Reference Materials

Development of an Underwater Floating-type Ocean Current Power Generation System and the Demonstration Sea-trial

[KEYWORDS] ocean current turbine / Kuroshio current / Kairyu

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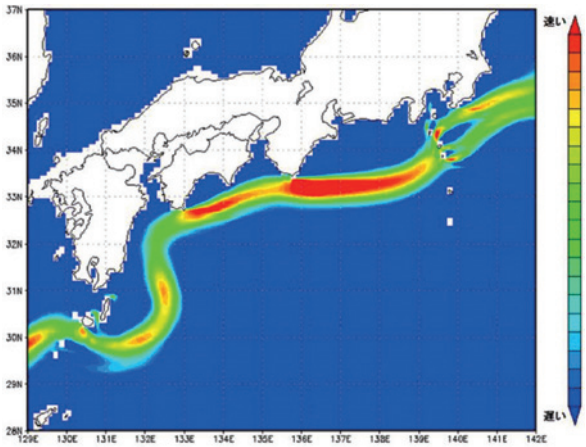
Ocean current power, an example of ocean renewable energy, is a renewable energy technology that aligns well with Japan's aims for effective utilization of the "Kuroshio" current. In August 2017, IHI Corporation and the New Energy and Industrial Technology Department Organization (NEDO) conducted an experimental test off the shore of Kuchinoshima in Kagoshima Prefecture, and gained data that can be utilized for future operationalization. The 100kW device is one of the largest devices for ocean currents in the world. Here, I will give an overview on the world's first floating offshore ocean current power system.

Power Generation Using the Kuroshio Current

Japan's territorial waters and exclusive economic zone (EEZ) are the sixth largest in the world, and the use of marine renewable energy in the EEZ is being actively promoted from the viewpoint of energy security and reducing greenhouse gas emissions. In particular, the Kuroshio current (Fig. 1), which flows in the waters near Japan, is one of the strongest ocean currents in the world, in which it is estimated that an enormous 205 GW of energy exists[*1*2]. Enabling power generation from the Kuroshio current would make it a very useful renewable energy source for Japan.

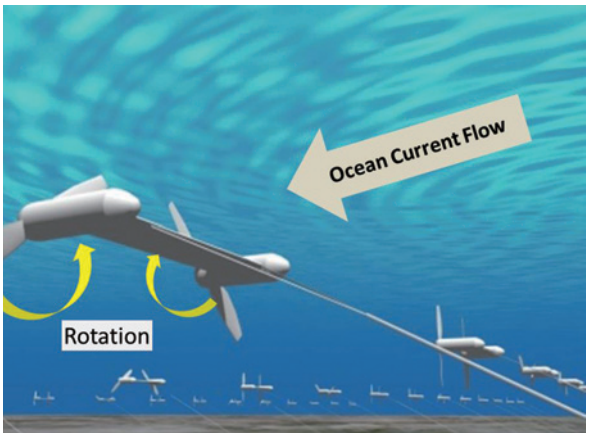
With respect to this ocean current power generation, the author and others started research and development of an underwater floating-type ocean current power generation system (Fig. 2) for a NEDO project in FY2011 as an efficient power generation device that has low power generation costs, and a power generation demonstration test in the Kuroshio area was completed in the summer of 2017. This article introduces an outline of it.

■Fig. 1: Example forecast by numerical analysis of the Kuroshio current's axial distribution



The Kuroshio current passes through the Tokara Strait and enters the Pacific Ocean.

■Fig. 2:Image of a large-scale power generation farm using underwater floating-type ocean current power generation systems



Features of Underwater Floating Ocean current power Generation Systems

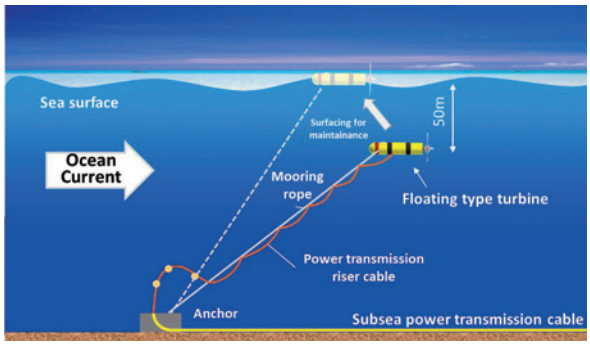
Marine currents must have the following characteristics in order to realize power generation from them: few daily or seasonal fluctuations in the speed and direction of the flow; a large current about 100km wide off the East China Sea and the Pacific Ocean, and; a flow near the sea surface in a sea area with a depth of several hundred meters.[*3] In order to generate power from such an ocean current, the underwater floating ocean current power generation system has the following characteristics:

(1) The goal is to achieve the capacity factor of 60% or higher, which is extremely high for renewable energy, due to being able to continuously use energy from stable ocean currents for a long time. This stable power supply can also be expected to be a base load power source.

(2) The floating body with turbine is moored to the bottom of the sea with a mooring line, and floating in the sea by the marine current as if it were a kite (Fig. 3). It can easily be installed in deep water by extending the mooring line, so it is possible to set a wide range of installable sea areas and to deploy large-scale power generation farms with a large number of power generators.

In addition, because they are all underwater, they can be

■Fig. 3:Conceptual diagram of an underwater floating ocean current power generation system



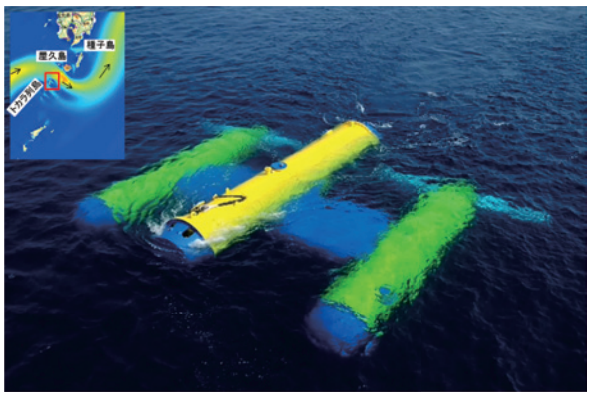
operated at a stable depth without being affected by waves, and they will not interfere with ship navigation. Furthermore, since it is possible to use simple mooring, the ease of installation also contributes to cost reduction.

(3) The rotational torque accompanying turbine rotation can be canceled by connecting two counter-rotating turbines, thus maintaining a stable position in the sea and enabling efficient power generation.

(4) Maintenance and repair are easy because the turbine can be sent to the ocean surface as needed by adjusting the direction and buoyancy of the turbine.

Taking advantage of these characteristics, it is assumed that an actual underwater floating ocean current power generation system would have a power output of 2MW (1,000kW x 2) per unit. A large-scale ocean current power generation farm with a large number of them would aim to achieve a power generation cost of ¥20/kWh or less, which is the target set for NEDO projects, and to realize a power generation system comparable to other power generation methods in terms of power generation costs.

■Fig. 4:External view of the 100kW "Kairyu" demonstration prototype and the demonstration test area



Offshore Operational Tests

Using the results of essential element technology development that began in 2011, a power generation demonstration experiment of an underwater floating ocean current power generation system was conducted in the actual Kuroshio current region from July to August 2017.

For this demonstration test, an actual demonstration prototype with a turbine diameter of approximately 1/3 scale (Fig. 4. Named "Kairyu" after soliciting names from local elementary and junior high school students) was developed and built at IHI Yokohama Engineering Center, using the same mechanism, structure, and materials as the actual machines of the future.

This "Kairyu" floats in the water with an overall length and width of approximately 20m and a weight of approximately 330 tons. It is composed of three watertight and pressure-resistant vessels (pods) that contain various machinery. At the rear ends of the left and right pods, there is a horizontal axis turbine equipped with a controllable blade pitch angle mechanism, with a rotor diameter of 11 meters. Together, the left and right pods can generate a maximum of 100kW in a 3-knot current. The central pod is equipped with a mechanism for adjusting buoyancy, power transmission equipment, and so forth. During power generation in the sea, the depth and position of the machine, power generation performance, and emergency response are controlled autonomously in response to the changing external environment by the built-in control device. In an advance trial run during which the unit was towed, it was confirmed that it can generate a maximum output of 100kW, as planned, and that it could stably float through autonomous control.

The next verification test in the Kuroshio area was conducted in the coastal area north of Kuchinoshima, Toshima Village, Tokara Islands, Kagoshima Prefecture, which has been approved as a marine energy demonstration field by the National Ocean Policy Secretariat, Cabinet Office. A power generation test was carried out by mooring "Kairyu" in the marine area where the Kuroshio current flows, about 5km offshore from Kuchinoshima, with a seafloor depth of approximately 100m. There was a current of 2 knots maximum during this test period, and power generation of approximately 30kW was achieved as a result of this demonstration test. Valuable data about the actual Kuroshio current area's characteristics was also obtained, such as the float stability of floating objects, and installation and operational work in the actual marine area. This is the world's first power generation using a 100kW class ocean current generator that is installed in an actual ocean current area.

Towards Practical Use

Underwater floating ocean current power generation systems are a new power generation technology that can shoulder the role of a base load power source through

1) Marine current energy and high efficiency underwater turbine power generators that bring high capacity factor, and

2) Low-cost float mooring methods, regardless of the sea area.

In the future, we aim to commercialize the ocean current power generation system in the 2020s by carrying out detailed investigations and research on the Kuroshio current as a renewable energy source, and long-term operation trials are planned to be implemented from 2019 to 2020. ■

● This paper is based on the results of a NEDO project, the "Marine Energy Technology Research and Development / Marine Energy Power Generation Technology Demonstration Study."

*1 New Energy and Industrial Technology Development Organization (NEDO): "NEDO Renewable Energy Technology White Paper -- Towards a New Energy Society" (2010)

*2 New Energy and Industrial Technology Development Organization (NEDO): Results report for "Research and Development of Natural Energy Technologies such as Wind Power / Research and Development of Offshore Wind Power Generation Technology, etc. / Operations Related to Understanding Marine Energy's Potential" (2011)

*3 In addition to ocean current power generation, tidal current power generation is a method of power generation that utilizes underwater currents. Tidal currents associated with tidal fluctuations are characterized by large fluctuations in the speed and direction of the flow during the day.

Efforts towards the Creation of an Oyster Farming Pipe Utilizing Biodegradable Plastics

[KEYWORDS] Hiroshima Bay / aquaculture materials / outflow prevention

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Oyster farming utilizes several plastic materials including oyster pipes (20cm-long polyethylene tubes to provide spaces for farmed oysters) and Styrofoam floats of oyster rafts. The number of oyster pipes used in Hiroshima Bay are estimated to be more than 200million, and some of them are lost due to ship collisions. Introduction of biodegradable materials used for oyster pipes could reduce the environmental problems associated with the lost and drifted pipes. To identify the strength of biodegradable oyster pipes, strength tests have been conducted since 2018, in addition to exiting studies to reduce pollutions caused by broken styrofoam floats.

Can Oyster Farming Pipes be Prevented from Outflowing?

The problem of oyster farming materials and drifting waste in Hiroshima Bay has been around for more than 20 years, and the Styrofoam floats (hereinafter referred to as "floats") and oyster pipes (hereinafter referred to as "pipes") have been alternately attracting attention over the past several years. In 2017, the Umi & Nagisa Foundation conducted a demonstration test in which float pellets were turned into fuel at four locations nationwide, and achieved a certain level of success, at the end of 15 years development. Next, an experiment using oyster pipes made of biodegradable plastic was conducted in Hiroshima. This has been a long-standing challenge, even before marine plastics became a social problem.

Plastic pipes for oyster farming are used when hanging scallop shells to which the seedlings will be attached, to secure a certain amount of space between them. The existing polyethylene (hereinafter referred to as PE) pipes are 20cm long, have a 1.5cm outside diameter, approx. a 1.0cm inside diameter, and cost only a few yen per pipe, but they are important materials and are kept for reuse, and not allowed to outflow. Pipe outflows have become both an economic and an environmental problem for oyster farmers. Currently, more than 200 million pipes are used in Hiroshima Bay, with 17,000 pipes per floating raft for oyster farming. Even if a tenth of a few percent of using pipes are outflowing, it means that 100,000 pipes will be released. This is a considerable amount if you have accumulated the outflow pipe, but the cause of outflows is not just the aquaculture work, and it seems impossible to completely prevent outflows by the efforts of fishermen alone. For example, over the past three years, there have been, average per year, 40 oyster farming floating rafts collide with the ship and are broken. If all the pipes became disengaged during these accidents, then the outflow from these accidents would be 680,000 pipes/year. Fishermen must work on outflow prevention and improvements, but because of this background, we decided to conduct a field experiment with biodegradable plastic pipes that would decompose faster than PE pipes.


Fragmented oyster pipes and white Styrofoam floats drifted down

Initiatives in Hiroshima Prefecture

More than 15 years ago, the Western District Hiroshima Prefectural Fisheries Promotion Council established a program for purchasing pipes that have been released and drifted out of the prefecture, but purchases are subject to conditions, such as the shape of the pipes, and local municipalities where the beach with drifted pipes is located may dispose of them. In addition, officers in charge at Hiroshima Fisheries Cooperative and the the Fisheries Division of Hiroshima Prefectural Government were aware of the problems and visited the float processing demonstration test conducted by the Foundation in FY2017, but it did not lead to a proper disposing project.

However, on May 14, 2018, a representative of Yamaguchi Prefecture visited the Hiroshima Prefectural Office and requested, in writing, "Thorough outflow prevention and recovery of plastic pipes used in oyster farming". In response, Hiroshima Prefecture sent an administrative guidance about outflow prevention to the head of the fishery cooperative that handles oyster farming in the prefecture. At the Governor's regular press conference, reporters asked questions about marine litter countermeasures, in particular about outflows of oyster farming materials and the request

lodged by Yamaguchi Prefecture.

When oyster farmers from Hiroshima Prefecture collected drifting pipes and other litter in Suo-Oshima Town and other places in Yamaguchi Prefecture on September 7, apparently some of them were surprised by the large number of pipes. It shows that there is not precise information of the issue amongst oyster farmers. On the other hand, there is also an initiative for float processing in which the Hiroshima Fisheries Cooperative acts as a contact point, and we expect that this will lead to an improvement in fishermen's awareness and efforts to solve the pipe outflow problem.

Challenges for Trial Production, Experimentation, and Introduction of Biodegradable Plastic Pipes

Two types of experiments were planned, using a total of three types of prototype pipes (20cm long PBS and 2 types of PLA)*1, and using the existing PE pipes for comparison. In Experiment (1), hanging the pipes down on an aquaculture cage, the percentage of good reusable pipes was measured by selecting not-reusable pipes that had cracks or were bent, assuming actual work such as moving rafts. As for biodegradable plastic pipes, unused prototype pipes and pipes that had deteriorated after being boiled in seawater for several hours were used and installed in the same rack for comparison. They were installed at the fisheries cooperative on October 25, 2018, and would be collected in January and May, 2019. For experiment (2), pipes will be installed at depths of 0m (surface level), 1m, and 5m, and then their weight and surface deterioration will be observed. The Hiroshima Prefectural Fisheries Division and Ocean Technologies Center of Hiroshima prefectural Technology Research Institute will begin a seawater immersion test on November 2, and will measure weight changes after 1, 3, and 6 months to investigate durability and degradability.

When compared to the ready-made PE, the PLA prototype seems to be very hard and strong, but it is vulnerable to cracking. The PBS prototype is flexible and seems to be the closest to the ready-made PE. In January 2019, we observed the status after three months of immersion. Just like in actual harvesting, scallop shells were dropped on the ship and the pipes were collected separately. According to the fishermen who cooperated in the experiment, they felt that more pipes had cracked than the PE pipes that they use on a daily basis, and they were worried that the pipes would break when put into a cleaning machine for reuse. There are still lots of tasks in this work.

It may be better to consider introduction to "blister pipe (mame-kuda)" first. For collecting oyster seedlings, a short pipe, cut to about 1 cm in length and known as a " blister pipe (mame-kuda)" is used. Blister pipes were the most commonly collected piece of the marine litter. Blister pipes are less likely to break due to resistance to running water, and are therefore easier to introduce into actual faming than longer pipes.

Hanging ropes with biodegradable plastic pipes

"Blister pipes" are used in between scallops

Also, as a matter of concern for their introduction, there is a specific gravity issue that is difficult to notice when used on land. Most biodegradable plastics sink, so more floats will be attached to the rafts if biodegradable plastic is used and the burden on fishermen will increase. In the case of outflows, PE pipes can be collected by rafts and work boats, but biodegradable plastic will become seabed waste and will be difficult to collect. It is said that used PVC pipes and PE pipes are still on the seabed. There is no material that is good to leave in nature, not just biodegradable plastic.

Sustainable Aquaculture

The non-use of plastic, such as straws and plastic bags that are provided directly to customers, will lead to improving corporate images, while measures for floats and pipes,

which are items not to be provided to customers, tend to be delayed, as they are unlikely to lead to increased product prices. For this reason, the Public Awareness of Hiroshima Prefecture residents are important, but at the same time, it is necessary that distributors show concern when fishermen take countermeasures against outflows and to see whether fishermen are properly managing their fishing gear. In addition, certification for eco-labels, etc., shall also require added items to be checked off regarding proper treatment and disposal of fishing gear.

Some ear-pleasing information has been reported on the problem of marine plastics, but there is no quick remedy for the marine litter problem. The best way is to keep up steady, uninterrupted efforts. This probably wouldn't have been so exciting if the Ocean Plastics Charter had been signed.

It is important not to focus on the G20 declaration to be held in Osaka in June 2019, but to focus on the subsequent government and industry efforts. ■

*1 PBS (polybutylene succinate) and PLA (polylactic acid) are both a type of biodegradable plastic.

Protecting Palau's Oceans through Disposal of Explosive Remnants of War (ERW)

[KEYWORDS] unexploded munitions disposal / conservation of ocean areas / international contributions

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In Palau, the non-governmental organization Japan Mine Action Service (JMAS) has been working to dispose of explosive remnants of war (ERW) since 2012. For example, the outsides of many depth charges (weapons for anti-submarine warfare) remaining on the Japanese cargo vessel known as Helmet Wreck have rotted in the 70 years since the war, releasing the poisonous picric acid. As this acid has negative impacts on the water condition in the gulf, JMAS took efforts to prevent this up until 2015. Currently, the organization deals with monitoring and disposing ERW found on sunken ships and in shallow waters and in securing safety in the oceans.

Japan Mine Action Service (JMAS)

Japan Mine Action Service (JMAS) is a designated non-profit organization (NPO) that has been certified by the Tokyo Metropolitan Government, and is sometimes referred to as an NGO because of its activities. Japan Ground Self Defense Force retirees set up the organization in 2002 and immediately started the Cambodia unexploded bomb disposal program. After that, the organization has worked in Afghanistan, Angola, and Pakistan. At present, the organization is involved in a comprehensive machinery project related to landmine and unexploded bomb disposal in Cambodia's Kampong Thom Province, a regional development promotion project that includes landmine and unexploded shell disposal in Banteay Meanchey Province, a "Safe Village Construction" comprehensive community development project in Battambang Province, a cluster munitions processing mechanization project in Laos's Xiangkhouang Province, a project to deal with unexploded munitions in Palau, and the Oil Leakage Countermeasures Project for World War II Wrecks in Truk Lagoon Marine Area, Federated States of Micronesia" (Chuuk State).

With the exception of the "Safe Village Construction" project in Cambodia, the organization is funded as part of Japan's Official Development Assistance (ODA) and is expected to contribute to the Sustainable Development Goals (SDGs), a global standard set by the United Nations.

Explosive Remnants of War

A basic bomb mechanism operates through the combination of an explosive charge, which is the center of the explosive power, and a fuse that ignites it. Normally, when the bomb is not used, the explosive charge and the fuse are separated to prevent the bomb from exploding unexpectedly, which allows the bomb to be stored safely.

What are commonly referred to as unexploded ordinance are either unexploded or abandoned ordinance. Unexploded Ordinance (UXO) are bombs that did not explode even though a fuse was attached to the explosive charge for use in combat. Abandoned Explosive Ordnance (AXO) are

Investigating depth charges in shallow water.

munitions that have been abandoned or left unattended because of withdrawal or disarmament, etc. In many cases AXOs had not been used and, usually, a fuse was not attached.

UXO and AXO are collectively defined as Explosive Remnants of War (ERW), but both ERW and UXO are used in the same way as terms for unexploded munitions.

Unexploded Munitions in Palau

After World War I, Palau became a Japanese mandate from a German colony, the Nan'yo Cho (Territorial Government of the South Seas) and its Palau Branch were established, and Palau became the core island of the South Pacific Islands. Palau became an important base for the Japanese Navy when World War II began, and was therefore subject to attack by the U.S. military. On March 30 and 31, 1944, aircraft launched from U.S. Navy aircraft carriers attacked ships and ground facilities, dropping mines in Palau's harbor and surrounding waterways. This was the so-called Palau Air Raid. As a result, every ship berthed on that day was sunk while at anchor.

JMAS Palau is currently dealing with unexploded bombs and shells used by the U.S. military, as well as abandoned bombs left in the sea, which were at the time mounted on Japanese ships that sank. In the three years from 2012 to

Protecting Palau's Oceans through Disposal of Explosive Remnants of War (ERW)

2015, JMAS dealt with the depth charges loaded on a ship known as the Helmet Wreck, which sank in water that is 30m deep and 1km off the coast of Malakal Port, Palau's only commercial port. Helmet Wreck is a tentative name and was a transport ship used by the Japanese military, but the ship's real name is unknown. A depth charge is a bomb that attacks submarines; it is dropped from a ship into the water and when reaching a set depth, the fuse is activated and it explodes.

The depth charges were disposed of because 70 years after the war, the depth charge containers in the water had corroded and cracked. Picric acid, which is a toxic explosive charge, was leaking from the inside and having an adverse effect on the environment. In 2013 the Palau government asked the Geneva International Centre for Humanitarian Demining (GICHD) in Switzerland to conduct an environmental survey. As a result of the survey, two depth charges, which had fuses attached and were leaking picric acid, were removed from the Helmet Wreck.

Permicron Guard (trade name), which hardens in water to form a harmless plastic, was used to prevent leakage of picric acid. Permicron Guard is used for reinforcement and rust prevention in harbors, river facilities, etc., and the components do not contain toxic substances and do not dissolve in water. Leakage of picric acid is prevented by smearing Permicron Guard on cracks in the depth charge containers.

In 2014, 105 depth charges were treated to prevent picric acid leakage, and the pH value of the seawater in the ship improved from 6.80 to 8.07, which is the average value for the ocean area, and seawater transparency increased. In addition, signs of fish life have increased and the ecosystem is also recovering. Two depth charges with fuses were destroyed on land in 2015. Thereafter, periodic monitoring is conducted to check for environmental abnormalities and new picric acid leaks, and to take measures to prevent leaks.

Raising a depth charge using a balloon.

Using Google Earth to record depth charges.

Slight leakage of picric acid continues, but it has been suppressed to such an extent that there is almost no major impact on the environment.

From 2016, JMAS surveyed 36 shipwrecks and unexploded munitions over approximately 700,000m2 of ocean in depths of less than 10m in Malakal Bay and the Rock Islands Southern Lagoon World Heritage site. Of the 36 recorded shipwrecks, 15 have been confirmed, 5 had unexploded munitions, and many depth charges, etc., were discovered, even in shallow waters.

The Palau government is trying to establish a database of unexploded munitions that records their location, type, number, etc., on a map, using it as an index to ensure safety. Initially it was registered in the Palau government's map system, but now it uses Google Earth, which is simpler and more generalized. The figure on the right shows shallow water depth charges recorded in Google Earth: red marks indicate depth charges scheduled to be disposed of, white circles have already been disposed of, and numbers identify each depth charge. The situation of this unexploded ordinance is clear at a glance, and JMAS intends to dispose of all depth charges in the area during the year.

In Palau, the Lagoon Monument legal provision requires the obtaining of approval from the President when working on underwater ruins. Therefore, depth charge disposal is also carried out with the President's permission. From next year, JMAS intends to dispose of an estimated 165 depth charges that are left in the Helmet Wreck. Unlike the work in shallow water, the water at Helmet Wreck reaches 30m depth, which makes it more difficult, but we want to make every effort to ensure that Palau is as safe as possible. ■

● NPO Japan Mine Action Service (JMAS) https://jmas-ngo.jp/

IPCC Special Report on the Ocean and Cryosphere in a Changing Climate

Headline Statements of the Summary for Policymakers

Section A. OBSERVED CHANGES AND IMPACTS

Observed Physical Changes

A1. Over the last decades, global warming has led to widespread shrinking of the cryosphere, with mass loss from ice sheets and glaciers (very high confidence), reductions in snow cover (high confidence) and Arctic sea ice extent and thickness (very high confidence), and increased permafrost temperature (very high confidence).

A2. It is virtually certain that the global ocean has warmed unabated since 1970 and has taken up more than 90% of the excess heat in the climate system (high confidence). Since 1993, the rate of ocean warming has more than doubled (likely). Marine heatwaves have very likely doubled in frequency since 1982 and are increasing in intensity (very high confidence). By absorbing more CO_2, the ocean has undergone increasing surface acidification (virtually certain). A loss of oxygen has occurred from the surface to 1000m (medium confidence).

A3. Global mean sea level (GMSL) is rising, with acceleration in recent decades due to increasing rates of ice loss from the Greenland and Antarctic ice sheets (very high confidence), as well as continued glacier mass loss and ocean thermal expansion. Increases in tropical cyclone winds and rainfall, and increases in extreme waves, combined with relative sea level rise, exacerbate extreme sea level events and coastal hazards (high confidence).

Observed Impacts on Ecosystems

A4. Cryosphere and associated hydrological changes have impacted terrestrial and freshwater species and ecosystems in high mountain and polar regions, through the appearance of land previously covered by ice, changes in snow cover, and thawing permafrost. These changes have contributed to changing the seasonal activities, abundance and distribution of ecologically, culturally, and economically important plant and animal species, ecological disturbances, and ecosystem functioning. (high confidence)

A5. Since about 1950 many marine species across various groups have undergone shifts in geographical range and seasonal activities in response to ocean warming, sea ice change and biogeochemical changes, such as oxygen loss, to their habitats (high confidence). This has resulted in shifts in species composition, abundance and biomass production of ecosystems, from the equator to the poles. Altered interactions between species have caused cascading impacts on ecosystem structure and functioning (medium confidence). In some marine ecosystems, species are impacted by both the effects of fishing and climate changes (medium confidence).

A6. Coastal ecosystems are affected by ocean warming, including intensified marine heatwaves, acidification, loss of oxygen, salinity intrusion and sea level rise, in combination with adverse effects from human activities on ocean and land (high confidence). Impacts are already observed on habitat area and biodiversity, as well as ecosystem functioning and services (high confidence).

Observed Impacts on People and Ecosystem Services

A7. Since the mid-20th century, the shrinking cryosphere in the Arctic and high-mountain areas has led to predominantly negative impacts on food security, water resources, water quality, livelihoods, health and wellbeing, infrastructure, transportation, tourism and recreation, as well as culture of human societies, particularly for Indigenous peoples (high confidence). Costs and benefits have been unequally distributed across populations and regions. Adaptation efforts have benefited from the inclusion of Indigenous knowledge and local knowledge (high confidence).

A8. Changes in the ocean have impacted marine ecosystems and ecosystem services with regionally diverse

outcomes, challenging their governance (high confidence). Both positive and negative impacts result for food security through fisheries (mediumconfidence), local cultures and livelihoods (medium confidence), and tourism and recreation (medium confidence). The impacts on ecosystem services have negative consequences for health and well-being (medium confidence), and for Indigenous peoples and local communities dependent on fisheries (high confidence).

A9. Coastal communities are exposed to multiple climate-related hazards, including tropical cyclones, extreme sea levels and flooding, marine heatwaves, sea ice loss, and permafrost thaw (high confidence). A diversity of responses has been implemented worldwide, mostly after extreme events, but also some in anticipation of future sea level rise, e.g., in the case of large infrastructure.

Section B. PROJECTED CHANGES AND RISKS

Projected Physical Changes

B1. Global-scale glacier mass loss, permafrost thaw, and decline in snow cover and Arctic sea ice extent are projected to continue in the near-term (2031–2050) due to surface air temperature increases (high confidence), with unavoidable consequences for river runoff, and local hazards (high confidence). The Greenland and Antarctic Ice Sheets are projected to lose mass at an increasing rate throughout the 21st century and beyond (high confidence). The rates and magnitudes of these cryospheric changes are projected to increase further in the second half of the 21st century in a high greenhouse gas emissions scenario (high confidence). Strong reductions in greenhouse gas emissions in the coming decades are projected to reduce further changes after 2050 (high confidence).

B2. Over the 21st century, the ocean is projected to transition to unprecedented conditions with increased temperatures (virtually certain), greater upper ocean stratification (very likely), further acidification (virtually certain), oxygen decline (medium confidence) and altered net primary production (low confidence). Marine heatwaves (very high confidence) and extreme El Niño and La Nina events (medium confidence) are projected to become more frequent. The Atlantic Meridional Overturning Circulation (AMOC) is projected to weaken (very likely). The rates and magnitudes of these changes will be smaller under scenarios with low greenhouse gas emissions (very likely).

B3. Sea level continues to rise at an increasing rate. Extreme sea level events that are historically rare (once per century in the recent past) are projected to occur frequently (once per year or more often at many locations) by 2050 in all RCP scenarios, especially in tropical regions (high confidence). The increasing frequency of high water levels can have severe impacts in many locations depending on exposure (high confidence). Sea level rise is projected to continue beyond 2100 in all RCP scenarios. For a high emissions scenario (RCP8.5), projections of global sea level rise by 2100 are larger than in AR5 due to a larger contribution from the Antarctic ice sheet (medium confidence). In coming centuries under RCP 8.5, sea-level rise is projected to exceed rates of several centimeters per year resulting in multi-metre rise (medium confidence), while for RCP2.6 sea level rise is projected to be limited to around 1m in 2300 (low confidence). Extreme sea levels and coastal hazards will be exacerbated by projected increases in tropical cyclone intensity and precipitation (high confidence). Projected changes in waves and tides vary locally in whether they simplify or ameliorate these hazards (medium confidence).

Projected Risks for Ecosystems

B4. Future land cryosphere changes will continue to alter terrestrial and freshwater ecosystems in high-mountain and polar regions with major shifts in species distributions resulting in changes in ecosystem structure and functioning, and eventual loss of globally unique biodiversity (medium confidence). Wildfire is projected to increase significantly for the rest of this century across most tundra and boreal regions, and also some mountain regions (medium confidence).

B5. A decrease in global biomass of marine animal communities, their production, and fisheries catch potential, and a shift in species composition are projected over the 21st century in ocean ecosystems from the surface to the deep seafloor under all emission scenarios (medium confidence). The rate and magnitude

of decline are projected to be highest in the tropics (high confidence), whereas impacts remain diverse in polar regions (medium confidence) and increase for high emission scenarios. Ocean acidification (medium confidence), oxygen loss (medium confidence) and reduced sea ice extent (medium confidence) as well as non-climatic human activities (medium confidence) have the potential to exacerbate these warming-induced ecosystem impacts.

B6. Risks of severe impacts on biodiversity, structure and function of coastal ecosystems are projected to be higher for elevated temperatures under high compared to low emissions scenarios in the 21st century and beyond. Projected ecosystem responses include losses of species habitat and diversity, and degradation of ecosystem functions. The capacity of organisms and ecosystems to adjust and adapt is higher at lower emissions scenarios (high confidence). For sensitive ecosystems such as seagrass meadows and kelp forests, high risks are projected if global warming exceeds 2℃ above pre-industrial temperature, combined with other climate-related hazards (high confidence). Warm- water corals are at high risk already and are projected to transition to very high risk even if global warming is limited to 1.5℃ (very high confidence).

Projected Risks for People and Ecosystem Services

B7. Future cryosphere changes on land are projected to affect water resources and their uses, such as hydropower (high confidence) and irrigated agriculture in and downstream of high-mountain areas (medium confidence), as well as livelihoods in the Arctic (medium confidence). Changes in floods, avalanches, landslides, and ground destabilization, are projected to increase risk for infrastructure, cultural, tourism, and recreational assets (medium confidence).

B8. Future shifts in fish distribution and decreases in their abundance and fisheries catch potential due to climate change are projected to affect income, livelihoods, and food security of marine resource-dependent communities (medium confidence). Long-term loss and degradation of marine ecosystems compromises the ocean's role in cultural, recreational, and intrinsic values important for human identity and wellbeing (medium confidence).

B9. Increased mean and extreme sea level, alongside ocean warming and acidification, are projected to exacerbate risks for human communities in low-lying coastal areas (high confidence). In Arctic human communities without rapid land uplift, and in urban atoll islands, risks are projected to be moderate to high even under a low emissions scenario (RCP2.6) (medium confidence), including reaching adaptation limits (high confidence). Under a high emissions scenario (RCP8.5), delta regions and resource rich coastal cities are projected to experience moderate to high risk levels after 2050 under current adaptation (medium confidence). Ambitious adaptation including transformative governance is expected to reduce risk (high confidence), but with context-specific benefits.

Section C. IMPLEMENTING RESPONSES TO OCEAN AND CRYOSPHERE CHANGE

Challenges

C1. Impacts of climate-related changes in the ocean and cryosphere increasingly challenge current governance efforts to develop and implement adaptation responses from local to global scales, and in some cases pushing them to their limits. People with the highest exposure and vulnerability are often those with lowest capacity to respond (high confidence).

Strengthening Response Options

C2. The far-reaching services and options provided by ocean and cryosphere-related ecosystems can be supported by protection, restoration, precautionary ecosystem-based management of renewable resource use, and the reduction of pollution and other stressors (high confidence). Integrated water management (medium confidence) and ecosystem-based adaptation (high confidence) approaches lower climate risks locally and provide multiple societal benefits. However, ecological, financial, institutional and governance constraints for such actions exist (high confidence), and in many contexts ecosystem-based adaptation will

only be effective under the lowest levels of warming (high confidence).

C3. Coastal communities face challenging choices in crafting context-specific and integrated responses to sea level rise that balance costs, benefits and trade-offs of available options and that can be adjusted over time (high confidence). All types of options, including protection, accommodation, ecosystem-based adaptation, coastal advance and retreat, wherever possible, can play important roles in such integrated responses (high confidence).

Enabling Conditions

C4. Enabling climate resilience and sustainable development depends critically on urgent and ambitious emissions reductions coupled with coordinated sustained and increasingly ambitious adaptation actions (very high confidence). Key enablers for implementing effective responses to climate-related changes in the ocean and cryosphere include intensifying cooperation and coordination among governing authorities across spatial scales and planning horizons. Education and climate literacy, monitoring and forecasting use of all available knowledge sources, sharing of data, information and knowledge, finance, addressing social vulnerability and equity, and institutional support are also essential. Such investments enable capacity-building, social learning, and participation in context-specific adaptation, as well as the negotiation of trade-offs and realisation of co-benefits in reducing short-term risks and building long-term resilience and sustainability. (high confidence) This report reflects the state of science for ocean and cryosphere for low levels of global warming (1.5℃), as also assessed in earlier IPCC and IPBES reports.

G20 Osaka Leaders' Declaration (excerpt)

PREAMBLE

1. We, the Leaders of the G20, met in Osaka, Japan on 28-29 June 2019 to make united efforts to address major global economic challenges. We will work together to foster global economic growth, while harnessing the power of technological innovation, in particular digitalization, and its application for the benefit of all.
2. Building on work done by previous presidencies, we will strive to create a virtuous cycle of growth by addressing inequalities and realize a society where all individuals can make use of their full potential. We are resolved to build a society capable of seizing opportunities, and tackling economic, social and environmental challenges, presented today and in the future, including those of demographic change.
3. We will further lead efforts to foster development and address other global challenges to pave the way toward an inclusive and sustainable world, as envisioned in the 2030 Agenda for Sustainable Development.

Global Environmental Issues and Challenges

34. Noting the important work of the International Panel on Climate Change (IPCC) and Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Sources (IPBES), and in the light of recent extreme weather events and disasters, we recognize the urgent need for addressing complex and pressing global issues and challenges, including climate change, resource efficiency, air, land, fresh water and marine pollution, including marine plastic litter, biodiversity loss, sustainable consumption and production, urban environmental quality and other environmental issues, and for promoting and leading energy transitions, with the best available science, while promoting sustainable growth. A paradigm shift is needed where the virtuous cycle of environment and growth is accelerated through innovations, and with business communities playing an important role, in synergy with the public sector. To this end we stress the importance of accelerating the virtuous cycle and leading transformations to a resilient, inclusive, and sustainable future. We emphasize the importance of taking concrete and practical actions and collecting international best practices and wisdom from around the world, mobilizing public and private finance, technology and investment and improving business environments.

Climate Change

35. To this end, we strive to foster inclusive finance for sustainable development, including public and private financing mobilization and alignment between them, as well as innovation in a wide range of areas for low emissions and resilient development. Climate actions at all levels with broad participation, including by nonstate actors, will be the key to realizing such a paradigm shift. In further enhancing this effort, as appropriate to each country's circumstances, we will look into a wide range of clean technologies and approaches, including smart cities, ecosystem and community based approaches, nature based solutions and traditional and indigenous knowledge. We need to enhance efforts to support actions and cooperation in adaptation and disaster risk reduction, in particular, for the most vulnerable communities, and to elaborate further and foster coherence between mitigation action, adaptation measures, environmental protection, and resilient infrastructure. We note the successful adoption of the implementation guidelines for the Paris Agreement and the completion of the stocktaking of the Talanoa Dialogue at the United Nations Framework Convention on Climate Change Conference of Parties (UNFCCC COP) 24 and the outcomes of the meeting of G20 energy and environment ministers in Karuizawa, subsequent to the successful G20 Buenos Aires Summit. We are determined to make best use of this momentum, and thus look forward to a successful Climate Action Summit of the UN Secretary-General and concrete outcomes at UNFCCC COP 25 in Santiago, Chile. Signatories to the Paris Agreement who confirmed at Buenos Aires its irreversibility and are determined to implement it, reaffirm their commitment to its full implementation, reflecting common but differentiated responsibilities and respective capabilities, in the light of different national circumstances. By 2020 we aim to communicate, update or maintain our NDCs, taking into account that further global efforts are needed. We emphasize the importance of providing financial resources to assist developing countries with respect to both mitigation and adaptation in accordance with the Paris Agreement.

36. The United States reiterates its decision to withdraw from the Paris Agreement because it disadvantages American workers and taxpayers. The U.S. reaffirms its strong commitment to promoting economic growth, energy security and access, and environmental protection. The U.S.'s balanced approach to energy and environment allows for the delivery of affordable, reliable, and secure energy to all its citizens while utilizing all energy sources and technologies, including clean and advanced fossil fuels and technologies, renewables, and civil nuclear power, while also reducing emissions and promoting economic growth. The United States is a world leader in reducing emissions. U.S. energy-related CO_2 emissions fell by 14% between 2005 and 2017 even as its economy grew by 19.4% largely due to the development and deployment of innovative energy technologies. The United States remains committed to the development and deployment of advanced technologies to continue to reduce emissions and provide for a cleaner environment.

Energy

37. We acknowledge the importance of energy transitions that realize the "3E＋S" (Energy Security, Economic Efficiency, and Environment ＋ Safety) in order to transform our energy systems into affordable, reliable, sustainable and low GHG emissions systems as soon as possible, recognizing that there are different possible national paths to achieve this goal. Recalling the G20 Ministerial Meeting on Energy Transitions and Global Environment for Sustainable Growth Communique, we acknowledge the role of all energy sources and technologies in the energy mix and different possible national paths to achieve cleaner energy systems. We also recognize opportunities offered by further development of innovative, clean and efficient technologies for energy transitions, including hydrogen as well as, depending on national circumstances, the Carbon Capture, Utilization and Storage (CCUS) taking note of work on "Carbon Recycling" and "Emissions to Value". We acknowledge the G20 Japanese Presidency's initiative called Research and Development 20 for clean energy technologies ("RD20"). In light of recent events highlighting concern about safe flow of energy, we acknowledge the importance of global energy security as one of the guiding principles for the transformation of energy systems, including resilience, safety and development of infrastructure and undisrupted flow of energy from various sources, suppliers, and routes. We recognize the value of international cooperation on a wide range of energy-related issues including energy access, affordability and energy efficiency, and energy storage. We reaffirm our joint commitment on medium term rationalization and phasing-out of Inefficient Fossil Fuel Subsidies that encourage wasteful consumption, while providing targeted support for the poorest.

Environment

38. We recognize that improving resource efficiency through policies and approaches, such as circular economy, sustainable materials management, the 3Rs (reduce, reuse, recycle) and waste to value, contributes to the SDGs, as well as to addressing a wide range of environmental challenges, enhancing competitiveness and economic growth, managing resources sustainably, and creating jobs. We encourage work with the private sector towards innovation in the cooling sector. We will also work with stakeholders in order to increase the demand for recycled products. We look forward to the development of a roadmap of the G20 Resource Efficiency Dialogue under the Japanese Presidency.

39. We reiterate that measures to address marine litter, especially marine plastic litter and microplastics, need to be taken nationally and internationally by all countries in partnership with relevant stakeholders. In this regard, we are determined to swiftly take appropriate national actions for the prevention and significant reduction of discharges of plastic litter and microplastics to the oceans. Furthermore, looking ahead beyond those initiatives and existing actions by each member, we share, and call on other members of the international community to also share, as a common global vision, the "Osaka Blue Ocean Vision" that we aim to reduce additional pollution by marine plastic litter to zero by 2050 through a comprehensive life-cycle approach that includes reducing the discharge of mismanaged plastic litter by improved waste management and innovative solutions while recognizing the important role of plastics for society. We also endorse the G20 Implementation Framework for Actions on Marine Plastic Litter.

40. As illegal, unreported, and unregulated (IUU) fishing remains in many parts of the world a serious threat to the sustainability of the ocean, we recognize the importance of addressing IUU fishing for ensuring the sustainable use of marine resources and conserving the marine environment including biodiversity, and reaffirm our commitment to end IUU fishing.

Displacement and Migration

41. We note the 2019 Annual International Migration and Displacement Trends and Policies Report to the G 20 prepared by the OECD in cooperation with ILO, International Organization for Migration (IOM) and United Nations High Commissioner for Refugees (UNHCR). We will continue the dialogue on the various dimensions of these issues in the G20.

42. Large movements of refugees are a global concern with humanitarian, political, social and economic consequences. We emphasize the importance of shared actions to address the root causes of displacement and to respond to growing humanitarian needs.

43. We thank Japan for its Presidency and for hosting a successful Osaka Summit and its contribution to the G20 process, and we look forward to meeting again in Saudi Arabia in 2020, in Italy in 2021 and in India in 2022.

ANNEX

Ministerial Declarations and Communiqués

1. G20 Agriculture Ministers' Declaration 2019 (11–12 May)
2. G20 Ministerial Statement on Trade and Digital Economy (8–9 June)
3. Communiqué G20 Finance Ministers & Central Banks Governors Meeting (8–9 June)
4. Communiqué G20 Ministerial Meeting on Energy Transitions and Global Environment for Sustainable Growth (15–16 June)

G20 Working Groups and Other Documents

1. G20 Principles for Quality Infrastructure Investment
2. Programme of Work to Develop a Consensus Solution to the Tax Challenges Arising from the Digitalization of the Economy
3. G20 Fukuoka Policy Priorities on Aging and Financial Inclusion
4. Proposed Global Partnership for Financial Inclusion (GPFI) Work Program
5. G20 Shared Understanding on the Importance of UHC Financing in Developing Countries
6. G20 Compendium of Good Practices for Promoting Integrity and Transparency in Infrastructure Development
7. G20 High Level Principles for Effective Protection of Whistleblowers
8. G20 AI Principles
9. Women at Work in G20 countries: Progress and policy action
10. G20 Initiative on Human Capital Investment for Sustainable Development
11. Osaka Update on the G20 Action Plan on the 2030 Agenda for Sustainable Development
12. Guiding Principles for the Development of Science, Technology, and Innovation for SDGs Roadmaps
13. Osaka Comprehensive Accountability Report on G20 Development Commitments
14. G20 Implementation Framework for Actions on Marine Plastic Litter
15. G20 Action Agenda on Adaption and Resilient Infrastructure
16. G20 Karuizawa Innovation Action Plan on Energy Transitions and Global Environment for Sustainable Growth

G20 Implementation Framework for Actions on Marine Plastic Litter PREAMBLE

We, the G20 members, recognize the increasing urgency to tackle the issue of marine litter, especially marine plastic litter and microplastics, on a global scale, further building on existing efforts. In this regard, we acknowledge the United Nations Environment Assembly (UNEA) resolutions 4/7 on Marine plastic litter and microplastics and 4/10 on Addressing single-use plastic products pollution, and note the decision at the 14th meeting of the Conference of the Parties to the Basel Convention to include plastic waste under the convention.

As the "G20 Action Plan on Marine Litter" adopted at the G20 Hamburg Summit in 2017 laid the foundation for the G20 members to address marine litter, this "G20 Implementation Framework for Actions on Marine Plastics Litter" is to facilitate further concrete actions on marine litter, especially marine plastic litter and microplastics, in line with the G20 Action Plan on Marine Litter, while taking into account our own appropriate policies, approaches and national circumstances, on a voluntary basis. This framework is expected to complement the work of the UNEP.

I. Facilitation of Effective Implementation of the Action Plan

We will facilitate effective implementation of the G20 Action Plan on Marine Litter through encouraging voluntary actions by the G20 members in accordance with national policies, approaches and circumstances, and their information sharing and continued updating as follows:

1. Implementation of actions

- Facilitate the implementation of the G20 members' actions in line with the G20 Action Plan on Marine Litter, based on respective national policies, approaches and circumstances, and in collaboration with Regional Seas Conventions and other relavant organizations and instruments.
- Promote a comprehensive life-cycle approach to urgently and effectively prevent and reduce plastic litter discharge to the oceans, in particular from land-based sources, through measures, inter alia, environmentally sound waste management, environmentally sound clean-up of marine plastic litter, deployment of innovative solutions, and international cooperation to enhance national capacities, as well as prevention and reduction of plastic waste generation and littering, promotion of sustainable consumption and production, including but not limited to promoting resource efficiency, circular economy, sustainable materials management, waste to value approach, and measures to address sea-based sources.

2. Information sharing and continued updating

- Share and update information on relevant policies, plans, and measures taken/to be taken in line with the G20 Action Plan on Marine Litter on a voluntary basis and promote policies and measures by peer learning from best practices, utilizing opportunities to co-organize with relevant meetings, inter alia, the G20 Resource Efficiency Dialogue and the multi-stakeholder platform to be established under the UNEP, which will be decided by G20 presidencies.
- The information to be shared may include effective measures to prevent and reduce plastic litter discharge to the oceans and their achievements and challenges1 where applicable and available. - Utilize the opportunity of the G20 Resource Efficiency Dialogue during the Japanese Presidency for the first information sharing, and make a portal site available with the support of the Government of Japan for efficient information sharing and updating, and possible outreach.

II. Collaborative Actions and Outreach of Implementation of the Action Plan

In addition to Section I, we will engage in collaborative actions among the G20 members and outreach activities beyond the G20, cooperating with and supported by relevant international and regional organizations and initiatives, while maximizing synergies and avoiding duplication of work, particularly with the work of the UNEP, as follows:

1. Promotion of international cooperation

- 1 Relevant indicators, data or other numerical information can be also included at the discretion of each G20 member, for example: the amount of wastes generated, reused, collected, recycled, and

properly disposed of ; the amount of marine litter cleaned up ; the scale of use of innovative technologies and materials including R&D investment ; the scale and/or effect of assistance for countries that need technical capacity development including the increased amount of wastes properly disposed of (encouraged to indicate the proportion/elements of plastic waste and/or microplastics, if available)

- Engage in international and regional cooperation and share best practices through relevant instruments, initiatives and programs. Emphasis should be placed on regional cooperation in collaboration with relevant Regional Seas Programs, Regional Fisheries Management Organizations and other regional initiatives, as appropriate.
- Promote cooperation among the G20 members and with other partners to empower governments, communities, and the private sector to advance measures mentioned in Section I. 1 including through technical assistance for those who need technical capacity development. - Invite relevant international organizations to develop policy tools/options such as best practice guidance for capacity development and infrastructure investment through, inter-alia, public-private partnership to remove barriers to private financing, in cooperation with the G20 members.

2. Promotion of innovative solutions

- Enhance collaboration internationally to advance innovative solutions such as for product design, resource efficient and circular approaches, waste management practice and technologies, waste water treatment technologies, environmentally sound products, taking into account their contribution to marine pollution and full life-cycle environmental impact, in cooperation with existing international fora and initiatives, including but not limited to the World Circular Economy Forum, the Platform for Accelerating the Circular Economy, the G20 Resource Efficiency Dialogue, and the G7 Innovation Challenge to Address Marine Plastic Litter. Encourage relevant actors to take a life-cycle approach in the development and market penetration of innovative solutions to reduce the negative environmental, economic and social impacts.
- Encourage voluntary activities by the private sector internationally on the advancement of innovative solutions including environmentally sound product design, resourceefficient business models, and value retention practices. Explore ways to support and further facilitate such activities, including through holding relevant workshops in collaboration with business communities.

3. Sharing scientific information and knowledge

- Encourage the ongoing work of GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) to strengthen scientific foundations and build scientific capacity including by promoting and piloting harmonized/comparable monitoring and analytical methodologies for measuring and monitoring marine litter, especially marine plastic litter and microplastics and their impact.
- Encourage the development of global-scale monitoring of marine litter, especially marine plastic litter and microplastics, using harmonized methodologies in cooperation with Regional Seas Conventions and Programmes, the IOC-UNESCO, the UNEP and other relevant organizations and initiatives.
- Encourage scientific communities and relevant experts to explore ways to identify and estimate the sources, pathways and fate of plastic waste leakage toward the development of global land and sea-based source inventories, including by holding relevant workshops, and contribute to the scientific and technological work of the UNEP, while noting that single-use plastics and fishing gears are reported to constitute significant sources.
- Encourage international coordination on scientific research, including socio-economic research and research on microplastics including nanoplastics, and the sharing of scientific knowledge such as the impacts of plastic pollution on human health, marine biodiversity and ecosystems.

4. Multi-stakeholder involvement and awareness raising

- Collaborate and cooperate with, and empower non-G20 countries, local governments, the private sector, civil society organizations, NGOs, and academia to work in a multisector manner and invite them to take actions in line with this framework, including in collaboration with partnerships or networks focused on global marine litter issues.
- Raise awareness globally on the importance of, among others, urgent and effective actions at all levels to prevent and reduce plastic litter discharge to the oceans, as well as sustainable consumption and production, including but not limited to promoting resource efficiency, circular economy, sustainable materials management, and waste to value, by utilizing opportunities such as the “World Environmental Day,” the “World Oceans Day,” and related national awareness days.

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