Project information

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Project leader
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Participants

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Flagship
Hazardous Substances
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Summary of Results

Workshop report

Microplastics in marine environments: pathways, toxicity and impacts on biota

held at the Oslo Centre for Interdisciplinary Social and Environmental Science (CIENS), 0349 Oslo, Norway

Rationale

Marine plastic litter is an important environmental problem and poses a risk for the health of marine ecosystems and human populations relying on marine resources

(Andrady 2011). The need for monitoring and research on marine plastic litter has recently been recognized both nationally and internationally, reflected by an increasing number of monitoring programmes, research projects and publications. The Research Council of Norway (NFR) *HAVKYST* programme currently funds a project on 'Microplastics impacts in marine environments' (MIME) and the Fram Centre supports a new research initiative on plastic pollution in Arctic waters in the flagship *Miljøgifter*. These projects develop sampling protocols for plastic particles in situ and from affected marine biota (e.g. Cole et al. 2014), as well as analysis techniques to characterize microplastics and their ecological effects (Cole et al. 2013). New approaches to assess socio-economic impacts on fisheries are also needed. Suitable methods for this emerging field are currently, however, heterogeneous or lacking, and often don't allow for regional or large scale comparisons (Cole et al. 2011). The workshop addressed the need to assemble experts from a diversity of relevant fields that encompass marine microplastics research (i.e. chemical analytics, ecotoxicology, ecology, and socio-economics). The workshop has initiated interdisciplinary communication that will lead to improved understanding of the uncertainties, knowledge gaps and potential of current approaches and develop strategies to tackle these issues.

Workshop outcomes

Sampling schemes and methods of detection and quantification of meso- and microplastics are currently in an early stage of development and require further optimization and standardization to produce reliable estimates of plastic particle distribution and pathways (Cole et al. 2011). Several reviews have recently been published to summarize our current knowledge on properties, sources and environmental impacts of microplastics (Andrady 2011, Cole et al. 2011, 2013). The key knowledge gaps identified include:

- disparity in the nomenclature and size definitions of microplastics causing lack of comparability of microplastic sampling methodologies
- toxicity of microplastics from additives and/or adsorbed contaminants
- fate of microplastics and adverse health effects on biota
- transfer of microplastics up the food chain
- risks for human health and associated socio-economic impacts on fisheries

The workshop provided an international forum for discussion within the research community regarding improvement and standardization of microplastics research and effective communication with relevant stakeholders.

Interdisciplinarity:

Research on microplastics encompasses a range of disciplines in the natural and social sciences ranging from physics and chemistry to ecotoxicology, ecology, socio-economics and human health. This diversity of disciplines requires coordinated research initiatives to ensure effective communication and synergies among them. Scientific knowledge and societal questions need to be addressed and combined in order to reduce the emissions and impacts of microplastics pollution. The workshop brought together national and international research communities in microplastics research in order to inform about current research efforts, summarize recent results and discuss coordinated ways forward. Communications on sampling strategies, detection and quantification methods, technological advances and experimental design are of particular interest with the aim of standardizing these approaches to generate high-quality data and achieve better comparability of results from oceanic regions world-wide.

Workshop Programme:

Day 1	Time	Session
	09:00	Welcome and introduction to the workshop Claudia Halsband (*Akvaplan-niva*): Microplastics research in the Fram Centre Kevin Thomas (*NIVA*): the MIME project (NFR)
Session 1		Research and outreach initiatives in Norway and beyond
Chair: Kriss R. Iversen	09:30	Joan Fabres (*GRID Arendal)* – Marine debris and microplastics: environmental policy instruments and outreach at the regional and global level
	10:00	Coffee
	10:30	Kriss Rokkan Iversen (*SALT*) – Raising awareness of marine litter: Why, how and towards whom?
	11:00	Discussion
	12:00	Lunch
Session 2		Physical and chemical properties, degradation/weathering in marine environments, contaminant absorption and leakage
Chair: Dorte Herzke	13:00	Berit Gewert (*Stockholm University*) – Pathways for degradation of plastic polymers floating in the marine environment
	13:30	Magnus Svendsen Nerheim (*University of Bergen*) – Microbial diversity of plastic-associated marine biofilms
	14:00	Coffee
	14:30	Dorte Herzke (*NILU*) – POPs in bird tissue and on ingested plastic in comparison to beach plastic
	15:00	Discussion
Session 3		Pathways of marine microplastics and assessment of socio-economic impacts
Chair: Eirik Mikkelsen	16:00	Martin Hassellöv (*Gothenburg University*) – Studies of abundance, transport and fate of microplastics in Skagerrak and Bohuslän archipelago
	16:30	Eirik Mikkelsen (*NORUT*) – Assessing the socio-economic impacts of marine microplastics
	17:00	Discussion
CIENS Toppsenter	18:00	Social gathering (Tapas)

Day 2	Time	Session
Session 4	09:00	Biological impacts and consumer safety
Chair: Geir W. Gabrielsen		Renske Vroom (*Akvaplan-niva/University of Wageningen*) – Microplastics ingestion by zooplankton: the role of shape and taste Zandra Gerdes (*Stockholm University*) – Microplastic-mediated transport of PCBs to *Daphnia magna* and its effect on life-history parameters
	10:00	Coffee
	10:30	Inger Lise Nerland (*NIVA*) – Long-term exposure of blue mussels (*Mytilus galloprovincialis*) to environmental concentrations of microplastics from toothpaste
	11:00	Discussion
	12:00	Lunch
Session 5		Best practices: development of standardized sampling and analysis protocols
Chair: Kevin Thomas	13:00	Bert van Bavel (*NIVA/University of Örebro*) – Innovative tools for marine litter monitoring
	13:30	Inger Lise Nerland (*NIVA*) – Challenges of sampling microplastic in marine biota
	14:00	Discussion
	15:30	Sum up and workshop closure

Participants:

The workshop was convened by selected national experts active in this field within the Fram Centre flagship Miljøgifter, who invited other national and international workers in this area to share their experiences and ensure interdisciplinarity.

Workshop organization:

Dr. Claudia Halsband (Akvaplan-niva, APN)

Dr. Kevin Thomas (Norwegian Institute for Water Research, NIVA)

Attendees:

Name	Affiliation	Main interest	Country
Joan Fabres	GRID-Arendal	Session 1	Norway
Kriss R Iversen	SALT	Session 1	Norway
Amund Måge	NIFES	Session 2	Norway
Anders Ruus	NIVA	Session 2	Norway
Annika Jahnke	Helmholtz Centre for Environmental Research	Session 2	Germany
Berit Gewert	Stockholm University	Session 2	Sweden
Dorte Herzke	NILU	Session 2	Norway
Magnus Svendsen Nerheim	University of Bergen	Session 2	Norway
Philippe Kerherve	University of Perpignan	Session 2	France
David Pettersen Eidsvoll	NIVA	Session 3	Norway
Eirik Mikkelsen	Norut	Session 3	Norway
Martin Hassellöv	Univ of Gothenburg	Session 3	Sweden
Bethanie Carney Almroth	University of Gothenburg	Session 4	Sweden
Claudia Halsband	Akvaplan-niva AS	Session 4	Norway
Daniel Hitchcock	University of Oslo	Session 4	Norway
Geir Wing Gabrielsen	The Norwegian Polar Institute	Session 4	Norway
Iurgi Salaverria	NTNU	Session 4	Norway
Marte Haave	Uni Research	Session 4	Norway
Renske Vroom	Akvaplan-niva	Session 4	The Netherlands
Zandra Gerdes	ACESx, Stockholm University	Session 4	Sweden
Bert van Bavel	NIVA	Session 5	Norway
Christine Schönlau	Örebro University	Session 5	Sweden
Inger Lise Nerland	NIVA	Session 5	Norway

Session reports

Session 1: Outreach initiatives in Norway and beyond

Chair:Kriss Rokkan Iversen (SALT)

Speakers:

Kriss Rokkan Iversen (SALT)

Joan Fabres (GRID Arendal)

Kriss Rokkan Iversen held the presentation ”Raising awareness of marine litter: Why, how and towards whom?”. She focused on the importance of formulating the goal of the message communicated, as well as identifying the central target group for generating the wanted actions. She gave an overview on selected initiatives and campaigns seeking to evoke awareness of the problem of marine litter. One of her conclusions was that while the number of efforts on communicating the gravity of the problem and how to clean up marine litter is increasing, still more needs to be done, especially on creating campaigns preventing the litter to reach the ocean. It is much more difficult and expensive to clean up litter from the marine environment than to prevent it to get out to the sea.

Joan Fabres held the presentation ”Marine debris and microplastics: environmental policy instruments and initiatives at national and international levels”. In his presentation, Fabres defined marine litter in a broad sense – including plastic debris and microplastics from all possible sources. He than gave an overview on important laws and conventions made on different decision-making levels, such as UN, OSPAR and EU MSDF. He also gave examples of effective initiatives on national and local levels, for instance in Nigeria and South America. Finally, Fabres zoomed in on international research initiatives that will be central in the progress of bringing decision-making forward when it comes to microplastics in the oceans, as in GESAMP WG 40. Here a joint group of experts working on the scientific aspects of marine environmental protection is developing a report on ”Sources, fate and effects of microplastics in the marine environment – a global assessment”.

After the initial presentations, the participants had fruitful reflections and discussions on dissemination and outreach concerning how to evoke awareness and actions regarding marine litter.

These four initial discussion points drove along the discussions:

1. What would be the most efficient means to prevent plastic litter to end up in the marine environment?
2. Who would be the most central players to address in the fight against marine litter?
3. How could the different initiatives and campaigns be coordinated in an optimal manner?
4. Which demographic segments would be optimal to activate to change human behaviour and the society? And which tools should be used?

The research field on effects of microplastics in the marine environment is still under development. One main aspects of the discussion was how to deal with the need to communicate to give decision-makers the tools needed to create measures while robust data are still being generated. Could the scientific focus be directed towards organisms and processes for which data quickly result in measures upon communication towards different audiences?

The group discussed who were the main target groups that needed to be informed to create the most efficient level of change, like stakeholders and politicians versus industry and consumers. The IPPC process was brought to the table as an example to learn from. Another main point of the discussion was the need for a change of mentality and consumer behaviour. Also, here it is essential to communicate knowledge to evoke people's awareness of the problem and how their daily behaviour can add to the problem - and the solution - based on their consumption and garbage disposal habits.

The general conclusion of the discussions was that dissemination and outreach are important tools when it comes to finding solutions to the marine litter problem. Change can only be achieved if the public, the industry and decision-makers are aware of the gravity of the problem and the possible solutions to it.

Session 2: Physical and chemical properties, degradation/weathering in marine environments, contaminant absorption and leakage

Chair: Dorte Herzke (NILU)

Speakers:

Berit Gewert (*Stockholm University*) – Pathways for degradation of plastic polymers floating in the marine environment

Magnus Svendsen Nerheim (*University of Bergen*) – Microbial diversity of plastic-associated marine biofilms

Dorte Herzke (*NILU*) – POPs in bird tissue and on ingested plastic in comparison to beach plastic

The main focus of session 2 was on raising awareness of 1) the fate of plastic litter in the environment by physical processes during their residence at sea, 2) the microbial composition found on marine plastics as well as 3) the fate of pollutants adsorbed to plastics and subsequently ingestion by marine organisms.

The first speaker, B. Gewert from Stockholm University, was focusing on the degradation of floating plastic caused by UV radiation, hydrolysis and biodegradation. It was pointed out that the different polymers used in plastic react differently to degradation processes. The carbon backbone will rather be affected by UV radiation whilst the applied heteroatoms chemically bound to the backbone will rather degrade by hydrolyses. In both cases, a complex mixture of chemicals is formed. However, the chemical process happens very slowly and microplastic is expected to degrade faster than macroplastic. Additives are suspected to have an effect on the degradation too, but have not yet been well enough investigated.

As a second speaker, M. Svendsen from the University of Bergen, was discussing the Diversity of plastic-associated marine biofilms. He presented the results of a series of experiments, testing 9 commercial polymers for 6 weeks under in situ incubation conditions. The bacterial diversity and pollutant load were investigated, showing spatial distribution for the plastic associated bacterial communities and their surrounding environment. Summarizing, bacterial communities on plastic differ from those in the surrounding environment; no variation with plastic type or properties could be found; no physical plastic-microbe interactions were observed.

Finally, D. Herzke from NILU, reported findings from the EU project CLEANSEA, on the topic of pollutants related to ingested plastic debris and tissue concentrations in Norwegian Northern Fulmars. In collaboration with NINA, 83 N. Fulmars were collected as by-catch in 2012/3 in North Norway and investigated for ingested plastic. An average

weight og\f ingested plastic was 0.11 g and plastic was found in 69 birds (83%). The maximum number of plastic pieces found reached up to 112 pieces in one bird. No relationship between measured persistent organic pollutants (POPs) in the plastic and number nor weight of the ingested plastic could be found. The dietary contribution of POP uptake via plastic ingestion was considered to be minimal and mostly dominated by the uptake via food. Beached plastic litter contained different POPs compared to ingested plastic, but could be considered harmful for coastal ecosystems due to the high amounts found.

In the following discussion a number of points were raised:

- Issue of definitions, size ranges and methods à to be further discussed in session 5
- Sampling size versus analysis size
- sampling mostly opportunistic and no agreed methods are available for sampling of seawater
- Analytical methods are still very laborious and basing on visual identification prior to polymer ID
- Different jargon in nano-terminology than microterminology: in the micro-world the longest length is used to determine size category, while nanomaterial research uses 'at least 1 dimension in the range 1-100 nm' as size definition ó opposite definition approaches
- Microplastics: the definitions root in mesh sizes of plankton nets, i.e. small microplastics < 200 µm > large microplastics
- Microplastics properties: what is more dangerous, the plastic itself or plastics as vector of contaminants? Micro- versus nano: difference in reactivity à large knowledge gaps in ID of nanoplastics, no real comparison possible
- Importance of a dynamic, turbulent environment: turbulence versus viscosity of seawater, particle behavior dependent on size in the microbial realm, the smaller the faster the degradation due to surface-volume ratio
- Fugacity issue for contaminant adsorption
- Criticism of studies with clean/pristine organisms
- Challenge to estimate/backcalculate realistic background levels of pollutants in feed and environment
- Challenge of cocktail effects: complex interactions of chemicals approaching equilibrium and associated transport of chemicals across tissues
- Challenge to distinguish direct contaminant exposure versus contaminants from plastic
- Can plastics be used as contaminant cleaners? à due to the physical adverse effect of ingested plastic and the amount necessary to achieve a cleaning effect, as well as the challenge of collecting the plastic this was not considered to be a viable option.
- Should future strategies focus on biodegradable plastic or improved waste handling and decreased use of plastic in packaging? à broad consensus that biodegrading plastic will lead to new problems due to

the complex nature of plastic degradation and chemicals formed.

Session 3. Pathways of marine microplastics and assessment of socio-economic impacts

Chair: Eirik Mikkelsen (Norut)

Speakers:

Martin Hassellöv (Gothenburg University): Studies of abundance, transport and fate of microplastics in Skagerrak and Bohuslän archipelago.

Eirik Mikkelsen (NORUT): Assessing the socio-economic impacts of marine microplastics.

This part of the workshop considered the influx, concentration and fate of plastics in the ocean, and how to assess the socio-economic impacts of marine plastics. Plastic is produced by humans, and thus come from society. Through a number of pathways it enters the marine environment. There it can affect the ecosystem services that the oceans provide to humans, and thus their welfare and wellbeing. This session in a sense provided a holistic picture of this circle.

The first presentation was entitled

Studies of abundance, transport and fate of microplastics in Skagerrak and Bohuslän archipelago

Introduction

The presentation started by pointing out that, while the coast of the Skagerak Sea and the Bohuslän archipelago area are pretty landscapes, they are also full of marine litter,

if one looks a little closer. There are a number of reasons why plastics in the sea are considered as ugly and why littering should be avoided, including that

- plastic litter in the environment is percieved as esthaetically unpleasant and xenobiotic (unnatural) / uncompatible with nature
- it decreases the recreational values of a visit to the coast
- coastal tourism worth billions is threatened
- high costs will arise for fishing and maritime operations

Plastic from macro to micro size impacts different organism classes in different ways, and risk assessments must be performed with methods that include both exposure and effects. To define, assess and compare exposure it is necessary to have good definitions of exposure, and studies of sources, emissions, plastic behaviour, transport and fate.

Global input, density, distribution and fate of plastics in the oceans

The input of plastics to the marine environment from different countries/regions of the world in 2010 and into the future has been assessed by Jambeck et al. (2015, Science). They estimated this based on global plastic production, estimates of consumption in different regions from coastal population density, and how this translated to emissions to the sea based also on the quality of waste management systems in the different countries/regions.

The amount of microplastics in the oceans has been investigated by a number of different methods. One is using surface plankton net tows. In the North Atlantic and Caribbean Sea more than six thousands such net tows were performed on annually repeated cruises from 1986 to 2008 (Science 2010). Some tows found microplastics densities higher than 200,000 pieces per km^2. Data are also available from the 5gyres institute.

Despite these high surface densities of microplastics from net tows, it is also estimated that there are mechanisms at play that remove very large quantities of plastic particles smaller than 4.75 mm from the ocean surface (Eriksen et al. 2014 Plos One). Still, Eriksen et al. estimate that there are more than 5 trillion plastic pieces afloat in the world's oceans, weighing over 250,000 tons.

The measured abundances is decreasing substantially below ~1mm compared to a conserved mass fragmentation model (Cozar et al. 2014, PNAS). Four possible explanations for this removal / loss are presented: Shore deposition, Nano-fragmentation, Biofouling and ingestion.

Investigations of ocean sediments from the deep sea (1000-5000 m deep) found microplastics there, confirming that this is one sink (van Cauwenberghe et al, 2013).

Resolving the fate of the missing plastic debris is of fundamental importance to determine the nature and significance of the impacts of plastic pollution in the ocean (Cozar et al. 2014, PNAS)

Microplastics in the Baltic Sea, Skagerrak-Kattegatt Seas and Bohuslän coast regions

There is a variety of types of polymers, which have different specific density. Some of these float initially, while some sink. Pure polymers constitute a primary source of microplastics. There is further a variety of products and materials that are combined with plastics and which constitute a secondary source of microplastics. Other sources of micro-*litter* include synthetic fibres, paint flakes, road dust,
synthetic football fields, combustion particles etc. Sampling methods & sampling selections, size definitions & analytical methods should capture this complexity.

Marine litter is transported from other countries to Skagerrak with North Sea and Jutland currents. The Bohuslän coast receives a high load. There can be intermittent accumulation of floating marine litter in Skagerrak. Westerly gales blow the litter onto the shores. Convergence of the saline North Sea water from Jutland current and more fresh Kattegatt/Baltic surface water can focus floating matter in long streaks

Plastic spill from a plastic production facility

The other theme covered in the presentation was the spill of plastic around and from plastic production facilities in the region.

Plastic nurdles/pellets are the first stage in the plastic life cycle. Plastic pellets are produced in large factories, and then transported as raw materials to factories where articles are produced. It has been stated that the handling of pellets used to be problematic, giving emissions. Yet, there is still much plastic pollution from this in beach debris, especially around the Stenungsund plastic industry area. Survey of raw material plastic pellets in beach debris have been performed at the ”high water mark” several locations in the region. The pollution can be both pellets (2-4 mm) and fluff (0.01-1 mm).

A manta-trawl survey of the Stenungsund harbour, (300µm) showed plastic concentrations comparable to what is in the North Pacific gyre marine litter hotspot.

Pollution from the technosphere (production facilities) is still ongoing.

Sampling has also been done at selected Danish beaches (Lökken and Thyborön).

There has also been analysis of microplastics in guts of trout smolt (first year juveniles) living in a river near a PE (Polyethylene) plant. The smolts are relatively stationary, and the frequency of plastic fragments upstream and downstream of the plant showed a clear pattern indicating that the plant was the source.

Conclusions

- This is still ongoing work.
- Microlitter is more than just plastics.
- Abundance in the Bohuslän area is in some places comparable to the marine litter hot spots subtropical gyres.
- Floating microlitter highly variable.
- Fate and transport processes are important to understand.
- Technosphere microplastic is still an important source for plastic marine litter.

The second presentation was entitled

Assessing the socio-economic impacts of marine microplastics

Eirik Mikkelsen, with contributions from Heidi Nilsen and Jannike Falk-Andersson (Norut).

Introduction

The aim of the presentation was to contribute to the understanding of what socio-economic impacts are /can be and the steps required for a socio-economic impact assessment of marine microplastics. It was also hoped to bring reflection on how the research/knowledge of the individual researchers at the workshop, which were mainly natural scientists, could contribute to such a socio-economic impact assessment. Finally, the presentation wanted to propose and open up for a discussion on a way forward for making a knowledge status and doing joint research.

The socio-economic impacts we considered here are related to humans' use of natural resources and the environment, or our appreciation of nature and a specific state of the environment even in the absence of any obvious or apparent use of nature. The socio-economic impacts can be related to goods and services traded in an ordinary market, but also those not traded in a market, and as stated even "non-use."

Socio-economic impact assessments can be performed to understand the importance and urgency of an issue, to be able to prioritise between different policy-measures, and to identify vulnerable groups. When making a socio-economic impact assessment a number of choices must be taken. At what level should it be performed in relation to geography, societal level and for what period. They can be historical impact assessments, but it can also be assessment of scenarios. The frame of reference for assessments of future possible impacts must choose between doing a «Ceteris paribus» assessment (where "all other things are held constant»), whether a scenario of other changes should be included (natural, climatic, social, demographic), and whether possible policy actions should be included, like mitigation or adaptation to change.

Ecosystem services

A useful concept for doing socio-economic impact assessments of changes in environment and ecosystems is *Ecosystem services*. They are services (and goods) that humans receive from ecosystems. The concept is clearly anthropocentric. Ecosystem services are divided into four main classes: Provisioning, Regulating, Cultural and Supporting services. The supporting ecosystem services support the other types of ecosystem services.

The current most authoritative classification system is provided by the *Common International Classification of Ecosystem Services* project. See http://cices.eu . They provide a system to classify, identify and describe ecosystem services quantitatively for different types of ecosystems.

Note that ecosystem services typically also require human inputs to be produced. The types and amounts of ecosystem services provided are thus not only dependent on the state of an ecosystem itself, but also human preferences and choices.

Assessing and valuing impacts

A number of methods have been developed to assess ecosystem services (or rather *changes* in ecosystem services). The choice of method depends on the type of service being assessed. See figure below. Some of the methods are based on market prices or costs: Market value of products, Market cost of replacement of services, market costs incurred to get «free» ecosystem service (e.g. cost of travel to a place where person has recreational use of ecosystem services). For non-market use or non-use values of ecosystem services one relies on some variant of stated preferences, giving persons' willingness to pay for the services.

An example of trying to assess the economic value of ecosystem services is WWF's 2015 report "Reviving the Ocean Economy". The authors conclude that the Ocean's «Gross Marine Product» is minimum US$ 2.5 TN. The services that underpin that value are direct outputs (fishing, aquaculture), services enabled (tourism, education), trade and transportation (coastal and oceanic shipping) and adjacent benefits (carbon sequestration, biotechnology). Outputs not generated by the ocean per se, such as those from offshore oil and gas or wind energy, were not included, nor were assets for which data is not yet available. The analysis did not include intangibles such as the ocean's role in climate regulation, the production of oxygen, temperature stabilization, or the spiritual and cultural services from the ocean. The authors' conclude that "that these additional values are not included in this analysis means that the actual value of the ocean is much higher."

Research ideas

Mikkelsen presented the following research ideas for the workshop participants:

- A case study directed towards assessing the socio-economic impact of marine microplastics in northern/Arctic areas. This would fit well with the objective of the Fram centre, which many of the participants are connected to. Doing an actual assessment will not be possible at the current stage due to large knowledge gaps, but rather analysing what is the knowledge status and knowledge gaps, in order to make research priorities so that a socio-economic assessment can be made later.

- Attitudes to microplastics and policy measures. A study of knowledge and perception on the marine microplastics issue, in the general population, and for specific industrial sectors that likely are important contributors to marine microplastics in the North. The study could also include their attitudes towards various policy measures. A related issue is how measures for clean-up, like beach litter collection, also can be used to raise awareness, both among the participants and others?
- A study should try to better assess the relative importance of various sources for marine microplastics in the North, so that measures can be directed towards the most important sources and for a cost-efficient policy.

As a possible start on a knowledge status and identification of knowledge gaps to perform a socio-economic assessment, Mikkelsen presented a scheme/excel-sheet that

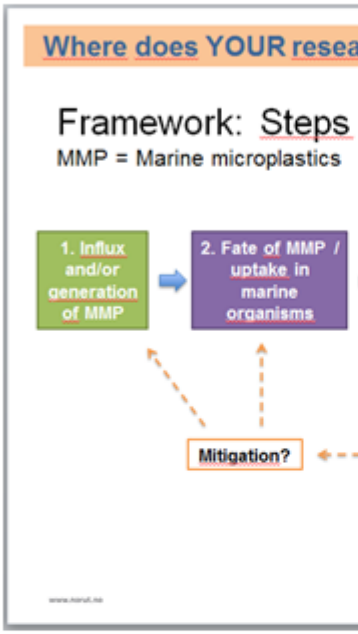
could be used to gather information from the participants, in line with the Framework presented earlier. See slide in figure below.

Rough knowledge status for assessm

Is this possible to do?

For specific case?

- Fill in table with your knowledge
- Colour-code according to certainty
- send to eirik.mikkelsen@norut.no
- I'll assemble and return…



Certain/ very likely	Some evidence	Uncertain

Step	What	Status of knowledge	Major knowledge gap(s) (for SEIA)	Comm / sour
2	Deposit/fate of MMP	Sea-bed sink for large-density MMP		
3	Ingestion in lower level orgs	Some microzooplankton ingest MMP	Amount in / uptake rate for major species	
3	Transfer through food chain	Goes through some pelagic food chains	Verify and quantify for specific food chains/ecosystems	Wright 2013 (r

Figure 1: Powerpoint slide presenting a way of collecting and systemising knowledge and knowledge gaps relevant for a socio-economic assessment of marine microplastics.

Discussion and agreement on actions

During the discussion the importance of doing the type of socio-economic assessments proposed by Mikkelsen was underscored by several participants. Not only was it seemed important for its relevance for designing policies and measures, but also for getting sufficient attention to the issue of marine microplastics. There seemed to be interest for contributing to the type of assessment proposed, making a knowledge status and identifying knowledge gaps for making a socio-economic assessment of marine microplastics in northern seas, focussing on the Barents Sea and Lofoten area.

Sources and status of knowledge on marine microplastics and marine litter to this area were discussed. In addition to various reports, beach litter analysis from clean-ups was one source, where some beaches in the region are OSPAR-beaches. OSPAR beaches are cleaned and litter counted according to a standardised methodology. For Norway, the impression is that fisheries/marine industry-related litter dominates in the north. This is in contrast to the Oslo-fjord area, where litter associated with recreation dominates (plastic cups and plates etc.).

It was agreed that Mikkelsen should send out the excel-file to the participants of the workshop, for them to fill out knowledge status and knowledge gaps for their specialised field. Focus should be on the Barents Sea area. A diagram with a simplified food web illustration for the Barents Sea would be included. Mikkelsen will assemble and return to those that have provided information.

Session 4. Biological impacts and consumer safety

Speakers:

Renske Vroom (*Akvaplan-niva/University of Wageningen*) – The Impact of Microplastics on Marine Zooplankton

Zandra Gerdes (*Stockholm University*) – Microplastic-mediated transport of PCBs to *Daphnia magna* and its effect on life-history parameters

Inger Lise Nerland (*NIVA*) – Long-term exposure of blue mussels (*Mytilus galloprovincialis*) to environmental concentrations of microplastics from toothpaste

This session was mainly addressing the effects of ingestion of microplastics on zooplankton and blue mussels. By doing exposure studies in the laboratory, the

investigators were able to study the effects of microplastic on mortality, reproductive rates and hatching success in zooplankton. By doing chronic exposure studies of zooplankton it has also been possible to study how clean and contaminated (loaded with PCB) microbeads affect life-history parameters in the parents as well as in the offspring. In blue mussels, the effect on ingestion was studied when the mussels were exposed to microplastic particles from toothpaste.

The first speaker Renske Vroom, from Akvaplan-niva and the University of Wageningen (NL), presented a study on how microplastic affected the ingestion by zooplankton (*Acartia* spp., *Pseudocalanus* spp. and decapod larvae). She also wants to study how exposure to microplastic affects mortality, reproduction rate, egg size and hatching success. Lately several studies have shown uptake of microplastic in zooplankton and the negative effects on feeding rates (Cole et al. 2013), survival and egg size. In this talk Renske (MSc student) presented her materials and methods (two experiments) to study uptake and carry-over effects this summer in Tromsø.

The second speaker, Zandra Gerdes from Stockholm University, presented studies on Daphnia magna. The two aims of the study was to investigate how ingestion of contaminated microplastic (loaded with PCB) affect life-history parameters and if chemicals associated with the microplastic transferred to the organisms. Zandra presented the treatment groups (clean and contaminated groups) as well as the reproductive tests. Preliminary results show that mortality increased in treatments with PCB-contaminated microplastic compared to clean microplastic and the control. A significant positive effect were observed on size and offspring production at the low to moderate concentrations turning significant negative effects on offspring production at higher concentrations. The uptake by daphnids was highest for the PCB congeners 128 and 153. It was also concluded that the hydrophobicity (logKOW) of PCBs affects bioaccumulation.

The third speaker Inger Lise Nerland, from Norwgian Institute of Water Research (NIVA), presented a study on long-term exposure of microplastic on blue mussels. Microplastic (in the range from 50-590 µm from toothpaste) was extracted and weathered before the mussels were exposed in three scenarios; control, only microplastic and weathered microplastic. Inger Lise presented the composition of plastic particles used, study design and sampling procedure before presenting the main results from the study. All mussels used were ingesting microplastic particles from toothpaste. The ingested particles varied in size from 60-380 µm (lower than what was available). It was a significant difference in size distribution for mussel ingesting microplastic and weathered microplastic. It was suggested that weathered microplastic

is more bioavailable than microplastic that is not weathered and thus without a biofilm. The mussels seem not to be harmed by the exposure, since the condition index was not significant different between the control and the exposed groups.

In the discussion following the presentations a number of points were raised;

- There is a need for more experimental studies related to effects of microplastic

- More knowledge are needed for fish and higher trophic levels; few studies that found microplastics in fish guts, but not in other tissues (guts not consumed in contrast to e.g. mussels), might be a matter of size range studied (no nano studies are done)

- A recent study on snow crabs and king crab from the Barents Sea showed that 20% of the population have consumed microplastics (Havforskningsinstituttet 2014)

- There is knowledge gaps on how contaminants behave in marine environments in relation to microplastics, how (much) they are adsorbed to plastic particles and how they are taken up/transferred to organisms, e.g. brominated compounds; more cooperations needed with chemists, more long-term studies

- There is a need for more international cooperation on studies related to the effects both across Europe and beyond (toward e.g. China and Japan).

- There is a need for methods that characterize the microplastic contamination of different habitats accurately (water column and sediments) and take into consideration abiotic variability such as turbulence, stratification/vertical density gradients and temperature effects on the behavior of microplastics, e.g. buoyancy/vertical position and transport

- There is a need to work on relevant model organisms. Criteria: abundance, key role in food chains and/or where much supporting information on biology, ecology and ecotoxicology is available, e.g. zebrafish, blue mussels, copepods and lugworms

- Crucial for future comparability of individual studies: complete reporting of information/method in publications: concentration, weight, volume and size range of particles, etc.: Not yet decided which of these will be standardized against (e.g. based on planned JPI Oceans project) or which methods will prevail as standard methods in the long term

- Need to go back to historical samples and obtain data from sediment sampling and sediment traps (Phillipe/Perpignan; Marte/Bergen)

Session 5. Best practices: development of standardized sampling and analysis protocols

Chair: Kevin Thomas (NIVA)

Speakers:

Bert van Bavel (NIVA/University of Örebro)

Inger Lise Nerland (NIVA)

Bert van Bavel (NIVA) held a presentation entitled "Innovative tools for marine litter monitoring and remediation", as part of the EU FP7 CleanSea project. The CleanSea project, through work package 3, proposes to demonstrate the utility of innovative marine monitoring systems capable of efficiently providing data for a range of GES indicators, integrate innovative monitoring systems with hyperspectral imaging to provide tools for large scale, cost-effective monitoring, investigate rates of fragmentation of macro- to micro-litter under field conditions, identify the distribution, accumulation and hotspots of litter by using hydrodynamic models, develop methods to identify polymers in environmental samples and provide novel 'litter' remediation (and monitoring) tools for sources and *hotspots*. Van Bavel described a number of different microplastics samplers including the manta trawl, microplastic sampler and the three-stage sampler (based on plankton pumps). The latter of these was shown to have been tested in the lab and field. The 3-stage sampler was also compared with the manta trawl with very different results obtained (Table 1).

Table 1: Comparison of microplastics collected with the Manta trawl and the 3-stage pump

sample device	Min particles/m3	Max particles/m3	sum particles/m3	average/m3	% fibers	% pieces
Trawl	0,03	2,11	8,01	0,31	90,74	9,26
Pump	0	157,94	431,55	39,23	86,03	13,97

A number of techniques were also described for polymer analysis. Hydraspectral imaging and micro near-infra red spectrophotometer were tested on model and field collected samples and shown to be useful for the analysis of larger particles.

Inger Lise Nerland (NIVA) presented her work on the determination of microplastics in the stomachs of fish. The presentation discussed the challenges of digesting whole stomachs and the standardization of approaches for the visual identification of different particles. Factors, such as finding a suitable location to perform the analyses without cross-contamination were discussed as well as suitable clothing and the precautions to be taken. It was recommended that glass petri dishes be used and that blanks were collected at every stage of the process. Examples of different particles found in the stomachs of Norwegian caught cod were presented as well as the process for their identification by Fourier-Transform infra-red spectrophotometry. Nerland also described a decision-based framework that she and others have been developing in an attempt to facilitate, what is a rather subjective analysis. This will soon be submitted for peer-review.

Discussion following the talks was based around which method should be adopted by the research community as the gold standard; this has yet to be agreed. It was generally agreed that it is too early to reach consensus on which methods should be standardized. Both equipment and protocols are under development and it remains to be seen which ones will be chosen by the majority of workers. Critieria for acceptance would be:

- Cheap/commercially available equipment (e.g. pump + filter setup designed by Örebro U), while e.g. FTIR & Raman spectroscopy and microplastics sediment separator (Hydrobios) are expensive
- Consistency of time series (Manta trawls)
- Accuracy/versatility of identifying plastic particles of various sizes (limiting factor for hydrospectral imaging)

The next part of the discussion was based around which matrix should be sampled.

Sediment was states to be good for monitoring, as it is expected that most particles will end up on the seafloor sooner or later (outcome of Ostende workshop in Jan 2015). However, it was also agreed that this depends on the research question, for understanding of interactions with pelagic biota sampling in the water column and at different depths is required as well. Blue mussels were suggested as a good monitoring organism, but that this may not be suitable for the Arctic.

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Framework for assessment of socio-economic impacts of marine microplastics (session 3)

A suggested framework was presented for making steps towards an assessment. See figure below. MMP = Marine microplastics.

The framework has these elements:

1. Quantifying the influx or generation of marine microplastics to the ocean area under consideration.
2. Fate of microplastics, including the degree of uptake in different marine organisms
3. The physical, chemical and/or biological impacts the microplastics can lead to, in the ocean itself or in the organisms living there.
4. Considering how ecosystem services can be impacted from this.
5. Valuing or assessing these possible changes in ecosystem service provision.
6. Summing up the economic and welfare changes
7. The framework also opens up for including mitigating or adaptation measures in the assessment.

While the framework might seem simple and reasonably clear on the linkages between each of the elements that should be analysed, reality can be very complex. See figure below from Wright et al. 2013 as an illustration. Even determining what is the major effects that one should focus on to get a rough estimate can be very challenging. Among the complicating factors are plastic types and sizes, specificities of the local ecosystem, the biology of different species, and complex food-web interactions. In addition comes the social aspects, including possible other factors that could impact the situation, and alos human choices and actions for adaptation and/or mitigation. Determining the natural exposure, the social vulnerability and the resilience (institutional capacity to counter changes and return to the original state after a perturbation) (Turner et al 2003, Adger 2006) can be very

complex.

Possible socio-economic impacts

What are the identified and possible main areas of socio-economic impacts of marine microplastics? According to the GESAMP 2015-report - a recent global assessment of microplastics in the ocean - there are no studies on social impacts of microplastics yet (GESAMP 2015).

Possible socio-economic impacts could be associated with the following, but it remains to be researched whether or where this is the case, and the magnitude and assessment of any effects:

- Seafood (provisioning ecosystem services)
    - Reduced stocks or altered size composition of commercial seafood species due to e.g. reduced food intake, increased mortality, reduced reproduction, etc?
    - Perceived or actual reduced quality of seafood lowering people's demand and willingness to pay for it, and also negative human health effects from eating polluted seafood?
    - Possible positive effect for feed aquaculture compared to wild caught fish if it is possible to limit and control microplastics input into farmed species?
- Recreation/enjoyment of nature/tourism (cultural ecosystem services)
    - Reduced recreation related to marine and coastal areas due to polluted seafood reducing the motive for seafood-related recreation?
    - How will knowledge or perceptions of marine ecosystems and species there being polluted and impacted by microplastics affect human well-being?
- Supporting and regulating ecosystem services?
    - Uncertain, but depending on the impact of microplastics on organisms, stocks and ecosystems, including also any impact on physical and chemical properties of the abiotic part of the ecosystems.
- Other effects…?

Presentation of results

When considering doing a socio-economic assessment it is also important to consider how the assessment results should be presented. Then it is crucial to consider for what main purpose the assessment is done, and what the main target group(s) is (are). Is it e.g. a technical assessment aimed at researchers and technical experts, is it for policy makers working on specific policies, or is it for more general outreach to the public and politicians in general? Whether the assessment should be presented in monetary terms (as far as possible) is one issue that could depend on this. Most would likely think it is ok to present impacts on goods and services already traded in a market in monetary terms. For impacts on non-marketed goods and services opinions on whether it is ok to present it in "dollar-terms" would diverge more. Particularly for issues like biodiversity and

species conservation and human health, people tend to reject monetising impacts to a larger degree.

For the description of effects that cannot be monetised or are highly contested to monetise, one could use a "consequence matrix" or more general verbal descriptions to present impacts. With a consequence-fan an ordinal assessment of the value(s) at stake and the extent of the impact(s) combine to give an assessed consequence. This can also be presented on a coloured chart for better visual communication.

Measures to reduce marine microplastics and its socio-economic impacts

It is important to identify, assess and develop relevant measures to deal with microplastics and reduce the socio-economic impacts. Some possible measures for mitigation and adaptation are the following:

- Mitigation
  - Reduce production and emissions of waste
  - Avoid dumping/leakage to sea
  - Collect/clean-up – litter on beach or in sea, or microplastics?
  - shift towards biodegradable Waste?
- Adaptation
  - Clean plastics from seafood?
  - More seafood production as aquaculture production in closed systems?
  - Abandon high-pollutant areas as Source of Food harvesting
  - Change fishing practise and processing due changes in fish stock sizes, distribution and composition?

    The figure below illustrates the general picture of the sources for marine debris and measures to reduce it. Globally, landbased activities are the most important ones for generation of waste that becomes marine debris. The situation in Norway is maybe the opposite, with economic activities in the sea being a more important source, but this is uncertain. The most cost-effective way to reduce marine debris and marine microplastics is likely to limit the generation of waste and plastic, and to limit the amount of waste that goes astray, ending up in the ocean. Some of the marine debris is degradable, but some only decomposes into smaller fragments, contributing to the amount of marine microplastics. Clean up of marine debris has predominantly occurred through beach cleanings. Shifting from plastic products to bioedegradable products would reduce marine microplastics in a more cost-efficient way than the preferred and dominating method today.

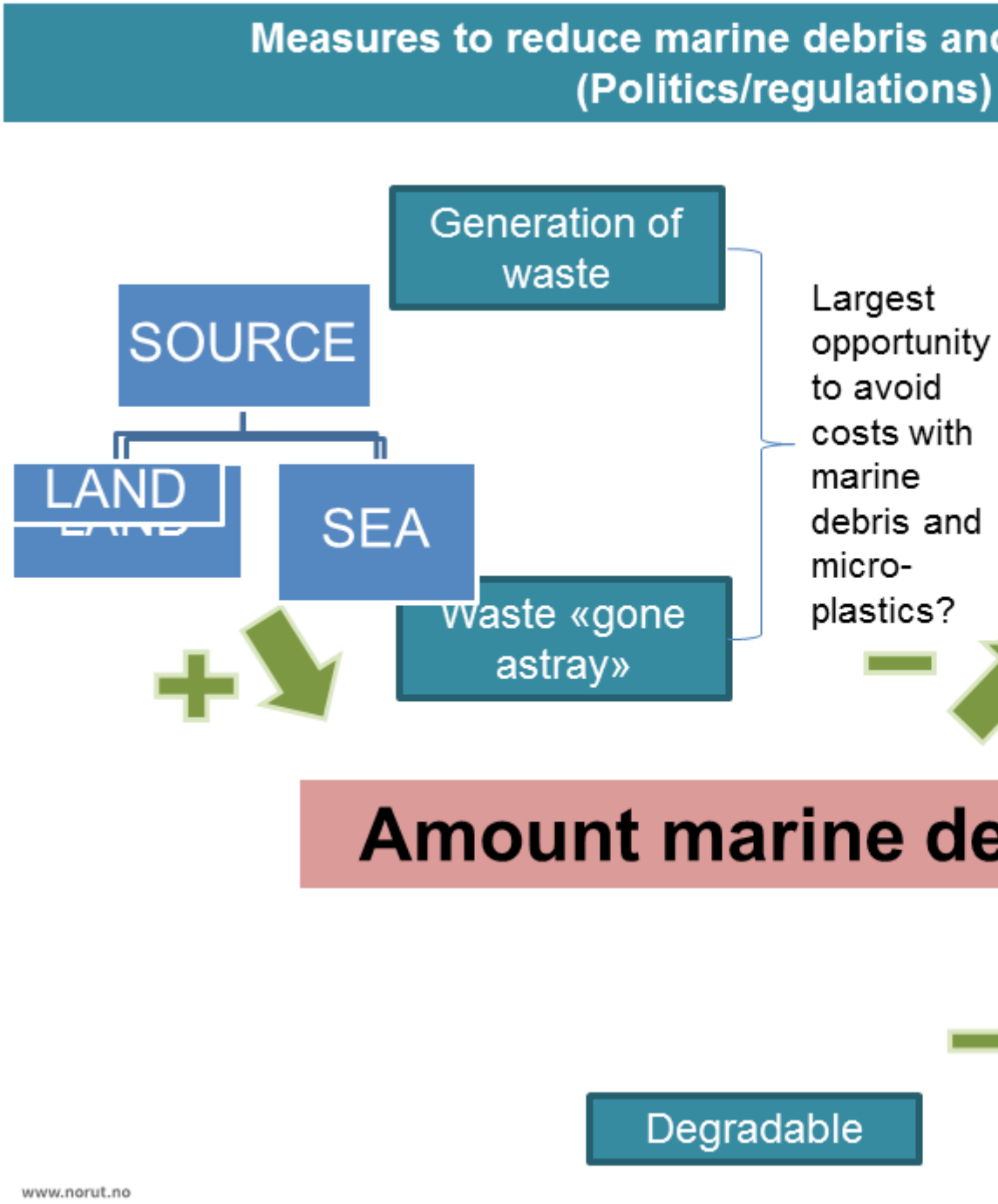

Figure 13: Situation, source and measures to reduce marine debris and microplastics (based on fig.1 of McIlgorm et al. 2011).

Knowledge gaps for socio-economic assessment

To be able to do sound socio-economic assessments of the impacts of marine microplastics a large amount of natural science research is clearly required. But also for the social/economic part of the assessment is much fundamental and specific research necessary to undertake.

In particular this regards the link between ecosystem state/quality, human preferences and use of ecosystem services, and the valuation of ecosystem services, especially non-market use and non-use. One also needs to identify and assess measures to find the most effective and efficient ones. This regards both mitigation and adaptation measures.

The GESAMP 2015 report's recommendations for further social/economic research include the following:

- To conduct empirical social research on microplastics to address: a) individuals' knowledge and understanding; b) perceived risks; and, c) the associated consequences on humans. Social perceptions are linked to behaviour and support of measures addressing the issue.
- To improve the geographical representativeness of this work – outside North and South America and Europe – to identify needs and tailor information to account for social, economic and other cultural differences, and promote effective mitigation strategies.
- To analyse the economic impacts of microplastics, in terms of cost-benefit to forecast future effects in response to any changes in microplastic use/input.
- Promote the collection and evaluation of examples of public engagement programmes (e.g. citizen science; beach cleans) in terms of their effects on perceptions and actions, including longitudinal follow-ups.

Published Results/Planned Publications

The workshop report isplanned to be published as part of the Fram Centre report series.

Budget in accordance to results

Budget in kNOK

salaries	APN	70
	NPI	20
	NILU	20
	NORUT	20
	SALT	20
direct costs	travel	70
	sum Fram	220
	NFR	150
	total	370

Could results from the project be subject for any commercial utilization

No