 2010

Arrive in Tacoma

Friday, 5 November 2010
Center for Urban Waters
Commencement Bay Room

8:30 Registration

9:00 Welcome
Joel Baker – University of Washington
Lisa DiPinto – NOAA Marine Debris Division

9:15 Introductions
Everyone will introduce themselves and share their organization's interest in microplastics, and any brief key messages from the 30,000 feet perspective.

9:45 The Workshop in Context: Reports for Recent Meetings
Peter Kershaw – GESAMP microplastics meeting, June 2010
Courtney Arthur – 1st International Research Workshop on Marine Microplastics Debris, September 2008

10:15 Break

10:30 Setting the State – Goals of the Second International Research Workshop on Microplastic Debris
Joel Baker

Technical Sessions. Session lead will provide 25 minute overviews. Each session participant will then have 5-10 minutes to introduce their poster, followed by the poster session.

11:00 Session 1: Measurement and occurrence of microplastics in the environment
Session lead: **Greg Foster** – George Mason University
Session participants: **Kara Lavender Law** – Sea Education Association
Heather Leslie – Institute for Environmental Studies, VU University, Amsterdam
Amy Merten – NOAA ORR
Joe Green – California State University, Chico
Anthony Andrady - Consultant

12:30 Poster Session 1 and Lunch

2:00 Session 2: Effects of microplastics on the environment
Session lead: **Shige Takada** – Tokyo University
Session participants: **Barbara Beckingham** – University of Maryland
John Kennish – University of Alaska, Anchorage
Eunha Hoh – San Diego State University
Andrea Neal – Blue Ocean Sciences

3:30 Break

4:00 Poster Session 2

5:30 Adjourn

6:00 Doors open at Museum of Glass

7:30 Dinner at the Museum of Glass

Saturday, 6 November 2010
Center for Urban Waters
Commencement Bay Room

8:30 Reflections on the previous day – Joel Baker
9:00 Engineering and degradation perspective - Anthony Andrady
New polymers (bio-polymers) perspective - Ramani Narayan

9:45 Break

10:00 Applying risk assessment principles to the microplastics problem
Wayne Landis – Western Washington University

10:45 Charge to break out groups

11:00 Breakout groups by habitats
A. marine gyres
B. estuaries and coastal ocean
C. urbanized embayments

12:00 Working lunch – continue discussing in breakout groups.

1:00 Report from groups and discussion.

2:00 Wrap-up discussion: Can we conduct an ecological risk assessment for microplastics with data currently available? Which data are still needed? On what scale should a risk assessment be applied – regional, national, global?

3:00 Optional activity: surface water trawling with UW Tacoma researchers. Please join us for a short (1 hour) cruise in Commencement Bay, Puget Sound where we will demonstrate our techniques for sampling microplastics from surface water.

Appendix B: Compiled Notes

These notes were compiled from four working groups, each of which brainstormed lists of microplastics sources, stressors, effects, and impacts for a specific marine habitat. Marine habitats included marine gyres, coastal waters, estuaries, and urban waters. Lists were meant to include all realized and potential sources, stressors, effects, and impacts of microplastic debris. Many commonalities were noted when lists were shared with all workshop participants. For this reason, these notes are structured to group together lists of sources, stressors, effects, and impacts from all habitats but do not combine similar thoughts. Repeated thoughts indicate that multiple groups shared the same idea. Information on the certainty level (*i.e.*, plausible with enough data; plausible with little data; plausible with no data) is included here to indicate some differences of opinion among the groups. Please note that these lists were not vetted for accuracy. Mention here does not constitute endorsement by or necessarily reflect the views of the National Oceanic and Atmospheric Administration or those of the University of Washington Tacoma.

SOURCES

Plausible, enough data
Runoff and land-based sources: overland, roads, railroads
Urban runoff
Effluents: storm drains, untreated effluents
Pipes: municipal and waste water treatment facilities, industrial effluent, stormwater
Waste Management: collection, disposal
Beach sources
Protected areas
Recreational areas, including stadiums, beaches, shorelines
Litter
Military vessels
Dumping and direct sources: maritime activities, illegal dumping at port/shores
Maritime activities: shipboard dumping, derelict fishing gear, sewage, shipyard activities
Shipping industry
Fishing industry
Aquaculture
Larger plastics
Macroplastics

Plausible, little data
Waste water treatment facilities
Effluents
Effluents: wastewater, industry, sludge, rivers
Rural runoff
Storm water
River runoff
Recreational (eg, beaches, sports stadiums)
Land: add beaches, waste disposal, dumping
Cruise ships

Dumping: ship- and land-based
Ocean sources: shipping, fishing gear, equipment, buoys, shipping containers, shipboard dumping
New plastic products
Wind and extreme storms

Plausible, no data
Offshore operations: drilling, military vessels
Energy production: wind turbines, etc.
Urban runoff from military
Industrial sources caused by: transportation access (train/ships), type of industry (chemical manufacturing and/or processing)
Waste disposal dumping: illegal domestic backyard dumping, barges, industrial (recycling, municipal solid waste composting)
Chipped bits from ships, kayaks, surfboards
Catastrophic events: plane crashes, abandoned vessels, space debris, large recreational (one time) events
Balloon releases
Migratory species
Wind from land
Sea level rise and/or climate change
Atmospheric or meteorological sources (eg, storms)

STRESSORS

Plausible, enough data
Physical interaction and interference
Mechanical blockage, ingestion, lesions/abrasions
Adsorbed materials from use as containers
Absorbed and desorbed environmental pollutants: PCBs, PBDEs, dioxins and furans, EDCs, pharmaceuticals, antibiotics
Plasticizers and other materials composing the plastic
Substrate for transport of environmental pollutants: PCBs, PBDEs, dioxins
Residual polymers
Additives
Sorbed chemicals
Invasive species and biofilms: bacteria-virus, spores, emergent diseases

Plausible, little data
Seafloor coating
Physical clogging of X; other physical interactions
Flame retardants (eg, PBDEs)
Pesticides
PAHs
Invasive species: other organisms, biofilms

Substrate for transport of biological species: macro species, micro species, invasive species
Sorbed invasive species

Plausible, no data
Affect biogeochemical cycles (eg, carbon)
Physical interactions with sediments (eg, changes in pore water, grain size, organic content)
Reduced light penetration
Increased transfer of POPs at the sea surface microlayer
Enhanced transboundary exchange
Organism buoyancy changes
Absorption of fat-soluble vitamins
Increased hydrogen peroxide production
Nano-toxicity
Residues from use as containers
Plastic additives: flame retardants, BPA, metals, degraders, whitening agents, nano additives, NP
Adsorbed pollutants: PBDE replacements, PFCs, emerging POPs
Absorbed and/or desorbed environmental pollutants: metals
Could depend on pH, temperature, salinity
Sorbed harmful species

EFFECTS

Plausible, enough data
Decreased aesthetics
Increased substrate
Creation of artificial reefs
Behavioral changes (eg, changes to feeding behavior)
Mortality
Endocrine disruption

Plausible, little data
Habitat damage
Microbial community structure
Changes to reproduction and growth
Transporting adsorbed pollutants (eg, PCBs) has direct impacts on fish/mammals/birds (eg, birds forage in the gyre and ingest)
Biomagnification of chemicals

Plausible, no data
Habitat effects: loss of production, supplier-structure, microclimate changes
Habitat effects: loss of production, increased turbidity, changes in surface area for settling, acoustic changes, optical property changes (IOPs), increased habitat (raft effect)
Community structure
Community structure
Succession

Diversity
Richness
Reduced primary production
Loss of production
Affects on plankton (and thus the food web)
Primary production/inverts/fish/mammals/birds: developmental effects, reproductive effects, starvation and nutritional effects (ingestion effects), mechanical impact (entanglement), endocrine effects
Psychological effects
Human health (eg, biomagnification and transfer)
Decreased gas exchange
Direct effects: fish, mammals, birds
Indirect effects: fish, mammals, birds
Migratory patterns of fishes
Biomagnification process
Biomagnification
Biomagnification of microplastic
Vector for disease

IMPACTS

Plausible, enough data
Water quality

Plausible, little data
Aesthetics

Plausible, no data
Reduced beach use: economic losses
Reduced intrinsic beauty
Increased albedo on beaches
Navigation safety
Increased clogging of pipes
Sequestration of organic chemicals
Decreased seabird survivorship
Changes to biodiversity
Species impacts: key invertebrate, fish, planktons, birds
Fisheries impacts: loss to industry
Reduced fishing capacity (long term)
Reduced fish farming revenue
Human health and welfare: drinking water, recycled water

Appendix C: Participant List

Anthony Andrady (participant)
Helix Science LLC

Courtney Arthur (participant)
NOAA Marine Debris Program

Joel Baker (participant)
University of Washington, Tacoma

Nir Barnea (participant)
NOAA Marine Debris Program

Bonnie Becker (observer)
University of Washington, Tacoma

Barbara Beckingham (participant)
University of Maryland

Christiana Boerger (participant)
Algalita Marine Research Foundation

Amanda Bruner (observer)
Sound Citizen, University of Washington

Ashley Carlson (participant)
American Chemistry Council

Heather Coleman (observer)
PacMARA

Lisa DiPinto (participant)
NOAA Office of Response and Restoration

Gregory Foster (participant)
George Mason University

Joseph Greene (participant)
California State University, Chico

Peter Hodum (observer)
University of Puget Sound

Eunha Hoh (participant)

San Diego State University

John Kennish (participant)
University of Alaska, Anchorage

Peter Kershaw (participant)
Center for Environment, Fisheries, and Aquaculture Science

Jen Kingfisher (participant)
Port Townsend Marine Science Center

Lydia Kleine (observer)
University of Puget Sound

Susan Klosterhaus (participant)
San Francisco Estuary Institute

Andy Kociubuk (observer)
Evergreen State University

Wayne Landis (participant)
Western Washington University

Kara Lavender Law (participant)
Sea Education Association

Heather Leslie (participant)
Institute for Environmental Studies at VU University, Amsterdam

Sherry Lippiatt (participant)
NOAA Marine Debris Program

Julie Masura (participant)
University of Washington, Tacoma

Amy Merten (participant)
NOAA Office of Response and Restoration

Ramani Narayan (participant)
Michigan State University

Andrea Neal (participant)
Blue Ocean Sciences

Giora Proskurowski (participant)
University of Washington, Seattle and Sea Education Association

Erika Raymond (observer)
MBARI

Janet Roach (observer)
University of Washington, Tacoma

Chelsea Rochman (participant)
San Diego State University

Seba Sheavly (participant)
Sheavly Consultants

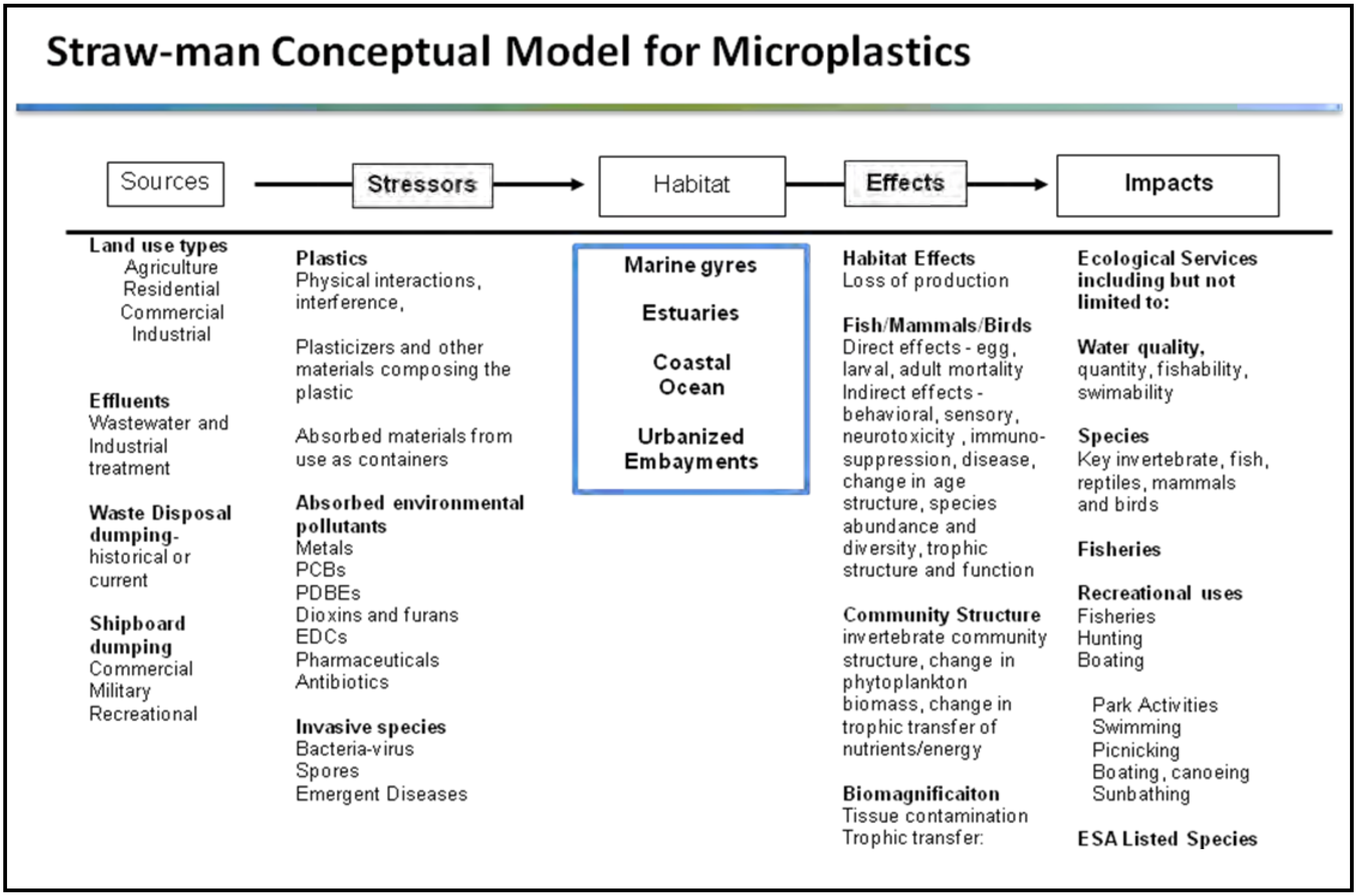
Kari Sheets (observer)
NOAA Office of Response and Restoration

Hideshige Takada (participant)
Tokyo University

Jean Walat (observer)
Port Townsend Marine Science Center

Peter Wimberger (observer)
University of Puget Sound

Appendix D: Conceptual Model for Microplastics (DRAFT)



Credit: Dr. Wayne Landis, Western Washington University

PROCEEDINGS OF THE SECOND RESEARCH WORKSHOP ON MICROPLASTIC DEBRIS

November 5-6, 2010
University of Washington Tacoma, Tacoma, WA, USA

Courtney Arthur[1] and Joel Baker[2] (eds.)

[1] National Oceanic and Atmospheric Administration
Office of Response and Restoration
Marine Debris Program
Silver Spring, MD 20910, USA
and
I.M. Systems Group
Rockville, MD 20852, USA

[2] The Center for Urban Waters
University of Washington Tacoma
Tacoma, WA 98402, USA

National Oceanic and Atmospheric Administration
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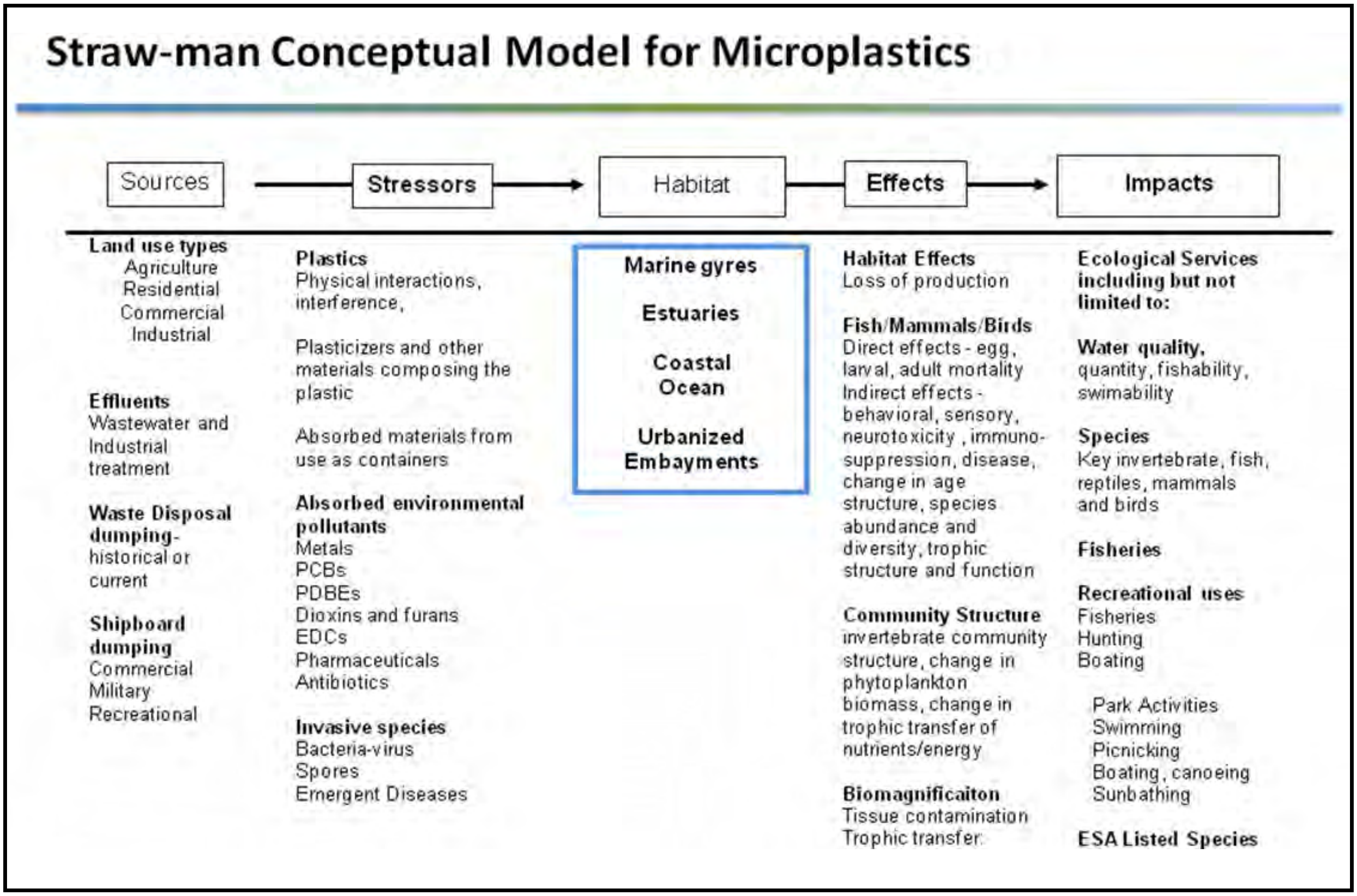
For copies of this document, please contact:
NOAA Marine Debris Program
N/ORR, SSMC-4
1305 East-West Highway
Silver Spring, MD 20910

www.MarineDebris.noaa.gov



Credit: Dr. Wayne Landis, Western Washington University

John Bryson
United States Secretary of Commerce

Jane Lubchenco, Ph.D.
Under Secretary of Commerce for Oceans and Atmosphere

David Kennedy
Assistant Administrator for Ocean Service and Coastal Zone Management