Report of the Study Group on *Marine Microplastics*

The Study Group on *Marine Microplastics* (SG-MMP) met from 9:00 to 18:00 on October 26, 2018, in Yokohama, Japan, under the chairmanship of Dr. Wonjoon Shim. Ten out of 14 SG members from 5 PICES member countries were in attendance as well as 6 observers (***SG-MMP Endnote 1***). SG-MMP reviewed and accepted the agenda (***SG-MMP Endnote 2***).

SG-MMP meeting participants at PICES-2018, Yokohama, Japan. Back row, from left: Taichi Yonezawa, Seung-Kyu Kim, Sang Hee Hong, Thomas Therriault, Takafumi Yoshida, Shuhei Tanaka, Haruhiko Nakata, Kazuhiko Mochida, Ryuji Kuwahara. Front row, from left: Yumi Okochi, Sarah Dudas, Lauren Howell, Wonjoon Shim, Matthew Savoca, Hideshige Takada. Missing from photo: Jennifer Lynch participated by conference call.

AGENDA ITEM 2

Background of SG-MMP and overview of Terms of Reference

Dr. Shim presented the background of SG-MMP and why it was proposed.

Along with microplastic topic sessions at PICES-2014 (Yeosu, Korea; MEQ Topic Session (S8) on "*Marine debris in the Ocean: Sources, transport, fate and effects of macro- and micro-plastics*") and PICES-2017 (Vladivostok, Russia; MEQ Topic Session (S2) on "*Microplastics in marine environments: Fate and effects*", there has been a growing need to establish an expert group on microplastic pollution in the North Pacific region which is considered one of the 'hot spots' on the globe.

The purpose of the proposed SG-MMP was to identify major microplastic issues in the North Pacific, including marginal coastal seas and to identify knowledge gaps. The Study Group's aim was to establish a list of priority research needs in PICES member countries as well as world society by avoiding duplication of the other international and regional working groups and programs on microplastics. This would help to fill urgent knowledge gaps through further expert group involvement and activity in PICES. Receiving input from regional and international bodies such as ICES (International Council for the Exploration of the Sea), GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) and NOWPAP (Northwest Pacific Action Plan), would increase efficiencies and the scientific value of the SG-MMP outcome.

The establishment of SG-MMP is consistent with the FUTURE Science Plan's research theme 3 (How do human activities affect coastal ecosystems and how are societies affected by changes in these ecosystems?), and contributes insight into the structure, function and resilience of ecosystems as in research theme components 1 and 2. This will provide a critical evaluation of highly complex microplastics, clarify priority concerns in the North Pacific, and provide a platform to evaluate the relative importance of microplastics compared to other stressors.

Dr. Shim reviewed the Terms of Reference of SG-MMP and reported that all tasks were completed (***SG-MMP Endnote 3***).

AGENDA ITEM 3
Achievements

Although the SG-MMP was established at PICES-2017, it was late in starting due to delays in receiving nominations for membership. However, the SG was very productive in meeting its terms of reference.

- Six members of SG-MMP (Amy Uhrin/USA, Hideshige Takada/Japan, Wonjoon Shim, Sang Hee Hong/Korea, Weiwei Zhang/China) held an informal meeting to discuss the SG mission and proposed activities during the 6th International Marine Debris Conference San Diego, USA, March 12–16, 2018.
- Dr. Shim met with the Co-Chairs of the ICES Group on Marine Litter, and discussed potential collaborations and joint activities.
- SG-MMP conducted a mini-review on contamination status for the North Pacific and its marginal seas:

Topic	Leader	Contributors
Floating (surface water)	Wonjoon Shim	Hideshige Takada, Chengjun Sun, Daoji Lee, Seung-Kyu Kim
Shoreline (beach)	Wonjoon Shim	Weiwei Zhang, Amy Uhrin
Biota (bivalve)	Sang Hee Hong	Sarah Dudas, Haruhiko Nakata
Biota (other than bivalve)	Jennifer Lynch	Matthew Savoca, Shuhei Tanaka

- SG-MMP answered a questionnaire developed by Dr. Shim (***SG-MMP Endnote 4***) to determine what were the key microplastic issues in the North Pacific, including knowledge gaps, outstanding issues in the North Pacific (or member country), and potential themes for the establishment of a new working group

AGENDA ITEM 4
'Hot spots' for MMP

Dr. Shim provided a short presentation to meeting participants on regional comparisons of microplastic pollution abundance in the surface waters coastal beach sediments in the world's oceans as well as regional comparisons of microplastic concentrations in bivalves (see ***SG-MMP Endnote 5***).

AGENDA ITEM 5
Proposal for a new Working Group

Dr. Shim introduced a proposal to establish a Working Group on *Indicators of Marine Plastic Pollution* (WG-MES), to be parented by the MEQ Committee. The proposal was circulated to all members of SG-MMP and MEQ for discussion prior to PICES-2018 (see ***SG-MMP Endnote 6***).

AGENDA ITEM 6
Topic Session proposal for PICES-2019

SG member, Dr. Matthew Savoca (USA), submitted a proposal for a Topic Session on "*Environmental indicators of plastic pollution in the North Pacific*" at PICES-2019 (***SG-MMP Endnote 7***). The session will be co-sponsored by NOWPAP.

AGENDA ITEM 7
Other business

SG-MMP discussed the request from ICES for PICES co-sponsorship of an ICES Symposium on "*The threat of plastic to Sub-Arctic and Arctic ecosystems*" to be held April 21–23, 2020 in Reykjavik, Iceland. SG members supported the event in principle, but due to lack of detailed information about the symposium, recommended that if the proposed Working Group on *Indicators of Marine Plastic Pollution* was endorsed by Science Board and Governing Council, it could make the recommendation to MEQ for discussion at ISB-2019.

SG-MMP Endnote 1

SG-MMP participation list

Members

Sarah Dudas (Canada)
Sang Hee Hong (Korea)
Lauren Howell (Canada, on behalf of Peter Ross)
Seung-Kyu Kim (Korea)
Jennifer Lynch (USA)
Haruhiko Nakata (Japan)
Matthew Savoca (USA)
Wonjoon Shim (Korea, Chair)
Hideshige Takada (Japan)
Shuhei Tanaka (Japan)

Observers

Ryuji Kuwahara (Japan)
Kazuhiko Mochida (Japan)
Yumi Okochi (Japan)
Thomas Therriault (Canada, acting AP-NIS Chair)
Taichi Yonezawa (Japan)
Takafumi Yoshida (NOWPAP)

Members unable to attend

Canada: Peter S. Ross
China: Daoji Li, Chengjun Sun, Weiwei Zhang
USA: Amy Uhrin

SG-MMP Endnote 2

SG-MMP meeting agenda

1. Welcome and self-introductions
2. Background of SG-MMP and overview of Terms of Reference
3. Achievements
4. Hot spots for MMP
5. Proposal for a new Working Group
6. Topic Session proposal for PICES-2019
7. Other business

SG-MMP Endnote 3

SG-MMP Terms of Reference

1. Identify knowledge gaps and establish research priority for impacts of microplastics and their associated chemicals on marine environment and biota;
2. Identify interactions within PICES scientific committees and expert groups that will complement the Study Group;
3. Explore potential partnerships with other professional or multilateral organizations (*e.g.*, ICES, GESAMP, NOWPAP) which could lead to joint activities (working group, sessions, publications), improve efficiencies and strengthen scientific outcomes;
4. Develop recommendations for a possible PICES WG on marine microplastics.

SG-MMP Endnote 4

Questionnaire circulated to SG-MMP on marine microplastic issues facing the North Pacific

Q1. What are the most important outstanding knowledge gaps in microplastic research?

Knowledge gap	# of answers	Keywords
Biological/Ecological impact	6	Ingestion >Population level Safe level Ecological risk
Sampling and analytical methods	4	Protocol Standardization Quick Reliable Nanoplastics
Source and Flux	4	Origin Fragmentation rate Amount gap
Distribution	4	Open ocean Multi-media
Fate and transport	3	Ocean current
Human impact, Chemical toxicity	1	

Q2. What are outstanding issues in your country or North Pacific and its marginal seas?

Country	Issue
Canada	• Understanding the extent and magnitude of the threat of MP to marine ecosystems and seafood
China	• A complete picture of the current MP distribution • Plastic waste control • Yearly plastic waste (including MP) ocean input • The sources and transport of MP including a three-dimensional numerical model • Methods for risk assessment
Japan	• To assess the behavior of MP in wastewater treatment plants, especially MP <20 mm • Understanding distribution kinetics of plastic debris and MP after the Japanese Great Tsunami • The occurrence and distribution of MP in 'deep-sea'
Korea	• Expanded polystyrene (EPS; Styrofoam) pollution • Ecological risk of MP in water and benthic environments • Occurrence, transport, and weathering and so on of plastics in freshwater environment
USA	• Lack of data on organisms at the base and top of the food chain • Lack of information on MP in the water column (off coast and estuary) • Massive amounts of mega, macro, meso, microplastics arrive on the Hawaiian beaches, more than most other locations globally: Origin, clean up, and impact on ecosystem, seafood safety and tourism • Chemical toxicity (vector for POPs into marine organisms) • Distribution of MP in the various environmental compartments (including factors that influence fate and transport) • Marine fauna exposure, risk to marine fauna due to ingestion, translation across tissue/ membranes, population-level impacts as a result of ingestion and subsequent impacts

Q3. What are the most interesting/required topics in a PICES WG for the next three years?

Country	WG suggestion
Canada	• Identification and prioritization of the most critical knowledge gaps in our knowledge of MP contamination and how they relate to ecosystem and human well-being • Standardization of methods/protocols to promote comparability among global studies
China	• High through-put sample analysis method • Standardized and reliable sampling and sample treatment methods • Critical evaluation of the current MP situation • The flux, transportation and fate of microplastics from rivers to estuaries, to the seas (to promote consistently coordinated plans and actions to reduce plastic waste and microplastics entering the oceans by the international society)
Japan	• How much size of MP and microfibers need to be analysed? • How to analyse the 1 mm MP and microfibers in many kinds of environmental samples
Korea	• Land- and sea-based Input of plastic debris, and their movement in North Pacific region • Current status of the environmental exposure of MP to marine wildlife • The effect of management and/or control to reduce mismanaged/discharged plastics (associated with long-term monitoring and policy of resource management) • Long-range transport of plastics in PICES domain, i.e., Pacific Ocean. How many plastics move and distribute through which pathways is associated with inter-countries and inter-continents issue
USA	• How can and should scientists engage legislators and members of the general public on these issues • What are policy changes we would like to see enacts to mitigate the issues of MP in our seas? • WG should not focus only on MP. Why limit the discussion to marine debris that is only 1-5 mm? (all of macroplastic debris fragments into sizes even smaller than MP)

SG-MMP Endnote 5

Mini review of microplastic abundance in surface water of the North Pacific and its marginal seas

1.1 Microplastic abundance in surface water of the North Pacific and its marginal seas

Microplastic abundance in the surface water of the North Pacific Ocean and coastal areas of six PICES member countries were reviewed from a literature survey (Web of Science; keyword, microplastics). A total of 33 abundance data were extracted from 24 papers in peer-reviewed journals from 1995–2018 (Table 1.1). Because the data were in various formats and units, thereby preventing direct comparison, data reported as the mean number of items per cubic metre, or means that could be converted from items per square kilometre into items per cubic metre, were selected. When the abundance using neuston or manta trawl nets was reported as items per square kilometre or square metre with about a top 20 cm sampling, the data were converted into a volumetric measurement (n/m^3) by adding a third dimension (*i.e.* conversion of items per square kilometre to items per square metre and multiplying by 0.20 m) (Shim *et al*., 2018).

Most water monitoring studies targeted surface water where floating microplastics accumulated, using neuston or manta trawl nets. Floating microplastics accumulated on the sea surface were collected using nets with mesh sizes of 20–1,000 µm, or by bulk water filtering with different port sizes. Several studies performed underway sampling by pumping from the subsurface during ship movement (Desforges *et al*., 2014). The mean abundance of microplastics in seawater reported worldwide ranged from 4.8×10^{-6} items/m^3 in the eastern equatorial Pacific (Spear *et al*., 1995) to 4.1×10^3 items/m^3 in the East China Sea near Yangtze River estuary (Zhao *et al*., 2014) (Table 1.1), showing a maximum difference of nine orders of magnitude.

Microplastic abundance tends to increase steeply with decreasing size (Song *et al*., 2014). Thus, it is crucial to consider the lower bound of microplastic size for sampling and detection in any comparison of abundance. Table 1.1 divides the results by net mesh size in sampling or post-sampling treatment of 33 studies. The mean abundances of microplastics in surface water according to each net mesh size range were 1.9×10^3 items/m^3 for 20–63 µm mesh, 47 items/m^3 for 153 µm, 2 items/m^3 for 330–350 mesh, 3.0×10^{-2} items/m^3 for 500–505 µm mesh, and 1.6×10^{-5} items/m^3 for 1,000 µm mesh. Microplastic abundance demonstrated a negative relationship with net mesh size regardless of sampling region and time (Figure 1.1). Therefore, further comparison of the spatial distribution was performed only for cases that used 330- to 350-µm mesh manta and neuston nets collecting surface water in marine environments.

Seventeen out of 33 studies used net mesh size of 330–350 µm. Study areas covered Chinese (5 studies), Japanese (2), Korean (2) and USA coasts (3) and North Pacific open ocean (5) (Figure 1.2). Unfortunately, microplastic abundance data using 330–350 µm mesh size nets were not available for Canada and Russia. The abundances of microplastics in coastal areas were higher than those from the open ocean of North Pacific. Except for a study in Hong Kong, microplastic abundances in coastal areas were in the range of 0.01–10 items/m^3 for four countries.

Table 1.1 Mean abundance of microplastics in surface water of North Pacific and the coastal area of six PICES member countries in the literature.

Basin	Location	Year	Sampling method	Mesh size (um)	Abundance (items/m^3)	Reference
Asian seas	East China Sea	2014	Pumping and sieveing	32	4137	Zhao et al. (2014)
Asian seas	Bohai Sea, China	2016	Bucket	20	2200	Dai et a. (2018)
North Pacific	Vancouver Island and NE Pacific, Canada	2014	Underway sampling (4.5 m)	62.5	2080	Desforges et al. (2014)
Asian seas	Kyunggi Bay, Korea	2013	Phytoplankton net	50	1602	Chae et al. (2015)
Asian seas	Jinhae-Geoje coast, Korea	2012	Hand net	50	754	Kang et al. (2015)
Asian seas	North Yellow Sea, China	2016	Niskin bottle	30	545	Zhu et al. (2018)
Asian seas	Coastal area, Hong Kong	2015-2016	Plankton net	153	47	Tsang et al. (2017)
Asian seas	Xiangshan Bay, China	2017	Plankton net	330	8.9	Chen et al. (2018)
North Pacific	Santa Monica Bay, USA	2000-2001	Manta net	333	7.3	Moore et al. (2002)
North Pacific	Santa Monica Bay, USA	2001	Manta net/Bongo net	333	3.9	Lattin et al. (2004)
Asian seas	East Asian Sea	2014	Neuston net	350	3.7	Isobe et al. (2015)
Asian seas	Jinhae-Geoje coast, Korea	2012	Manta net	330	3.7	Kang et al. (2015)
Asian seas	Pearl River Estuary, China	2015	Manta net	333	3.6	Cheung et al. (2018)
North Pacific	Central gyre Northeast Pacific	2001	Manta net	330	2.2	Moore et al. (2001)
Asian seas	Seto Inland Sea, Japan	210-2012	Neuston net	350	0.39	Isobe et al. (2014)
Asian seas	Bohai Sea, China	2016	Manta net	330	0.33	Zhang et al. (2017)
Asian seas	Kyunggi Bay, Korea	2013	Manta net	330	0.19	Chae et al. (2015)
Asian seas	East China Sea	2014	Neuston net	333	0.17	Zhao et al. (2014)
North Pacific	San Fransico Bay, CA, USA	2015	Manta net	333	0.14	Sutton et al. (2016)[a]
Asian seas	Chinese Yellow Sea, China	2015	Bongo net	500	0.13	Sun et al. (2018)
North Pacific	Bering Sea	2006	Sameota sampler/manta net	505	0.045	Doyle et al. (2011)
North Pacific	NW Pacific (Kurshio current system)	2000-2001	Neuston net	330	0.034	Yamashita and Tanimura (2007)[a]
North Pacific	NE Pacific (Accumulaiton zone)	2001-2012	Plankton net	335	0.031	Law et al. (2014)[a]
North Pacific	Central gyre Northeast Pacific	2011	Manta net	333	0.017	Carson et al. (2013)[a]
Asian seas	Near-shore waters, Japan	1985-1988	Ring/neuston net	500	0.015	Day et al. (1990)[a]
North Pacific	Subtropical gyre Northwest Pacific	1985-1988	Ring/neuston net	500	0.012	Day et al. (1990)[a]
North Pacific	Transitional water	1985-1988	Ring/neuston net	500	0.012	Day et al. (1990)[a]
North Pacific	Subarctic North Pacific	1985-1988	Ring/neuston net	500	0.0026	Day et al. (1990)[a]
Asian seas	Coastal area, Hong Kong	2016-2017	Manta net	335	0.0025	So et al. (2018)[a]
North Pacific	NE Pacific (Non-accumulation zone)	2001-2012	Plankton net	335	0.00037	Law et al. (2014)[a]
North Pacific	South Equatorial current, North Pacific	1995	Neuston net	1000	0.00003	Spear et al. (1995)[a]
North Pacific	Bering Sea	1985-1988	Ring/neuston net	500	0.00002	Day et al. (1990)[a]
North Pacific	South Equatorial counter current, North Pacific	1995	Neuston net	1000	0.000005	Spear et al. (1995)[a]

[a] Converted abundance from km^2 to m^3

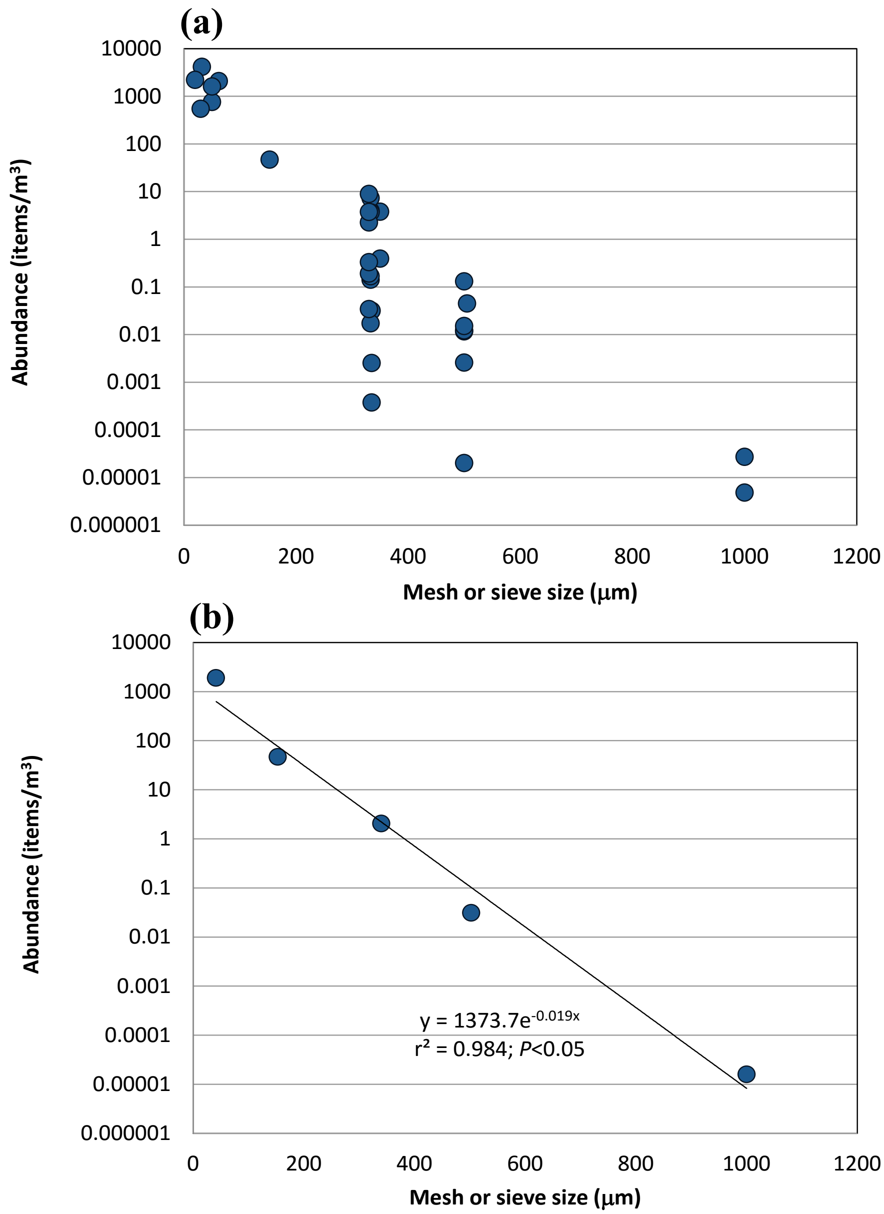

Figure 1.1 Relationship between sampling net or sieve mesh size and microplastic abundance; (a) all the abundance data from Table 1.1 and (b) average abundance data with each mesh size interval (20–63, 153, 330–350, 500–505, and 1000 μm).

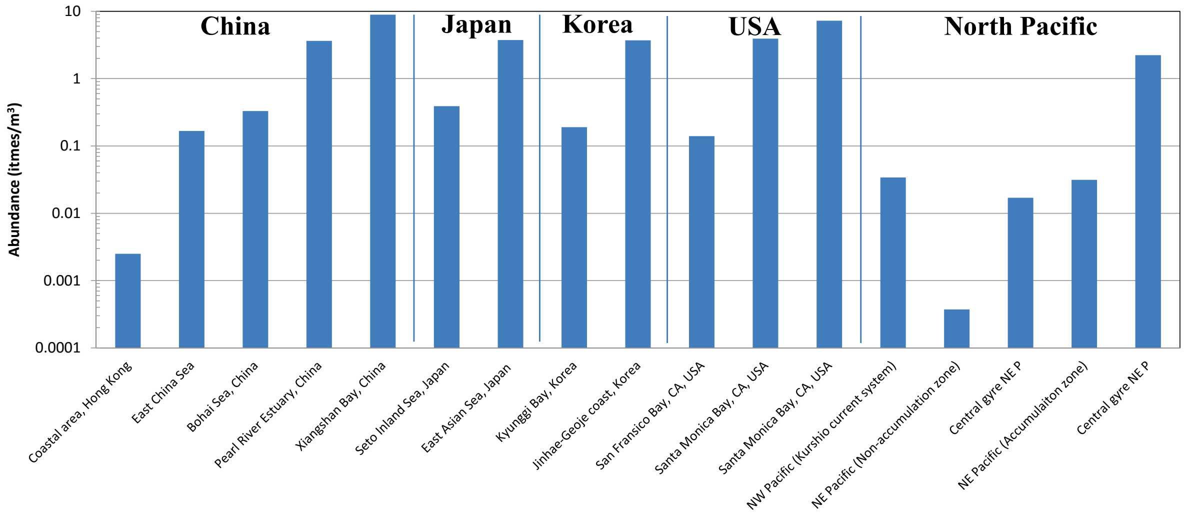

Figure 1.2 Microplastic abundance in surface water by region using 330–350 μm mesh size net.

Monitoring data of microplastics in seawater has limitations such as inconsistencies in measurement and sampling methods, and snapshot grab sampling, which makes them to be compared directly. Sea salt is directly produced from bulk seawater. The volume of sea water necessary to extract salt is very large and hence the sea salt sample represents a reasonable 'integrative sampler' of coastal water. So, sea salt can be a better representative for seawater pollution than the seawater sample obtained by snapshot grab sampling, unless disrupted by refining or additional contamination during manufacturing. On the basis of this hypothesis, recently Kim *et al*. (2018) compared microplastic content in 28 table sea salt brands produced from geospatially different sites (16 countries on six continents). In that study, it was distinctly observed that salt produced in Asian countries contained relatively high amounts of microplastics. Furthermore, they obtained significant linear correlations with plastic emissions from rivers worldwide and with microplastic pollution levels in surrounding water in the published literature. Even with some limitation, their results showed a possibility that sea salt can used as a good indicator of the magnitude of microplastic pollution in surrounding seawater, and suggested that microplastic pollution levels in environmental compartments of coastal regions are strongly related to one another and tend to increase proportionally to the amount of mismanaged plastic debris entering the sea.

1.3 References (Seawater)

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1.2 Microplastic abundance in sediments of the North Pacific and its marginal seas

Microplastic abundance in sediments from beach and subtidal areas of the six PICES member countries were reviewed from a literature survey (Web of Science; keyword, microplastics; 30 September 2018 and an additional report from NOAA). Microplastic abundance in inter- and subtidal sediments have been reported from 22 studies in the literature. As noted in studies of microplastics in water (see section 1.1), microplastic abundance in sediments has been reported using various metrics and units. Sediment data were selected for further comparison when they were reported as the mean value of the number of items per square meter or number of items per kilogram, and such units are relatively common in the literature. When studies provided information on quadrat size, sediment sampling depth, and volume of the sample, items per kilogram were converted into items per square meter. The conversion factor from weight to volume of sand sample (1 kg = 0.73 L) was based on Korean sand beach data (n = 20; Shim *et al*., 2018).

The mean abundance of microplastics in sediments ranged from 31 to 46,334 items/m^2 or 49 to 3266 items/kg for beaches and 72 to 2174 items/kg for subtidal sediments. The maximum difference in mean abundance of microplastics in sediments among the studies was in the range of three orders of magnitude, which was much less than that of seawater (see section 1.1). There was no clear relationship between the lower bound of microplastic size for sampling or detection and abundance in sediments (Fig. 1.3). The narrow range of the mean abundance of microplastics in beach sediments might be explained by sampling method, *e.g*. sampling of only high strandlines or wrack lines on beaches. For example, although only large microplastics in the size range 1–5 mm were monitored in the high strandline of Korean beaches, the mean abundance was 27,165 items/m^2 due to the high amount of expanded polystyrene spherules (Lee *et al*., 2015). On the other hand, 31 items/m^2 were reported from Japanese beaches for microplastics larger than 0.3 mm in size.

Among the 22 studies, there were 11 studies for China, including Chinese Hong Kong and Taipei, four studies for the United States, three studies for Korea, respectively, two studies for Japan, and one study for Canada and Russia, respectively. The abundance of microplastics in beach sand reported from China, Japan and Korea were relatively higher than those in Canada, Russia and the United States.

Table 1.2 Mean abundance of microplastics in sediments from beach and coast of six PICES member countries in the literature.

Location	Year	Sieve size	Abundance (items/m^2 or /kg)	Reference
Beach			items/m^2	
Soya Island, Korea	2013	> 0.050 mm	46334	Kim et al. (2015)
Coastal beach, Korea	2013	1-5 mm	27165	Lee et al. (2015)
Coastal beach, Korea	2016	0.02-5 mm	13687	Eo et al. (2018)
Guangdong, China	2015	0.315 - 10 mm	6675	Fok et al. (2017)
Hong Kong	2014-2015	0.315 mm mesh	3242	Cheung et al. (2016)
Coastal beach, Japan	2000	> 0.3 mm	2610	Kusui and Noda (2003)
Tokyo, Japan			>1000	Kuriyama et al. (2002)
Coastal beach, Taiwan	2015	>0.25 mm	528	Kunz et al. (2016)
Salish Sea, Washington, USA	2008-2011	1-5 mm	48	Davis and Murphy (2015)
Coastal beach, Russia	2000	> 0.3 mm	31	Kusui and Noda (2003)
			items/kg	
Qinzhou Bay, China	2016	0.05-5 mm	3266	Li et al. (2018)
Hawaii, USA	2015	<20 mm	134	Whitmire and Van Bloem (2017)
Bohai, China	2015	> 0.001 mm filter	128	Yu et al. (2016)
West coast, USA	2015	<20 mm	92	Whitmire and Van Bloem (2017)
Alasak, USA	2015-2016	<20 mm	68	Whitmire and Van Bloem (2017)
Vancouver Island, Canada	2015	>0.1 mm	60	Collicutt et al. (2019)
Hawaiian Island, USA		1-15 mm	38	Mcdermid and McMullen (2004)
Hawaiian Island, USA		1-15 mm	4.9	Mcdermid and McMullen (2004)
Subtidal			items/kg	
Qinzhou Bay, China	2016	0.05-5 mm	2174	Li et al. (2018)
Bohai Sea, China	2016	0.001 mm filter	172	Zhao et al. (2018)
Northern Yellow Sea, China	2016	0.001 mm filter	124	Zhao et al. (2018)
Changjiang Estuary, China	2015	GF/B filter	121	Peng et al. (2017)
Hong Kong	2015-2016	> 0.032 mm	118	Tsang et al. (2017)
Southern Yellow Sea, China	2016	0.001 mm filter	72	Zhao et al. (2018)

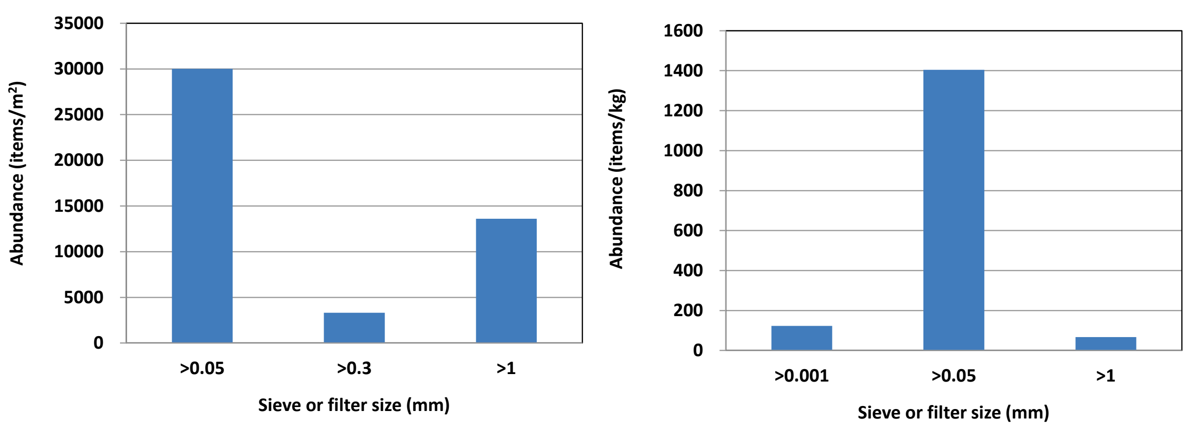

Figure 1.3 Mean abundance of microplastics on beach or subtidal sediment according to the sieve or filter size for sample preparation (left; abundance in items/m^2 for beach sediment, right; abundance in items/kg for both beach and subtidal sediment).

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1.5 Microplastic abundance in bivalves of the North Pacific and its marginal seas

Bivalves have been used as an indicator species for the assessment of environmental contamination by heavy metals and persistent organic pollutants due to their broad distribution, sedentary nature, high tolerance to a wide range of environmental stressors, and low rate of metabolism. Bivalves filter a large volume of seawater while feeding, leading to the accumulation of microplastics present in seawater. Bivalves are also popular seafood, and can be a direct route for human exposure to microplastics as they are consumed whole. For these reasons, effort has been devoted to assessing the contamination of microplastics in bivalves inhabiting the marine environment and sold in the market. In this section, the contamination levels and characteristics of microplastics in bivalves from North Pacific coastal regions were reviewed from the literature. Additionally, the data from coastal regions outside the North Pacific region were also collected and used together for analyzing the levels and physicochemical characteristics of microplastics ingested by bivalves. The majority of the publications on bivalves were published from 2014 onwards. So far, a total of 18 articles have been published in peer-reviewed journals (Table 1.3). Among them, 6 articles dealt with the North Pacific coasts; four were for China (Li *et al*., 2015, 2016, 2018; Qu *et al*., 2018), one for Canada (Davidson and Dudas, 2016), and one for USA (Rochman *et al*., 2015). The publications include a range of information regarding species, sampling method (field or market survey), and the abundance, size, shape, and polymer type of microplastics. Among bivalve species, mussels and oysters (12 and 4 of 18 articles, respectively) were widely used as monitoring species. A large variation in microplastic levels was found according to location, bivalve species, and sampling method. The microplastics in bivalves from the North Pacific coast ranged from 0.07 to 10.5 items/g wet weight (w.w.), comparable to those from the European coasts (0.04–13.2 items/g w.w.) (Table 1.3). Assessment of microplastics using bivalves has been conducted in two ways such as field- and market-based studies. Compared to field study, market-based study covered more species. The highest microplastic concentration was found in mussels from the Dutch coast (13.2 items/g w.w.), ark shells from the Chinese market (10.5 items/g w.w.), mussels from the Canadian market (75 – 178 items/g individual), mussels from Italian coast (4.4–11.4 items/g w.w., and 34–178 items/individual). If comparing only with data of mussels and oysters, microplastic levels in bivalves taken from the field showed relatively higher than those from the market (Table 1.3 and Fig. 1.4) . Some studies observed that the abundance of microplastics was relatively high in mussels from areas with intensive human activities compared to more pristine areas (Li *et al*., 2015, 2016). The morphological features and polymer types of microplastics ingested by bivalves were relatively similar in most regions including the North Pacific and Europe (Table 1.3). Except for the report from France (Phuong *et al*., 2018), fibres were the most common type of microplastics in bivalves. Microplastic size varied from a few micrometers to a few millimeters, where particle size less than 300 μm was more abundant (9 of 13 articles measured the size of particles). Among 18 studies, 9 studies identified polymer types of microplastics. Various polymers were found in bivalve tissues, including polyethylene terephthalate, polyethylene, polypropylene, polyamide, polystyrene, nylon, polyurethane, *etc*. where polyethylene terephthalate was the most dominant, followed by polyethylene (Catarino *et al*., 2018; Li, J. *et al*., 2018; Li, H.-X. *et al*, 2018; Qu *et al*., 2018). Interestingly, in the UK supermarket study (Li, J. *et al*., 2018), relatively high concentration of microplastics were found in pre-cooked mussels (1.4 items/g) compared with mussels supplied live (0.9 items/g), implying secondary contamination during processing or cooking. This should be considered when assessing human exposure to microplastics via seafood consumption.

Table 1.3 Abundance of microplastics in bivalves from coastal regions and markets by region.

	Country	Species		Sampling location	Microplastic concentration (n/g wet weight)	Microplastic concentration (n/individual)	Dominant shape	Common size (μm)	Reference
North Pacific	China	9 species [a]		MARKET	2.1 – 10.5	4.3 – 57.2	Fiber	<	Li et al. (2015)
	Canada	Mussel	*M. edulis*		NA [d]	75 – 178 [g]	Fiber	NA	Mathalon and Hill, (2014)
	USA	Oyster	*C. gigas*		NA	0.6 ± 0.9 (0 – 2) [f]	Fiber	2270 – 15840	Rochman et al. (2015)
Other regions	France	Oyster	*C. gigas*		0.47 ± 0.16	NA	NA	16 – 20	Van Cauwenberghe and Janssen (2014)
	〃	Mussel	*M. edulis*		0.06 ± 0.13	NA	Fiber	NA	Vandermeersch et al.(2015)
	Spain	Mussel	*M. galloprovincialis*		0.04 ± 0.09	NA	Fiber	NA	Vandermeersch et al.(2015)
	Belgium	Mussel	*M. edulis*		0.35 [d, g]	NA	Fiber	1000 – 1500	De Witte et al. (2014)
	UK	Mussel	*M. edulis*		0.9 [e]	NA	Fiber	5 – 250	Li et al. (2018)*
North Pacific	China	Mussel (F,W) [b]	*M. edulis*	FIELD	2.2 (0.9 – 4.6)	4 (1.5 – 7.6)	Fiber	5 – 250	Li et al.(2016)
	〃	Mussel (W)	*M. edulis, P. ciridis*		1.52 – 5.36	0.77 – 8.22	Fiber	250 – 1000	Qu et al. (2018)
	〃	Oyster (W)	*Saccostrea cucullata*		1.5 – 7.2	1.4 – 7.0	Fiber	< 100	Li et al. (2018)**
	〃	Manila Clam (F)	*V. philippinarum*		1.7 ± 1.2 (0.07 – 5.47)	11.3 ± 6.6	Fiber	NA	Davidson and Dudas (2016)
	〃	Manila Clam (W)	*V. philippinarum*		0.9 ± 0.9 (0.07-5.47)	8.4 ± 8.5	Fiber	NA	Davidson and Dudas (2016)
Other regions	Canada	Mussel (W)	*M. edulis*		NA	34 – 126 [g]	Fiber	NA	Mathalon and Hill (2014)
	Thailand	Oyster (W)	*S. forskalii*		0.57 ± 0.22 (0.2 – 0.6)		Fiber	NA	Thushari et al. (2017)
	Iran	3 species [c] (W)			0.01 – 0.3	0.27 – 8.83	Fiber	10 – 25	Naji et al. (2018)
	Belgium	Mussel (W)	*M. edulis*		0.2 ± 0.3	NA	NA	20 – 90	Van Cauwenberghe et al. (2015)
	France	Mussel (W)	*M. edulis*		0.23 ± 0.09	0.7	Fragment	50 –100	Phuong et al.(2018)
	〃	Mussel (W)	*M. edulis*		0.04 – 0.81	NA	Fiber	1000 – 1500	De Witte et al. (2014)
	Denmark	Mussel (F)	*M. edulis*		ND [f]	NA	ND	NA	Vandermeersch et al. (2015)
	Germany	Mussel (F)	*M. edulis*		0.36 ± 0.37	NA	NA	5 – 10	Van Cauwenberghe and Janssen (2014)
	Italy	Mussel (W)	*M. galloprovincialis*		0.05 – 0.16	NA	Fragment	NA	Vandermeersch et al. (2015)
	〃	Mussel (F)	*M. galloprovincialis*		0.25 ± 0.26	NA	Fragment	NA	Vandermeersch et al. (2015)
	〃	Mussel (W)	*M. galloprovincialis*		7.2 [e]	3.0	Fiber	1700 – 1900	Renzi et al. (2018)
	〃	Mussel (F)	*M. galloprovincialis*		4.4 – 11.4	3.6 – 12.4	Fiber	1700 – 1900	Renzi et al. (2018)
	Netherland	Mussel (W)	*M. edulis*		13.2 [e]	NA	Fiber	10 – 300	Leslie et al. (2017)
	〃	Mussel (F)	*M. edulis*		0.32 ± 0.22	NA	Fiber	NA	Vandermeersch et al. (2015)
	Portugal	Mussel (W)	*M. galloprovincialis*		0.08 – 0.34	NA	Fiber	NA	Vandermeersch et al. (2015)
	Spain	Mussel (W)	*M. galloprovincialis*		0.11 – 0.15	NA	Fiber	NA	Vandermeersch et al. (2015)
	UK	Mussel (W)	*M. modiolus*		0.09 ± 0.03	3.5 ± 1.29	Fiber	NA	Catarino et al. (2018)
	〃	Mussel (W)	*M. edulis*		3.0 ± 0.9	3.2 ± 0.52	Fiber	NA	Catarino et al. (2018)
	〃	Mussel (W)	*M. edulis*		0.7 – 2.9	1.1 – 6.4	Fiber	5 – 250	Li et al. (2018)

[a] 9 bivalve species: *Sc. Subcrenata, T. granosa, My. Galloprovincialis, P. yessoensis , A. plicatula , Si. constricta , R. philippinarum , Me. lusoria , C. sinensis*; ; [b] F: field, W: wild; [c] 3 bivalve species: *Amiantis umbonella, Amiantis purpuratus, Pinctada radiate*; [d] NA: not available; [e] Mean value; [i] ND: not detected; [h] Size range; [b] 3 bivalve species: *A. umbonella , A. purpuratus , P. radiata* ; [k] Calculated value from dry weight basis to wet weight basis

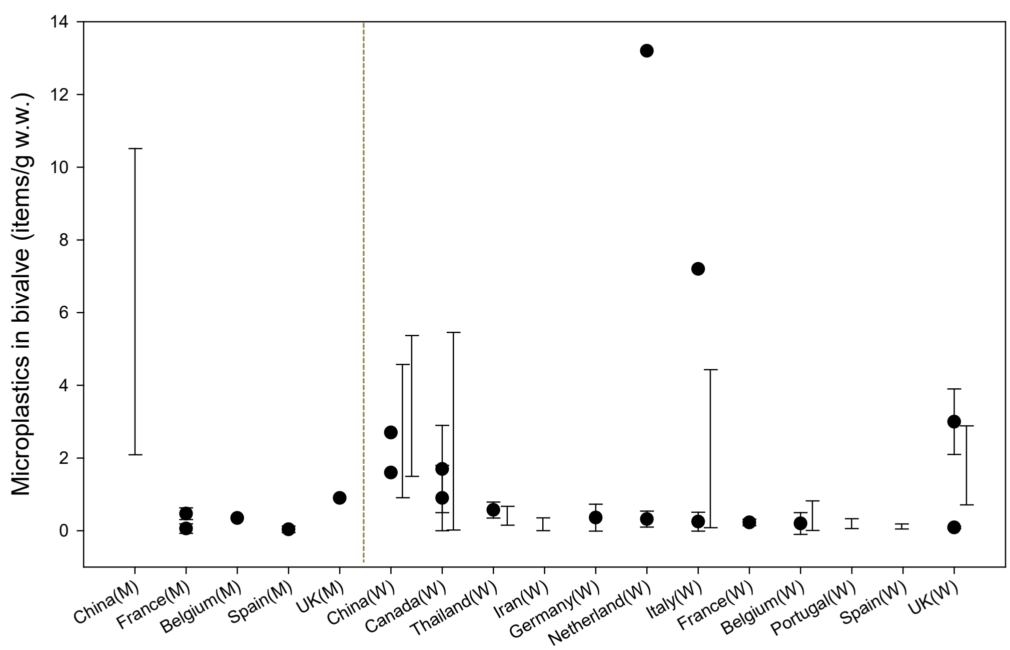

Figure 1.4 Microplastic concentration in bivalves from markets (M) and coasts (W) by region.

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1.7 Microplastic abundance in biota of the North Pacific and its marginal seas

In the North Pacific, studies on plastic debris ingested by (non-bivalve) biota were most prevalent on seabirds (n = 25 primary studies of plastic ingestion; 6 other [modeling, experiments, terrestrial birds]), followed by sea turtles (n = 7), and fish (n = 8 primary; 2 other). We found very few published studies on non-bivalve invertebrates (n = 3) and marine mammals (n = 2) from the North Pacific. Papers we located were published between 1969–2018. The vast majority of studies were based on specimens collected in the high seas or in the United States EEZ, including Hawaii.

- Of 62 **seabird** species examined across the 25 primary studies we located, the majority ingested some amount of plastic (range 0–1; mean proportion of individuals ingesting plastic: 0.4573).
- Of 91 **fish** species examined across the 8 primary studies, many of these species had not ingested plastic (range 0–1; mean proportion of individuals ingesting plastic: 0.1632).
- 4 species of **sea turtle** from 7 primary studies had a high average incidence of plastic ingestion (range 0–1; mean proportion of individuals ingesting plastic: 0.6445). There was a very high incidence of plastics ingestion in sea turtles, except for Leatherbacks. Leatherback turtles in the studies reviewed did not ingest plastic.
- 8 species of **non-bivalve invertebrate** were recorded ingesting plastic in the 3 studies we located.
- 2 species of **marine mammal** were recorded ingesting plastic in 2 studies we located.

The term "microplastic" was used in only a small fraction of the studies, usually in more recent studies. Studies published prior to 2010 rarely mentioned the term "microplastics".

Studies were not consistent in what they measured and reported. Some only recorded plastic incidence, and not how many individuals did not ingest plastic, such that plastic ingestion prevalence cannot be accurately assessed within a population. Others reported the proportion of individuals that had ingested plastic and no further quantitative data. More thorough studies quantified plastic in some way (total mass, volume, or number of pieces per individual), and some recorded characteristics of the plastic (*e.g.*, type, color). Overall, however, studies were inconsistent in their methodologies and in the data they reported, making meta-analyses challenging.

Table 1.4 Abundance of microplastics in biota from in North Pacific region.

# Species Studied	# ind w/ in gested pla stic	Total # studied	Proportion w. in gested plastic	Group	Reference
19	64	470	0.1362	seabird	Ainley et al. 1990
1	245	251	0.9761	seabird	Auman et al. 1997
1	62	67	0.9254	seabird	Avery-Gomm et al. 2012
1	1	1	1.0000	seabird	Avery-Gomm et al. 2013
9	24	96	0.2500	seabird	Baltz and Morejohn 1976
10	32	51	0.6275	seabird	Blight and Burger 1997
3	21	1824	0.0115	seabird	Boersma 1986
4	1	2546	0.0004	seabird	Bond et al. 2010
5	232	326	0.7117	seabird	Day 1980
1	314	363	0.8650	seabird	Donnelly-Green et al. 2014
2	59	74	0.7973	seabird	Fry et al. 1987
2	47	78	0.6026	seabird	Gray et al. 2012
1	74	100	0.7400	seabird	Kenyon and Kridler 1969
1	135	190	0.7105	seabird	Nevins et al. 2005
2	458	542	0.8450	seabird	Ogi 1990
16	245	360	0.6806	seabird	Rapp et al. 2017
21	470	1770	0.2655	seabird	Robards et al. 1995
17	1121	1336	0.8391	seabird	Robards et al. 1997
6	533	1127	0.4729	seabird	Sileo et al. 1990
9	84	406	0.2069	seabird	Spear et al. 1995
1	12	12	1.0000	seabird	Tanaka et al. 2013
1	227	330	0.6879	seabird	Vlietstra and Parga 2002
1	20	307	0.0651	seabird	Watanuki 1985
1	99	99	1.0000	seabird	Yamashita et al. 2011
1	23	23	1.0000	seabird	Young et al. 2009
6	235	671	0.3502	fish	Boerger et al. 2010
10	112	595	0.1882	fish	Choy and Drazen 2013
27	13	141	0.0922	fish	Davison and Asch 2011
2	49	1373	0.0357	invertebrate	Desforges et al. 2015
1	2	19	0.1053	fish	Gassel et al. 2013
1	129	385	0.3351	Invertebrate	Goldstein and Goodwin 2013 [a,b]
1	47	192	0.2448	fish	Jantz et al. 2013
27	0	27	0.0000	fish	Khalida et al. 2017
22	31	135	0.2296	fish	Rochman et al. 2015
1	49	64	0.7656	fish	Tanaka and Takada 2016
6	NA	20	NA	invertebrate	Xiaoxia Sun et al. 2018
1	1	1	1.0000	sea turtle	Arauz Almengor and Avila 1994
4	50	55	0.9091	sea turtle	Clukey et al. 2017
1	2	8	0.2500	sea turtle	Ng et al. 2016
1	18	52	0.3462	sea turtle	Parker et al. 2005
1	7	10	0.7000	sea turtle	Parker et al. 2011
1	1	1	1.0000	sea turtle	Van Houtan et al. 2016
3	102	121	0.8430	sea turtle	Wedemeyer-Strombel et al. 2015
1	2	2	1.0000	marine mammal	Jacobsen et al. 2010
1	NA	10	NA	marine mammal	Fossi et al. 2016

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SG-MMP Endnote 6

Proposal for the establishment of a Working Group on *Indicators of Marine Plastic Pollution*

Parent Committee: MEQ

Term: November 2018– November 2021

Linkage(s) to previous PICES expert groups or activities: Study Group on *Marine Pollutants*

Linkage(s) to other organizations and programs: SCOR, GESAMP, ICES, WESTPAC

Linkages to FUTURE:

3. How do human activities affect coastal ecosystems and how are societies affected by changes in these ecosystems?	
3.1. What are the dominant anthropogenic pressures in coastal marine ecosystems and how are they changing?	**Characterize plastic pollution priorities in the North Pacific**
3.2. How are these anthropogenic pressures and climate forcings, including sea level rise, affecting nearshore and coastal ecosystems and their interactions with offshore and terrestrial systems?	**Document effects of plastic pollution in the North Pacific Ocean, especially in the coastal environment**
3.3. How do multiple anthropogenic stressors interact to alter the structure and function of the systems, and what are the cumulative effects?	**Collaborate with other expert groups to document importance of plastic pollution in the context of multiple stressors**

Motivation and Goals

- Marine debris is increasingly recognized as a threat to biota in the ocean, which can have a range of socio-economic impacts from coastal areas to the open ocean.
- Small plastic debris can increase the bioavailable fraction of marine litter and act as a vector for the delivery of intrinsic additive toxic chemicals to exposed biota.
- Floating and beached small plastic debris have been documented in the North Pacific Ocean and its marginal seas, and their abundances are ranked at the top position in the world.
- However, both organismal and non-organismal indicators, which are consistently available across the North Pacific region, for plastic pollution status and trend and ecological impacts are not established.
- The Working Group will strengthen partnerships and collaborate with other organizations (*e.g.*, WGML of ICES, GESAMP WG40, NOWPAP, and IOC/WESTPAC) to address marine plastic pollution related issues.

Terms of Reference

1. To review micro- and mesoplastic pollution (e.g. abundance, distribution, composition, and potential impacts) in North Pacific and its marginal seas;
2. To identify multiple organismal and non-organismal indicators of plastic pollution and its environmental impacts including associated chemicals in North Pacific and its marginal seas;
3. To recommend guidelines for monitoring environmental indicators and a target improvement goal for the established indicators;
4. To convene a topic session and/or workshop on environmental indicators and impacts of plastic pollution and coordinate a special issue in an international peer-reviewed journal;
5. Contribute to FUTURE by publishing a final report summarizing results of Working Group deliberations.

Proposed membership

Proposed Co-Chairs: Jennifer Lynch (USA), Chengjun Sun (China)

Canada
Sarah Dudas (Fisheries and Oceans Canada)
Chelsea Rochman (University of Toronto)
Peter Ross (Coastal Ocean Research Institute)
S. Avery-Gomm (University of British Columbia)

China
Chengjun Sun (First Institute of Oceanography)
Daoji Li (East China Normal University)
Juying Wang (National Marine Environmental Monitoring Center (NMEMC))
Connie Ng (City University of Hong Kong)
Qiufen Li (Yellow Sea Fisheries Research Institute (CAFS))

Japan
Hideshige Takada (Tokyo University of Agriculture and Technology)
Haruhiko Nakata (Kumamoto University)
Shuhei Tanaka (Kyoto University)
Yutaka Wtanuki (Hokkaido University)

Korea
Wonjoon Shim (Korea Institute of Ocean Science and Technology)
Sanghee Hong (Korea Institute of Ocean Science and Technology)
Seung-Kyu Kim (Incheon National University)

Russia
Nikolai Kozlovskii (Pacific Geographical Institute)

USA
Jennifer Lynch (National Institute of Standards and Technology)
Matthew Savoca (Stanford University)
David Hyenbach (Hawaii Pacific University)
Michelle Hester (Oiknos)
Amy Uhrin (NOAA)

SG-MMP Endnote 7

Proposal for a
Topic Session on "*Environmental indicators of plastic pollution in the North Pacific*"
at PICES-2019

Duration: 1 day

Co-sponsor: NOWPAP

Co-Convenors: Matthew Savoca (USA), Chengjun Sun (China), Lev Neretin (NOWPAP)

Potential invited speakers: Chelsea Rochman (Canada), Anela Choy (USA), Lindsay Young (USA), David Hyrenbach (USA)

Small fragments of plastic debris – known as meso- and microplastics – are pervasive in marine systems. These synthetic particles may transfer contaminants and pathogens to organisms that consume them; as such, meso- and microplastics are now considered hazardous, persistent marine pollutants. Sampling an entire system for debris is challenging; therefore, having environmental indicators of plastic debris is critical to assess the status and trends of plastic pollution in addition to predicting ecosystem risk and quantifying potential impacts. This session will identify and discuss potential organismal and non-organismal (*e.g.*, sediments) indicators of small synthetic material in the marine environment, including the potential sources and input pathways of small plastic debris (*e.g.*, wastewater effluent) to the North Pacific and its marginal seas. Presenters will also focus on indirect indicators of plastic pollution, such as plastic additives leading to chemical contamination in organismal tissues. A deeper understanding of these marine debris sentinels will help us elucidate the status and trends of small plastic pollution and their environmental impacts in the North Pacific and globally, thus allowing is to make informed decisions for plastic usage and litter management policies.