Modelling workshop summary report to the United Nations Environment Program

A summary report and recommendations to UNEP from modelling workshops held in April and August, 2015

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Signed

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1 Workshop overview

1.1 Purpose of the workshops

The objective of the work undertaken is to increase awareness on marine litter by reviewing the state of knowledge and to apply modelling approaches to identify sources, sinks, distribution and movement of marine litter, including microplastics. The aim of this increased understanding is to increase our ability to identify key areas where new data will be most informative, to make recommendations that will facilitate an improved understanding of plastics movement, sources, fate and distribution, and to employ tools that can help to identify important geographic regions where increased sampling would be of benefit.

At the two workshops, we set out to summarize the current state of knowledge (based upon the expertise of the participants (see Appendix I) in order to inform and outline key areas in need of further research. By focusing on identifying the state of knowledge across the globe, we can better discern gaps in knowledge, such as the perceived gaps in regions such as the Caribbean, South Pacific and Eastern Africa.

We specifically brought together experts from around the world whose research focuses on oceanographic modelling. This is because this UNEP sub-project aims to apply modelling approaches to consider the broad spectrum of marine plastic debris (from mega, macro and meso to micro and nano, following NOAA definitions), given that particles break down from large to small and they will have different physical and chemical effects on a wide variety of organisms. Furthermore, pathways and fates may differ, depending on the size and properties of the plastics themselves.

1.2 April Workshop Summary

Immediately following the GESAMP microplastics working group meeting hosted by the Food and Agricultural Organization campus in Rome, Italy from 20-23 April, 2015, CSIRO organized a one day modelling workshop which included some of the participants of the prior (WG42) working group.

The modelling workshop was associated with the UNEP/CSIRO collaboration project '*Modelling and monitoring marine litter movement, transport and accumulation*'.

The following participants contributed to the one day workshop which took place on Thursday, 24 April 2015 (Table 1).

Table 1. Workshop participants, April Modelling Workshop 2015

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The objective of the one day workshop was to identify approaches, knowledge gaps, and data required to increase awareness on marine litter. The day's conversation began with participants reviewing the state of knowledge and discussing the utility of combining empirical data with modelling approaches to identify sources, sinks, distribution and movement of marine litter. While some of the conversation focused on microplastics, we discussed that we are not solely focused on microplastics, but that they are an important component to consider. We brainstormed about key areas where new data will be most informative, as well as the types of (and priority for) information that would be optimal for improving our global, regional and local understanding of marine litter movement.

The workshop was structured with an introduction about priority questions, approaches to address the issue, and the data required to answer key questions. The discussion then moved to the utility of applying models to test hypotheses, and particular mention was made of the advantage of having empirical data against which to compare model outputs.

There was vigorous discussion about the utility of models, their appropriateness, information that could be used to improve model accuracy, and the need for integration of models in space, time, and depth. Importantly, it was noted that while models will not tell us where the plastic is, they can be used to interpolate and predict where things are going (e.g. inverse modelling).

It was highlighted that there is little information on fragmentation, but that understanding fragmentation processes is clearly importantly. Fragmentation is a function of wind speed, solar UV radiation, and other physical processes. The question was raised about what do the factors that affect fragmentation do to the size distribution plastic. We discussed looking at the spatial distribution of different sized fragments (the size spectra), specifically asking *where do we find large vs. small fragments?* It was acknowledged that there are quite sparse data on both buoyant floating plastics and on the vertical distribution of plastic debris (particularly for micro and nan-sized particles) and this was identified as an important knowledge gap to fill.

It was also discussed that if sources and sinks are known and models are overestimating sinks, one could perform inverse calculations to look at how much biofouling is required to have model solutions match what is actually observed. Furthermore, a focus on *processes* was identified as fundamental. To make the most effective use of models requires knowledge about litter inputs, flows and outputs (e.g. the mass conservation problem identified in Thompson's 2004 Science paper entitled "Lost At Sea: Where is all the Plastic").

It was worth pointing out that we want to consider checking assumptions. For example, do polymers change specific gravity? Putting in the appropriate caveats is important, but is not something to preclude doing the work. In some regions more than in others, this sort of detail may be more important. For example, there are good data from Korea and the Mediterranean. For carrying out modelling work at regional or subregional scales, need to consider other sources outside of those regions.

One of the identified gaps is the need to develop a clear theoretical model which explicitly considers the 'black boxes' and gaps. This would be useful to also explain to users the complexity of problem. Within such a theoretical model it would be good to include both two and three dimensions and incorporate upwelling, down welling, and other important processes that affect movement, distribution and fate of plastics in the marine environment.

The importance of quality data was mentioned throughout discussions, as was the importance of communicating clearly. One example of this is with the terminology 'hotspots' and 'accumulation zones'. Hotspots, rather than accumulation zones are something that UNEA would consider as high priority (e.g. Gulf of Biscay, Caribbean, etc.). Hotspots are regions that may be considered higher priority than gyres. Hotspots may be associated with proximity to source, however, some are in transition regions and others may be accumulation zones.

Communication will be most effective when targeted appropriately. There are opportunities for science and outreach, and integrating the two is perceived as positive. There is also a need for different tools and communication strategies for scientific vs. lay audiences. Considering how data are presented is important. For example, maps can leave a lasting impression that may not always be entirely correct, but they are powerful means of displaying and imparting information. While it is worth showing accumulation areas (gyres) as those areas where particles will always go, it is also appropriate to note the dynamic nature of accumulation zones.

Emerging issues that were identified by participants included:

- The need to better **understand ageing, fragmentation and biofouling**. There are some experiments being carried out to look at fragmentation (Delft, Netherlands) and incorporating modelling work with fragmentation and biofouling experiments.
- The need to **evaluate the likelihood of deep sea bacteria to consume plastics**. A team of scientists in Brazil are running an experiment at depths of 1500m and 3000m. Samples are sitting on the bottom for a year in an oligotrophic environment, off the Brazilian coast. The question being addressed is whether, and at what rates, do bacteria consume oil (in the form of plastics).
- The need to **identify the appropriate data for use in assessments**. Is it appropriate to use reports and grey literature or do you restrict assessment to peer-reviewed journal articles?

- The importance of **taking lessons from other ocean movement research** which is rigorous and has applicability to modelling litter movement. For example, lessons can be learned from larval dispersal models, as similar processes take place. Larval movement is likely also driven by tide and wind direction, storms, and bathymetry, shoreline, and other processes that affect litter movement). Investigating similarities and differences in approaches could inform debris model transport.
- The importance of **the nearshore zone needs to be more fully considered**. Typically researchers ignore the zone between shore and 25km or 50km offshore due to lack of data in global models. Global models are poor at incorporating regional processes, and current regional models cannot be scaled to global.
- **Vertical and temporal resolution is an issue** with our current movement/transport models.
- There are also **opportunities to engage with citizen scientists**. There is a group called 'Sailing with a Purpose group' which engages with ca. 30 boats around the world. Sailors are taking photos of the water to look at chlorophyll. A similar approach could be used to look at debris as well. Kara's data has huge variability in sampling/concentration. Can't model on a global scale.
- **Ideally there would be a global model that is useful, sufficiently detailed, user-friendly and accessible to countries, governments, researchers and citizens around the world.**

In discussing potential data types and sources to explore, potential approaches or research groups with whom to engage might include:

- Data from/groups working on larval dispersal or iceberg movement models;
- Data from/groups working on mercury transportation in biota;
- Data from/groups working on extreme event models (e.g. GNOME NOAA model used for tsunami response).

Some key challenges and opportunities include:

- Many current models retain all particles (e.g. there is no loss; ADRIFT). While it may not be difficult to take into account sinking, fragmentation, and other processes, models such as ADRIFT require data/parameterization to make these improvements.
- There are data gaps in many models due to areas with no or poor drifter data.
- Many of the current models include surface drifters only
- Time series resolution needs to be appropriate for the question/region being studied, particularly in light of the importance of seasonal variability in litter movement and deposition.
- Models such as ADRIFT are flexible. For example, sources can be added to the model, can be labelled tracked and followed.

One of the first and most significant improvements would be to add a loss term to look at losses in the environment. One of the big 'black box' areas in this work is in suspension/resuspension rates back on shore. The question raised was *can we establish a reasonable loss term for coastal regions*? If so, what would be required? Adding a loss term would be an improvement and having data from standing stock surveys to look at the *Coast-Ocean-Coast* (C-O-C) suspension and resuspension would be critical.

Additional information required might include data on:

- Wind and Tides;
- Forcing models and advection models;
- Removal terms;
- Rates and/or frequency of active biofouling (whether due to plankton concentrations or other processes);
- Solar radiation.

To improve modelling efforts, the ideal situation would include having a comprehensive list of datasets that can be used. These data sets would be geographically dispersed, long term, and with a high frequency of data collection. Addressing the C-O-C knowledge gap was identified as an area of great interest that would yield new insights.

To address the C-O-C knowledge gap, one way forward would be to have a transfer function from the coast to ocean and back again. Perhaps the best way to incorporate this into existing models is to find a few locations where there are long term data of coastline litter stocks. Analysing such an empirical data set, coupled with relevant covariates (wind speed, direction, tides, etc.) would be useful. The ideal data set would be a long time series with frequent sampling intervals.

Specific datasets that may be useful for modelling plastic movement include:

- The North Sea fisheries data. There is a high quality long term dataset from the North Sea Fisheries. With records of bird nests that contain fishing debris. Fisheries will be important to include as a source of plastic debris in the ocean.
- Midway and Tern Island both ran long term experiments and there are approximately 20 years of coastal debris data where they performed bi-weekly cleanings of sites. There has been a time series analysis to look at when debris arrives on shore (given the population of the islands). Extreme events appear to drive debris deposition and there are non-linear processes that result in local deposition
- OSPAR long term dataset
- NOAA data may be suitable (long term time series with high frequency and reasonable geographic spread).
- NOPAC region data
- Japan data
- Korean data from OSEAN

The meeting finished with a discussion of potential participants for the second workshop, as well as logistical considerations of dates, travel and duration.

1.3 August Workshop Summary

The second modelling workshop was a multi-day workshop associated with the UNEP/CSIRO collaboration project '*Modelling and monitoring marine litter movement, transport and accumulation*'. The workshop was held at UNESCO offices in Paris, France from 31 August - 3 September, 2015.

The following participants contributed to the workshop (Table 2). See Appendix IV for the workshop agenda.

Table 2. Workshop participants, Aug/Sept Modelling workshop

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* remote participation via skype

The workshop started with an overview of UNEP and GESAMP activities which was provided by Heidi Savelli. This was followed by introductions by each participant, a reminder of the goals of the multi-day meeting, and a potential roadmap for discussions.

This modelling sub-group aims to provide content that contributes to a larger body of work that will inform the UNEA report. As such, a main goal of the workshop is to identify gaps and key areas on which to focus future research needs and directions, while providing information about the state of knowledge, challenges and opportunities.

Generally, those participating in the workshop focus on larger scale models of marine litter movement (at the global or large geographic regional scales). It was acknowledged that this research focus may result in a bias in perspectives.

Overall, the group was united in the view that there are two ultimate goals: to **improve our understanding of plastic budgets and impacts of marine debris**. Identifying where, how and why plastic enters (and leaves) the ocean is very different than understanding the biodiversity, economic, and environmental impact plastic is having in the marine environment. With an understanding and evaluation of budgets and impacts, however, there is the opportunity to develop a policy responsive. Importantly, whereas modelling may take place at a global or regional scale, waste management policy happens at small spatial scales. Striking a balance between the spatial scale at which the research takes place and the scale at which policy decisions occur requires thinking about outcomes and impacts at very different scales.

The marine litter problem is a source, pathway and sink issue. If there is a clear understanding of each of these three, there is no need for models. Where, however, there is a knowledge gap in any of three, models can aid in the resolution. Essentially, modelling can act as a hypothesis testing tool. There are multiple modelling approaches that can be (successfully) employed to confront a problem and achieve resolution. Clearly identifying the region, focal question, key issues and what the modelling aims to achieve is a fundamental first step.

It was highlighted that improvements can be made in process models, but it is useful to consider whether improvements are worth the effort in areas where there may be insufficient or particularly noisy data. Some of the noise at large scales can be smoothed if the aim is a mass balance (whereby the noise becomes a statistical anomaly).

There was significant discussion around the key issues, with a focus on the following questions:

What are the sources?

- What is the source of the litter or microplastic?
- Is the plastic or microplastic primary or secondary microplastic?
- In absence of knowledge of sources, can we model the behaviour of microplastics from coast to ocean and back to coast?
- What are the rates of inputs to ocean (better empirical estimates)

How does it move?

- How can laboratory experiments improve models of plastics in the oceans?
- On what time/spatial scale do we need information to be able to address issues of risk or harm?
- What improvements can be made on litter budgets and losses in the marine environment?
- What are rates of fragmentation?
- What is the/are the buoyancy/sinking/re-floating rates?
- What are the priorities in understanding movement through the ocean?

What is the fate?

- Where are the plastic reservoirs?
- What is the impact or harm that results?
- How can we apply knowledge gained for policy impact

Central to improving our understanding at all scales, and in relation to each of the priority research actions identified remained the core question: Would it be possible to have a *global, centralized data repository* where data could be made available? The group did not extensively focus on what that might look like, where it might be hosted or the permissions that would be required for use, rather the group noted the utility of such a data repository. Such a repository could be utilized not only for researchers, but for countries, governments and policy makers.

Reservoirs: Where does plastic occur?

Plastic occurs throughout the ocean from the surface, throughout the water column to the deep ocean floor. It can reside in sediment, biota, and ice, and may be trapped along the coastline or in estuaries, waterways and lakes, and can be trapped in the atmosphere. The reservoirs deemed most relevant for modelling movement of plastics in the ocean includes the following compartments: surface, coastline/estuaries, ocean floor, sediments, ice, biota and water column. While it was acknowledged that there are other reservoirs (e.g. the atmosphere, lakes and waterways), those were considered to fall outside of the current scope and focus.

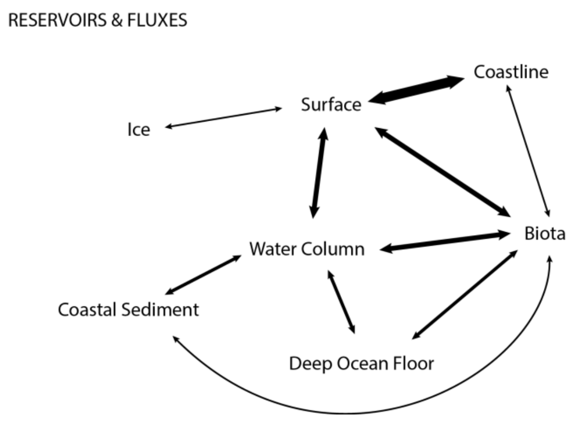

Figure 1. Schematic representation of reservoirs and fluxes for marine plastics. The weight of the arrow indicates the magnitude of marine debris flux hypothesised to occur between compartments, and the fluxes or flows between them.

Evaluating budgets (losses, sources and sinks into the environment) or leakage between these reservoirs or compartments requires understanding several key processes. Those highlighted as particularly important include rates of fragmentation, buoyancy/sinking/re-floating rates, as well as the rates and quantities of inputs of litter to the ocean and time trends for plastics in ocean.

When assessing the reservoirs, identifying in which reservoirs there is the greatest uncertainty will facilitate a ranking of transitions on which efforts could be focused, taking into account the key question (whether that relates to sources, losses between transition zones or impacts).

Table 3. Transfers from reservoirs to reservoirs, with the approaches required to increase our understanding and improve models. Hashes indicate a lack of direct interaction between compartments (e.g. movement takes place through an intervening reservoir; see Figure 2).

	Surface	Ocean floor	Sediment	Ice	Biota	Coastline	Water column
Surface	Lagrangian modelling, field tracking exper.	Lab exper./ modelling/ empirical	-	Modelling/ Field measure.	Field measure./ Spatial analysis	Lab and field exper.	Lab exper./ modelling/ empirical
Ocean floor	(Lab and field exper.)	Field exper.	Lab/ field exper.	Field exper.	Empirical sampling	-	Lab/ field exper.
Sediment	-	Field sampling of ocean floor sediments	-	Field exper.	Lab exper.	Monitoring/ sampling of sediment cores	Modelling/ exper.
Ice	Modelling	-	-	Modelling/ Field obs	Field obs	Field obs	Modelling
Biota	Lab/ field	Lab/ field/ spatial analysis	Lab/ field/ spatial analysis	Field obs	Field/ lab/ modelling	Lab/ field/ spatial analysis	Lab/ field/ spatial analysis
Coastline	Field, modelling	-	Coastline monitoring for sediments	-	Field/ lab/ modelling	Field/ lab/ modelling	Field/ lab/ modelling
Water column	Lab/ modelling	Lab/ modelling	Lab/ modelling	Field obs	Field/ lab/ modelling	-	Lagrangian modelling, field tracking exper.

Identifying key fluxes (movement between reservoirs)

There are five main fluxes that were considered to be of highest priority. Those are the fluxes that occur between the ocean (whether surface, water column or floor) and biota; movements between the ocean and the coast; movements from biota to the ocean, and the coast to ocean interface. The two reservoir fluxes considered to be of highest priority for increased understanding are those occurring between the ocean to coast and those occurring from the coast to ocean. Part of the driver for identifying the coast and ocean interfaces as important is that the nearshore environment is where most plastic must pass through to reach the open ocean. This is also a zone of high biodiversity and hence, where much of the biological impact is likely to occur.

This does not rule out the importance of ocean to ocean movement between reservoirs or movement between the surface and water column, rather it highlights the critical need for better understanding of movement between key reservoirs. Fluxes between ice and other reservoirs were considered to be of lesser importance, though there is agreement that modelling fluxes between ice and other reservoirs may not be particularly difficult.

It was widely believed that information can be gathered to evaluate fluxes between the ocean surface and water column, surface to coastline fluxes and litter in coastal reservoirs. In contrast, due to lack of data, fluxes from biota to the water column (and other reservoirs) would be difficult to constrain, as would be movement from the deep ocean. One of the main challenges is the disparity between what is recognized as the most important fluxes to understand, and our current knowledge not only of fluxes, but of the plastic residing in those key reservoirs.

Both for a mass balance modelling approach and to evaluate impacts, understanding of the accumulation of plastic in biota is needed. Importantly, this is a 'sink' where empirical data *can* be collected – whether through necropsies of deceased animals, through excreta, or with non-invasive sampling techniques. There is a growth in the number of papers reporting on the interactions between plastics and marine fauna (see Gall and Thompson 2015), with ingestion of debris, entanglement, and chemical contamination increasingly reported in the literature. It might now be reasonable to estimate microplastics residing in biota, but to date, an estimate of the overall mass of debris in wildlife has yet to be carried out.

Progressing our knowledge

Modelling efforts have greatly improved in recent years, and as computing power increases, so too does our ability to incorporate additional parameters into marine debris modelling. There are presently a variety of modelling approaches available, including circulation models, risk models and bioaccumulation models (ecosystem scale modelling). Each has a relevant role to play in increasing our knowledge and understanding of marine litter transport, and the development and employment of different modelling approaches depends upon the question asked, the region studied, and the overall aim of the research.

One of the advantages of applying modelling approaches to the marine litter issue is that modelling can allow us to apply a variety of approaches at a multitude of scales. With models we can focus on major drivers at a global scale that can scale down to consider local processes. There currently exist global data on wind, tides, waves, pressure and other processes that are identified as critically important. These global data can be scaled down to achieve model solutions at more local scales. While there may be some loss in resolution through such scaling, these approaches will nevertheless improve our ability to map risk – and impact - to marine biota, regions, and ecosystems.

Where possible, researchers should aim to validate models with independent data. Independent validation of models can be used to not only increase model utility and confidence in results, but also increases our understanding of uncertainty. Quantifying, and indeed, acknowledging uncertainty in model solutions can help identify research opportunities and key knowledge gaps. Validating models against empirical data may also yield greater insights to processes, highlight regions or taxa of greater (or less than) predicted risk, provide additional opportunities for policy impact, as well as improve model calibration.

It is generally recognized that coastal areas are especially important due to much higher space and time variability of atmospheric and oceanic conditions, frequent erosion and sedimentation processes, anthropogenic activities (especially fishing), sewage discharge, use of beaches for recreation, presence of industries that manufacture plastics, transport of materials by large vessels, boats maintenance and cleaning, and several engineering operations, like dredging and marine building. Preferably, coastal models will have very high spatial resolution (e.g. 10 m in the horizontal and less than 1 m in the vertical) and include the parametrizations of several bio-geo-chemical processes (such as fragmentation and beaches deposition). Ideally, the time scale would consider short-term effects (periods of few minutes) up to seasonal and decadal variabilities. Interactions with atmosphere, rivers, land and deep ocean areas would all ideally also be included (as highlighted previously). While the general view is that the greater the resolution the better, the importance of acknowledging the significant contributions to be made with poorer resolution (both vertically and horizontally) cannot be overstated.

Tracing plastics to their sources is often highlighted as critical. This can be difficult in part due to variability between and within regions, which is often greater than realized. Models can, however, be tuned to consider empirical data collected in various regions (e.g. incorporating country, region or basin specific inputs, waste mismanagement and other covariates). Even in the absence of complete data (e.g. from all regions), including sparse or incomplete data can still prove valuable.

Overlapping spatial mapping (for example, with accumulation models) with species distributions facilitates our ability to quantify the risk of plastics to biodiversity and marine ecosystems. Dynamically modelling of the risk or impacts becomes critically important not only for individuals and populations, but also for marine species that are exposed to multiple threats to survival and persistence. Identifying key geographic regions and taxa at higher or lower threat from marine plastics (e.g. Wilcox et al. 2015; Schuyler et al. 2015) can provide a useful lever to drive policy.

1.4 Key Challenges and Recommendations

Workshop participants identified a number of challenges and knowledge gaps and made specific recommendations to improve our understanding of marine litter movement and for marine litter monitoring. The recommendations from the workshop participants include various aspects of litter inputs, plastic movements, impacts to biota and opportunities for policy impact.

Some challenges and specific recommendations

Data gaps remain a significant challenge. While there do exist some large datasets of floating marine litter, for most regions there are **no data for longer time frames** (e.g. 30 years or more). The recommendation is to have *repeated sampling in consistent areas over a large geographic expanse and for decades* would provide significant opportunities to increase our understanding. In the north Pacific and north Atlantic there may be sufficient data, but generally, there are data limitations.

There are currently data from surface trawls, beaches/coastline through coastal clean ups and other efforts, sediment cores, riverine inputs and other sources. However, many or mo*st studies are limited in time and space* due to resources, time and other logistical constraints. *Making use of* *proxies* for areas in which data are lacking can improve model solutions and is an approach that has been under-utilized. Further exploration of the use of proxies in combination with statistical and process models (particularly considering missing data) will undoubtedly prove useful.

While data gaps remain a challenge, there are untapped communities who can (and are eager to) contribute to fill data and knowledge gaps. Public participation in scientific research (citizen science), has long been used to tackle research questions that would otherwise not have been addressed due to lack of resources, time or geography. These *citizen scientists can play an integral part in scientific data collection* and may include beach goers, recreational sailors, SCUBA divers, school groups, corporate groups and other interested members of the public. Using data on population density and waste mismanagement will facilitate model projection over the next century and can be ground-truthed with empirical data from a subset of sites with repeated surveys through time. Even something as simple as asking people to weigh or count litter collected from cleaning activities or fishing for litter programs would significantly contribute to fill a critical knowledge gap. We do suggest that such activities include surveys not only 'hot spots' or accumulation zones, but also areas that do not have a high density of litter.

To date, there has been a **lack of standardized reporting**. *Consistency in reporting could be achieved via a centrally hosted website with open source, freely available methodology and datasheets*. Hotlinks to other research projects applying particular methodologies would also increase communication. Improved reporting would improve our ability to compare between types, sources, quantities, around the globe.

It is widely acknowledged that there is **uncertainty in the Coast-Ocean-Coast zone.** This coastal and off/nearshore mismatch is of potentially greater concern than the finer resolution details in the models. If there is a significant over – or under – estimate of how much litter is entering the marine environment, bounding those estimates and the uncertainty around them would be useful. Currently, models typically fail to present uncertainty and to date, model solution assume there are not transitory dynamics along coastal regions (as well as within or among countries or geographic regions). *Incorporating uncertainty and transitory dynamics in the C-O-C* through scenario modelling will provide a tremendous advance that would likely enable significant policy engagement.

Air pollution is potentially a significant source of pollution, particularly for micro and nano plastics (textiles, manufacturers, etc.), but most model efforts to date fail to consider atmospheric deposition. *Experiments, identification of monitoring sites and inclusion of air pollution* as a contributor to microplastics would be of benefit. Furthermore, establishment of monitoring sites around the globe would facilitate the identification of important sources, the documentation of which is an important step in regulation.

Few studies have considered the **interaction between climate change and plastics**. Ocean currents are changing, migration routes and species distributions are changing, so understanding the interaction between climate and plastics may be particularly relevant for understanding impacts to biodiversity. For example, as the ocean's surface warms more quickly than does the deeper ocean and there is greater density contrast, this may require consideration. In the arctic, it may be that there is more plastic entering and then recirculating. While there has been some discussion of plastics trapped in or stored in ice, there has been relatively little discussion on the new habitat availability on plastics (plastisphere). *Modelling efforts* that specifically address plastics movement *between compartments with consideration of changing temperatures and associated processes* will improve our predictive ability particularly for risk to wildlife. Would more buoyant plastic polymers occur at the surface due to vertical differentiation? If so, this would result in differential availability for surface feeding species? These are some of the challenging questions. The vertical distribution of plastics may be particularly important to visual predators (turtles, fish and some seabird species). If winds increase as well, that may drive additional mixing.

The risk that plastic pollution poses to marine fauna is still poorly understood. **Evaluating the effects of plastic contamination on the food chain and environment is difficult**, but necessary. A combination of *modeling and experimental approaches* (including meso or microcosm experiments) would be useful here. Experiments could provide needed data on endpoints that correlate to energy (e.g. growth, mortality and reproductive output); and DEP modelling (dynamic energy budget modelling) can be employed to look at effect of productivity on trophic levels of the food chain).

We still know relatively little about the impacts of pollutant concentration in and on plastics and the associated effect on marine biota**. Plastics** may contain, **accumulate and carry pollutants**, inserted as additives or absorbed by the environment, which may act as soon as they are delivered to organisms. These plastics accumulate in oceanic and coastal areas and can be ingested by marine fauna in coastal, benthic and pelagic zones. However, the risk of such ingested material depends on the type, size and amount of plastic present in the environment, the presence of contaminants in plastic and contact with sensitive biota. Additional *experiments to evaluate pollutant assimilation, accumulation and transport between tissues* are needed to more fully quantify ecological risk at individual, population and species levels.

Other significant opportunities that can aid in advancing the state of knowledge include *environmental accidents* and *extreme weather events*. Taking advantage of such can be fruitful. Environmental catastrophes or similar occurrences can be used to train or improve models as they provide opportunities for large scale ‘natural’ experiments. Further opportunities exist with creative thinking. For example, combining oceanic plastic movement models with shipping data and fishing effort data could be used to better estimate and quantify at-sea losses into the ocean and community level surveys to address waste management, flows and loss rates from coastal communities can be applied to tune models with respect to the coastal component.

Overall, it was highlighted that research should relate small to large-scale sampling, monitoring and modeling, considering:

1) Identification of plastic sources in coastal areas,
2) Cataloguing historical and recent releases,
3) Regular and permanent monitoring,
4) Standardization of sampling methods,
5) Coverage of known impacted and not impacted sites (standardized random sampling),
6) Measurements in the atmosphere, rivers, sandy beaches (surface and deep sampling), sea surface and water column, sediments (surface and below),

7) Implementation of several data banks on plastic data recording and dissemination, (single data bank that is mirrored in multiple sites)
8) Use of circulation and tracking drifters models,
9) Improvements on the representation of plastic bio-geo-chemical processes in the models,
10) Analysis of plastic concentration transfer from atmosphere – land – ocean – sediments compartments,
11) Standardization of modeling techniques, including time and space resolutions, (perhaps use particular sites with detailed information to inform particular models)
12) Model results validation and model calibration,
13) Use of inverse lagrangian models to detect potential sources of plastics: using hindcasting to see where things come from. A main point of consideration is not to be deterministic to appreciate stochastic processes)
14) Evaluation of the influence of climate change in the plastic dispersion,
15) Integrate expertise of several scientific areas (e.g. ecology, medical, other fields, chemists, ecotoxicologists into discussion),
16) Evaluating the effects on plastic contamination on the food chain and environment. Experimental approaches would be useful here, use DEP (dynamic energy budget modelling to look at effect of productivity on trophic levels of the food chain). Can do some experiments for this – what is needed is data on endpoints that are related to energy (growth, mortality, reproductive output).
17) Use of biomarkers as indicators of toxic effects
18) Estimates of contamination on sandy beaches by Persistent Organic Pollutants (POPs) and heavy metals due to plastic dispersion,
19) The utility of including scenarios about potential environmental risks,
20) Multiple means to effectively dissemination data and model results (e.g. science communication),
21) The need to inform and support governmental policies on pollutants control;

Experimental research would also benefit from:

1) Laboratory experiments, particularly those which focus on fragmentation rates;
2) Experiments (whether lab based or in situ) to look at sinking rates;
3) Field particle tracking experiments are required to improve model fits of geostrophic currents, stokes drift, wind waves, windage, water drag
4) Exploration of fine resolution satellite observations to increase knowledge of surface currents
5) Strandings-release experiments (standing litter stock monitoring) for coastal exchanges

6) Toxicological impacts experiments to evaluate risk and impacts to biota
7) Experiments to quantify ingestion, filtering and transport from biota to compartments
8) Field experiments to document atmospheric deposition

In summary, our understanding of litter sources, fate and movement is rapidly increasing. This is an exciting time in marine debris research as it is a growing field that can adapt, integrate and benefit from learnings in other related research areas. While there remain a number of knowledge gaps with respect to marine litter modelling, there are significant advancements that can, and are, being made in our understanding. Importantly, many of these advancements are being applied to underpin and inform policy and decision making at several scales, and we are seeing an increase in a collaborative approach to addressing the issue. While global plastic production continues unabated, the public's interest in and appetite for engagement through volunteering and citizen science can be provide both broad and deep opportunities for data collection, outreach and behavioural change.

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APPENDIX I Modelling workshop Agenda for Thursday 24 April 2015

Project: Modelling and monitoring marine litter movement, transport and accumulation

Our specific objective is to increase awareness on marine litter by reviewing the state of knowledge and to apply modelling approaches to identify sources, sinks, distribution and movement of marine litter, including microplastics in order to identify key areas where new data will be most informative (e.g. such as a power analysis to identify most important areas to sample).

9.00 – 9.15	Intro, purpose and outline for the day's activities
9.15 – 10.00	Aspirational goals next 1-2, 3-5, 10+ years (brainstorm session)
10-10.45	Data/areas of high confidence areas of low confidence (with concern)
10.45-11.00	Coffee break
11.00-12.30	Approach to modelling sources, sinks, hotspots at global and regional levels
	What do we know, are we happy with current approaches etc.?
12.30-13.30	Lunch
13.30 – 15.00	Specific outputs from WG – manuscript(s)? State of art/knowledge, best approaches?

Topics to Discuss: Regions of mismatch (Mediterranean), gaps in at-sea data (South Pacific, Indian), uncertainty around losses in the environment (where going – wildlife, bottom, coast? Ocean to coast?) Linking Jambeck et al.'s 2015 Science paper – actual loss rates and predict to see how well they match? Budgets losses. Upwelling and down-welling; relevant importance of various processes.

Next working group: dates, duration (3-5 days) participants, outcomes, outputs, gauge interest

APPENDIX II Some of the available ocean circulation models and oceanographic datasets used for marine debris modelling/tracking (adapted from A. Markic)

Model/Dataset	Description	Reference
Adrift.org.au	Web-tool developed by E. van Sebille based on trajectories of Global surface drifters	van Sebille 2014
Connie2	Australian Connectivity Interface, web-tool developed by CSIRO	Reisser *et al.* 2013
BLUELink	CSIRO Ocean modelling and analysis tool used for accurately forecasting ocean conditions	Wilcox *et al.* 2013
ECCO	Estimation of Circulation and Climate of the Ocean - Scripps Institution of Oceanography (SIO), the NASA Jet Propulsion Laboratory (JPL) and the Massachusetts Institute of Technology (MIT)	Potemra 2012
ECMWF ORA-S3	Ocean analysis/reanalysis system of European Center for Medium-Range Weather Forecasts (ECMWF)	Potemra 2012
Global Drifter Program	Satellite-tracked surface drifting buoy observations of currents, sea surface temperature, atmospheric pressure, winds and salinity (NOAA)	Maximenko *et al.* 2012; Reisser *et al.* 2013; van Sebille *et al.* 2012
HYCOM	Hybrid Co-ordinate Model – forced by US Navy's Operational Global Atmospheric Prediction System (NOGAPS)	Lebreton *et al.* 2012; Lebreton & Borrero 2013; Potemra 2012
NLOM	1/32° global Navy Layered Ocean Model run daily by the Naval Oceanographic Office (NAVOCEANO) – real time	Potemra 2012
NCOM	1/8° global Navy Coastal Ocean Model (NAVOCEANO) – real time	Potemra 2012
OSCAR	Ocean Surface Current Analysis – Real time (NOAA)	Martinez *et al.* 2009
OSCURS	Ocean Current Simulator Model (NOAA Fisheries Service)	Ebbesmeyer & Ingraham 1994; Ebbesmeyer *et al.* 2012
PELET-2D	Lagrangian particle tracking model (Helmholtz–Zentrum Geesthacht)	Neumann *et al.* 2014
Pol3DD	Lagrangian 3-D numerical dispersal model	Lebreton *et al.* 2012; Lebreton & Borrero 2013
SCUD	Surface CUrrents from Diagnostics –developed by International Pacific Research Centre	Carson *et al.* 2013
SODA	Simple Ocean Data Assimilation model (by Cummings, 2005)	Potemra 2012

APPENDIX III Specific gravity of common plastics (adapted from Andrady, 2011).

Plastic class		Specific gravity
Polypropylene	PP	0.83-0.85
Low-density polyethylene	LDPE, LLDPE	0.91-0.93
High-density polyethylene	HDPE	0.94
Polystyrene	PS	1.05
Seawater		1.025
Thermoplastic polyester	PET	1.37
Poly(vinyl chloride)	PVC	1.38

APPENDIX IV Agenda for august 2015 modelling workshop

Modelling movement, fate and transport of (micro)plastics in the ocean

IOC Headquarters; 7 place de Fontenoy, 75007 Paris, France

August 31st – 3 September, 2015

Updated Room Location: Room VI, Main Entrance

AGENDA

<u>Room VI</u>

Monday 31 August 2015

8.30-9.00 Main entrance – pick up name badges

9.00-10.15 Gather for coffee at closest cafeteria to rooms IV and VI, informal discussion of plans for the coming days

10.30 GESAMP-2 opening Introduction (Meeting Room IV)

11.30 Overview of Agenda and Goals of Meeting

Address key questions/recap from April Meeting and web-based discussion

- Key discussion topics
- Data required
- New ideas/topics – further discussion

12.30 Lunch

13.30 Discussion of priority knowledge gaps and data required to fill gaps

- Improved source distributions
- Approaches to addressing questions about sinks

15.00- Break out groups (2) based upon morning discussion

16.30-16.45

17.15 Recap, summary and discuss group dinner for Tuesday evening

<u>Room VI</u>

Tuesday, 1 September

9.00	Overview of plan for the day including responsibilities, group leaders, process
9.30	Morning session breakout groups
	Topics TBD Day 1
11.10	Morning break
11.30	Morning sessions continued
13.00	Lunch
14.00	Afternoon breakout sessions
16.00	Groups report back, identify next steps for tomorrow
17.00	Close
19.00	Group dinner, venue to be decided

<u>Room VI</u>

Wednesday, 2 September

9.00	Reconvene and review workshop progress and goals
10:00-12.30	Breakout groups (i.e. analysis, write content, teleconference with group members, mini-discussions etc.)
12.30	Lunch
13.30	Breakout groups (i.e. analysis, write content, teleconference with group members, mini-discussions etc.)
15.00	Groups develop draft work plan with tasks (and names) for uncompleted work
16.00	Groups report back, identify next steps, specific tasks, leads on particular sections
17.00	Summary and close
17.15	Adjourn

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