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IEEE planet positive 2030

# Strong Sustainability by Design

## PRIORITIZING ECOSYSTEM AND HUMAN FLOURISHING WITH TECHNOLOGY-BASED SOLUTIONS

## OCEAN AND COASTS

An initiative supported by the IEEE Standards Association

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IEEE

# Strong Sustainability by Design

This Compendium has been created by committees of the IEEE Planet Positive 2030 Initiative supported by the IEEE Standards Association (IEEE SA). The IEEE Planet Positive 2030 Initiative community is composed of several hundred participants from six continents, who are thought leaders from academia, industry, civil society, policy and government in the related technical and humanistic disciplines. At least one hundred seventy members of this community from about thirty countries have contributed directly to this Compendium and have worked to identify and find consensus on timely issues.

The Compendium's purpose is to identify specific issues and recommendations regarding sustainability and climate change challenges to achieve "Planet Positivity" by 2030, defined as the process of transforming society and infrastructure by 2030 to:

- Reduce Greenhouse Gas (GHG) emissions to 50% of 2005 GHG emissions by 2030.
- Significantly increase regeneration and resilience of the Earth's ecosystems.
- Be well on the path to achieving net zero GHG emissions by 2050 and negative GHG emissions beyond 2050.
- Continue to widely deploy appropriate technology as well as design and implement new technological solutions in support of achieving technological solutions designed and deployed to achieve "Planet Positivity."

### In identifying specific issues and pragmatic recommendations, the Compendium:

- Provides a scenario-based challenge (how to achieve "Planet Positivity by 2030") as a tool to inspire readers to get engaged.
- Advances a public discussion about how to build from a "Net Zero" mentality to a "Net or Planet Positive" ("do more good," that is, doing "more" than "don't harm") societal mandate for all technology and policy.
- Continues to build a diverse and inclusive community for the IEEE Planet Positive 2030 Initiative, prioritizing the voices of indigenous and marginalized members whose insights are acutely needed to help make technology and other solutions more valuable for all. Of keen interest is how to encourage more in-depth participatory design in these processes.
- Inspires the creation of technical solutions that can be developed into technical recommendations (for example IEEE SA recommended practice for addressing sustainability, environmental stewardship and climate change challenges in professional practice, IEEE P7800™) and associated certification programs.
- Facilitates the emergence of policies and recommendations that could potentially be intraoperative between different jurisdictions (e.g., countries).

By inviting the general public to read and utilize *Strong Sustainability by Design*, the IEEE Planet Positive 2030 community provides the opportunity to bring multiple voices from the related scientific and engineering communities together with the general public to identify and find broad consensus on technology to address pressing environmental and social issues and proposed recommendations regarding development, implementations and deployment of these technologies. You are invited to Join related IEEE activities, such as standards development and initiatives across the organization.

- For further information, learn more at the IEEE Planet Positive 2030 Initiative website
- Get in touch at: PlanetPositive2030@ieee.org to get connected to and engaged with the IEEE Planet Positive 2030 community.
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*Strong Sustainability by Design* is not a code of conduct or a professional code of ethics. Engineers and technologists have well-established codes, and the IEEE Planet Positive 2030 community respectfully recognizes the formative precedents surrounding issues of sustainability and the professional values these codes represent. These codes provide the broad framework for the more focused domain addressed in this Compendium, and it is hoped that the inclusive, consensus-building process around its design will contribute unique value to technologists and society as a whole.

This Compendium is also not a position, or policy statement, or formal report of IEEE or any other organization with which IEEE is affiliated. It is intended to be a working reference tool created through an inclusive process by those in the relevant scientific and engineering communities prioritizing sustainability considerations in their work.

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## A Note Regarding Recommendations in This Document

*Strong Sustainability by Design* was created in two versions ("draft" and this current edition) that were iterated over the course of two years. The IEEE Planet Positive 2030 Initiative follows a specific consensus building process where members contributing content identify specific potential issues and proposed recommendations.

## Membership

IEEE Planet Positive 2030, an initiative supported by the IEEE Standards Association as part of the Industry Connections Program, Sustainable Infrastructures and Community Development program (SICDP), currently has more than four hundred experts involved, and remains eager for new voices and perspectives to join in this work.

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# OCEAN AND COASTS

*The ocean plays a crucial role in the achievement of the Sustainable Development Goals and the livelihoods of billions of people. We urgently need to change how we interact with it.*

United Nations Secretary General António Guterres[1]

## Future Vision

It is 2030.

It has been an incredible decade. The fact that the ocean produces half of the world's oxygen has evolved from obscure science trivia to common knowledge. The world has been educated about the ocean's influence on people and their influence on the ocean, inspiring grassroots groups of citizen scientists to organize globally, collecting data on ocean and coastal change, resilience, diversity, population, and economy. Society has met the 30 × 30 (30% of the ocean protected by 2030) goal. A definitive map of the ocean floor is complete.

Circular economy practices have moved from an emerging field to a central principle in both the private and the public sectors. Broad investments in process improvements and waste stream mining have resulted in 100% reuse and recycling of plastic, and nearly every jurisdiction has eliminated the use of single-use disposable plastic items. Where goods cannot be produced locally or nationally, they are transported via green shipping. Wind-, wave-, and current-driven renewable energy projects along the coastline now produce and buffer a substantial fraction of the electricity to power society day and night without relying on carbon-based fuels.

Ocean and coastal-based carbon dioxide ($CO_2$) removal strategies have been proven and are being built on a scale that will soon be able to remove carbon dioxide at rates comparable to the residual carbon output from human activities. There is now a clear economic and technological path to removing the human contribution to the rate of change in the Earth's climate.

Coastal desalination plants powered by salinity gradient energy technology (Kempener & Neumann, 2014) provide abundant clean water and clean energy to areas where freshwater is scarce. Sustainable aquaculture provides an important food source for global populations. Coastal communities are aware of and exposed to only a reasonable level of flood risk through sustainable defenses, nature-based solutions, and managed realignment. The residual risk is managed by robust advanced early warning systems in place and democratized globally.

As impressive as these technological achievements are, what is most meaningful to the average person is that the ocean is visibly healthier. Their favorite beaches no longer have garbage washed up from off the shore. Ocean economies are booming as biodiversity has rebounded, leading to increases in everything from whale watching to recreational fishing. Protected coastal wetlands and mangrove forests both make coastal communities safer and provide beautiful recreational spaces.

[1] António Guterres, "Foreword" in *The Second World Ocean Report*, vol 1. (New York: United Nations, 2021).

Events and trends from the early 2010s precipitated a profound change in maritime shipping that has long reaching positive consequences. The Fukushima nuclear disaster (2011) caused early retirements of many nuclear power plants in favor of natural gas over coal and other forms of power generation, igniting concern about energy security. The COVID-19 pandemic upended supply webs and society in general for nearly two years from 2020 through 2021, causing concern about supply web security. The invasion of Ukraine in 2022 interrupted supply webs again, bringing more concerns on how to assure geopolitical stability. These events began pushing forward a new consensus on economic, energy, food, and geopolitical security that effectively began a seismic shift in new supply webs and trade patterns. The growing importance of climate change became a permanent priority as well.

Shipping is a graphic example of the change: As of 2030, we are seeing the first generation of truly advanced ships that have zero emissions, more efficient trade patterns, and a new breed of ship operators either working as part of or considered to be a high-value, critical piece of organizations that use ships instead of low-cost, minimum compliance subcontractors.

Simply stated, society cares about the ocean and interacts in an ocean economy like never before.

# Issue 1: Imminent threat of sea-level rise to coastal communities

## Background

As it stands, sea-level rise is a major threat to coastal communities in terms of increased economic losses, coastal erosion, and destruction to ecosystems such as wetlands and mangroves. Immediate mitigation is necessary to protect coastal communities and regenerate coastal ecosystems due to accelerating sea-level rise.

Since 1880, the sea level has risen by 0.21 m to 0.24 m, and the rate of sea-level rise is accelerating. Even with reduced greenhouse gas (GHG) emissions, coastal communities face an additional global mean sea-level rise (GMSLR) of between 0.28 m and 0.62 m (above 1995–2014 levels) by 2100. In future scenarios, not assuming significant GHG reductions, GMSLR of 0.44 m to 1.01 m by 2100 is likely (IPCC, 2021). Irrespective of the GHG pathway, the sea level will continue to rise well beyond 2100 by at least another 1 m to 2 m, possibly more, due to inertia already in the climate system. The main drivers of sea-level rise are thermal expansion of seawater due to excess heat being absorbed into and heating the ocean and increasing seawater mass from melting glaciers and ice sheets.

The high population and industrial facility densities near the coast, with around 680 million people less than 10 m above sea level, are forecasted to increase to more than 1 billion people by 2050 (IPCC, 2019). Rising sea levels are threatening lives, infrastructure, and water supplies. Higher sea levels allow storm surge and high tides to travel further inshore and result in increased high-tide flooding of coastal communities. Sea-level rise threatens the habitability and existence of small island nations, which are currently home to 65 million people (UN Office of the High Representative for the Least Developed Countries, "About Small Island States"). Ecosystems protecting the shoreline in many areas cannot evolve and migrate due to the impacts of humans, so the rate of erosion of these ecosystems increases as sea levels rise.

Sea-level rise is effectively changing the ecosystems of the coastline, including flora and fauna. Existing ecosystems, such as barrier islands, are evolving slower than the sea-level rise is occurring, meaning storm events are routinely exposing coastal areas to conditions outside of the normal realm of experience. Human activity affects the ability of the ecosystem to accommodate storm events and changes the evolution mechanisms. Subsidence of marshes and accelerated erosion are examples of changes precipitated by human activity.

Communities will require storm protection, coastal impact assessments/response plans, and better ways to measure direct local impact of climate change. The modeling and prediction of climate change is needed to determine coastal communities' vulnerability to storm surge, increasingly common flood inundation, saltwater intrusion, and natural disasters. Considering just extreme sea-level rise at the coast, rare once-in-a-century events are projected to occur at least once a year in many locations by 2050 in all future GHG scenarios. Perhaps much of the real damage goes unmeasured in the areas where less technology is available for monitoring and measurement. Sharing knowledge is important, especially for developing countries that may be disproportionately affected by climate change—both its acute hazards and its long-term effects.

The modeling and technical data are especially important to identify the sovereignty of each coastal state over its sovereignty area. The maritime boundaries are set "from the baseline, which is the low-water line along the coast as marked on large-scale charts officially recognized by the coastal state" (UNCLOS, "Outer Limit of the Territorial Sea"). Since the United Nations Convention on the Law of the Sea (UNCLOS) treaty "does not explicitly provide that the maritime boundaries shall shift with a change in baselines, it can be said that UNCLOS does not decidedly exclude the possibility of states resorting to either of the two approaches" (Goyal & Gupta, 2020): (1) to fix the baseline or (2) to shift it according to the rising sea level. Therefore, constant ongoing measurements are needed to determine how far the baseline has shifted (Arcanjo, 2019).

## Recommendations

1. **Support the equitable distribution and deployment of low-cost, easy-to-use monitoring equipment and satellite data products to track sea-level rise and coastal erosion, providing early warning indicators and data for early warning systems.**
2. **Make available customized global and regional operational flood modeling and early warning systems to help protect life and infrastructure, including to some small nations and other countries that may not have such capability.**
3. **Maintain and provide access to critical long-term data sets of sea-level rises, such as from tide gauge networks [e.g., Global Sea Level Observing System (GLOSS)] and satellite altimetry missions, to detect trends and identify as early as possible any accelerations in sea-level rise, storm surges, and tides.**
4. **Carry out definitive mapping of the global seafloor, which is necessary for accurate modeling.**
5. **Model sea-level rise, storm surge dynamics, and erosion locally and globally.** This modeling will aid in developing smart maps to inform the placement and protection of critical infrastructure or the relocation, ecosystem-based adaptation, and planned shoreline retreat of coastal communities to help reduce or prevent loss.
6. **Focus adaptations on local drivers of exposure and vulnerability, dependent on regional sediment sources and budgets.**
7. **Restore and protect bio-coastal restoration in addition to or in place of infrastructure protection.** Restoration should target key coastal ecosystems, such as mangroves, saltmarshes, sandy beaches, and vegetated dunes. These ecosystems provide important services, such as habitat for diverse biota and coastal protection. Wherever possible, beneficial space should be made or protected for these natural ecosystems to migrate inland with sea-level rise.
8. **Build innovative financing models for ecosystem restoration**. New blended financing structures should be explored that increase funding available for ecosystem conservation and engage private- and public-sector players.

## Case studies

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1. CoastSnap—A Global Citizen Science Project to Capture Changing Coastlines

   *"CoastSnap is a global citizen science project to capture our changing coastlines. No matter where you are in the world, if you have a smartphone and an interest in the coast,*

*we welcome you to participate! CoastSnap relies on repeat photos at the same location to track how the coast is changing over time due to processes such as storms, rising sea levels, human activities and other factors. Using a specialised technique known as photogrammetry, CoastSnap turns your photos into valuable coastal data that is used by coastal scientists to understand and forecast how coastlines might change in the coming decades…"*

2. Land Change Assessment, Monitoring, and Prediction Using Landsat

   *"LCMAP Monitoring uses all available Landsat observations to perform nationwide characterization of change in land cover and condition annually. Validation provides a measure of map accuracy for use in evaluating the appropriateness of a map for a specific application. LCMAP collects reference data that is used to perform a validation analysis, and all datasets are available…."*

3. Environment | Mangroves for the Future—Investing in Coastal Ecosystems

   *"All coastal ecosystems such as mangroves, coral reefs and seagrass beds are under threat from climate-change and variability; however, the long-term survival and functioning of key ecosystems is crucial for the communities depending on ecosystem services such as provisioning (e.g., timber, fuel wood, and charcoal), regulating (e.g., flood, storm and erosion control; prevention of salt water intrusion), and habitat (e.g., breeding, spawning and nursery habitat for commercial valuable fish species)…."*

4. National Oceanic and Atmospheric Administration's Sea Level Rise viewer and NASA's Sea Level Change Portal

## Further resources

1. Oppenheimer, Michael, Bruce C. Glavovic, Jochen Hinkel, Roderik van de Wal, Alexandre K. Magnan, Amro Abd-Elgawad, Rongshuo Cai, et al. "Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities." Chp. 4 in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. Edited by Hans-O Pörtner et al. Cambridge and New York: Cambridge University Press, 2019.
2. Seabed 2030. The Nippon Foundation-GEBCO Seabed 2030 Project.[2]
3. Sweet, William V., Benjamin D. Hamlington, Robert E. Kopp, Christopher P. Weaver, Patrick L. Barnard, David Bekaert, William Brooks et al. *2022 Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines.* NOAA Technical Report NOS 01. Silver Spring, MD: NOAA, National Ocean Service, Feb. 2022.

[2] "Our mission is to inspire ocean mapping and deliver a complete seabed map for the benefit of people and the planet." The Nippon Foundation and General Bathymetry Chart of the Ocean (GEBCO) website at https://seabed2030.org/our-mission/.

# Issue 2: Warming and acidification of the ocean

## Background

It will be nearly impossible for society to reach our sustainable development goals (SDGs) without a healthy ocean, and the largest threat to the ocean is the absorption of excess heat and atmospheric $CO_2$.

The ocean has until now been the largest climate buffer, absorbing 90% of excess heat and 25% of excess $CO_2$ (WMO, 2021). As a result, the physical, chemical, and biological processes in the ocean have been broadly affected, which in turn has adversely affected many ocean ecosystems and ocean health. In particular, ocean acidification is directly linked to absorption of atmospheric GHGs such as $CO_2$.

Are the strata of heat in the ocean understood? Climate is a heat engine. Heat is most abundant at the equator, and the rest of the climate system is designed to remove heat from the equator. The system has three parts: land, water, and atmosphere; the ocean is 72%. The high heat capacity of the ocean has (until now) smoothed the variations in heat input/output. This ocean heat uptake comes at a cost, including the thermal expansion of ocean water and the resulting sea-level rise and intensification of storms.

The warming of the ocean and the warming of the atmosphere affect ocean circulation, and likewise, the altered ocean circulations affect the weather in complicated and dynamic feedback loops: The fear is that these dynamics may become unstable and potentially irreversible.

If the rate of ocean acidification is not slowed or mitigated in its effects, there is a risk of significant impacts to biodiversity, especially in coral reefs and shellfish, but there is also a significant knowledge gap about the fuller impacts of acidification. Increased ocean heat combined with nutrient discharge (in this chapter, this topic is discussed in the issue covering pollutants) also reduces the capacity of the ocean to hold oxygen. Declining oxygen contributes to a loss of biodiversity and shifting species distributions; it also threatens to disrupt the ocean's food provisioning services. These changes make effective management of ocean resources extremely difficult.

## Recommendations

1. **Act with urgency.** Develop and implement policy advancements in research, technology, and economics to make the circular economy the reality. Urgent action is required to stem the most detrimental changes in ocean warming and acidification in responsible ways, and to shape long-term behaviors in technology and practices that emphasize the circular economy.
2. **Urgently and vastly increase ocean and ocean systems observations to inform both technology development and management policy.** A solid understanding of any system is needed to design good technologies for it. With the ocean, not only is there a poor understanding of the baseline, but also because of human-induced climate change, the baseline is moving while different societies each try to measure, understand, and responsibly manage the vast ocean resources. This complex, interconnected problem calls for revolutionary increases in ocean observations.
3. **Invest in research and development.** A major increase in public, private and philanthropic science investments is needed to carry out the following:
    a. Basic research and development, including everything from scientific measurements of the carbon cycle to improving the understanding of how the ocean acts as a buffer to the

climate system, to physical measurements to support safety and energy transformation (bathymetry, currents, weather, hazards), to biological assessments to inform good management from both civil society and government policy.

b. Significant technology development in sensors, platforms, and autonomous vehicles. The UN Decade of Ocean Science for Sustainable Development 2021-2030 was launched with the goal of "The Science We Need for the Ocean We Want." Achieving the goals of the ocean decade will require significant technology development in parallel with coordination of public, private, and philanthropic science funding.

c. Early-stage design, engineering, and qualification to reach a Technology Readiness Level (TLR) 6 to encourage and produce promising technologies and practices that reduce global warming and effectively extract $CO_2$ from the atmosphere and dissolve $CO_2$ in effluent streams into the ocean.

4. **Structure investment with a longer-term return period to support maturing the above-mentioned technologies.** For these promising technologies and practices, scaling from demonstration and qualification is a task that can require significant efforts characterized by excellent project management, project delivery, advanced manufacturing processes, and use of sophisticated quality systems to adopt new practices. Therefore, investments with return periods longer than currently acceptable limits for many industries will likely be required, which means policy to encourage capital practices to change may need to be changed as well.
5. **Advance policy and regulation in areas such as forcing reduction or elimination of single-use plastics and general advancements to directly sponsor or encourage basic research, applied research, and scaling to promising technologies and better practices.**
6. **Restore coastal (tidal marshes, wetlands, and mangroves) and ocean (seagrass meadows and kelp forests)**. This regeneration could substantially contribute to carbon sequestration.
7. **Consider, investigate, and evaluate marine carbon dioxide removal (mCDR) technology. As** it stands, slowing anthropogenic $CO_2$ release will not meet 1.5 °C targets. Marine carbon dioxide removal technology may provide a path to limit net-carbon emissions. The ocean could potentially provide up to 20% of global carbon sequestration. To responsibly evaluate mCDR technologies relative to the economic and ecological costs of other carbon solutions, societies need to understand the costs and ecological impacts of various carbon dioxide removal (CDR) approaches to have the information at the time it is needed for the massive investments that may be required in carbon solutions.

## Case studies

*This information is given solely for the convenience of users of this document as examples of case studies that were known at the time of publication, and does not constitute an endorsement of any company, product, service or organization by the IEEE or IEEE Standards Association (IEEE SA).*

1. The OSPAR 2017 Intermediate Assessment and the OSPAR 2023 Quality Status Report 2023 confirms acidification in the northeast Atlantic Ocean. OSPAR, 2023.

   "Climate Change Thematic Assessment." In: *OSPAR, 2023: Quality Status Report 2023*. OSPAR Commission, London. Available at:
2. The UN Intergovernmental Panel on Climate Change (IPCC) and its latest status report.

## Further resources


1. Aliaga, Bernardo, Ward Appeltans, Rick Bailey, Julian Barbiere, Mathieu Belbeoch, Aileen Bohan, Elisabetta Bonotto et al. Edited by Henrik Enevoldsen, Kirsten Isensee, and Ikroh Yoon. *State of the Ocean Report 2022*. Paris: UN Educational, Scientific and Cultural (UNESCO) Intergovernmental Oceanographic Commission, 2022.
2. *Blueprint for Ocean Climate Action: Recommendations for the Ocean Policy Committee.* June 2022.[3]
3. Global Ocean Acidification Observing Network (GOA-ON) (website).
4. OASIS. Observing Air-Sea Interaction Strategy.[4]
5. Ocean Frontier Institute. North Atlantic Carbon Observatory.[5]
6. Ocean Visions. Ocean-Based Carbon Dioxide Removal Road Maps.
7. United Nations (UN). *The 2nd World Ocean Assessment: World Ocean Assessment II*. 2 vols. New York: United Nations, 2021.


[3] The Blueprint recommendations are backed by 93 organizations, ranging from environmental groups, ocean advocates, think tanks, and aquariums, to outdoor recreation brands, who came together to develop these comprehensive recommendations. The recommendations focus on 12 key policy areas identified by ocean experts to improve sustainability, resilience, conservation, equity, and justice and demonstrate the broad solutions offered by the ocean.

[4] Better understanding of the air–sea exchanges in important climate cycles.

[5] Observing carbon uptake within major ocean basins.

# Issue 3: Impacts of unsustainable ocean-based food production

## Background

Wide-scale changes in the methods, regulation, and social awareness of ocean-based food production are necessary to improve equity and food security and to help prevent the destruction of marine habitats.

Fisheries and aquaculture provide food and livelihoods for billions of people, while being a threat to marine biodiversity through both direct fishing impacts combined with bycatch and habitat destruction (Maxwell et al., 2016; O'Hara et al., 2021).

Approximately 60% of fish stocks are currently harvested at the maximally sustainable level; 33% are harvested beyond sustainable levels (UN FAO, 2022).

The 2017 annual value of fisheries was estimated at US$127 billion; the World Bank also estimated that US$88 billion of net loss occurred due to impacts of overfishing (UN, 2021). In addition, illegal, unregulated, and unreported (IUU) fisheries threaten the livelihoods of small-scale fisheries, which primarily support local food consumption and are vital to food security, particularly in developing states.

Challenges to sustainable ocean food production are many, including difficulty in identifying and tracking IUU fisheries, harmful subsidies, lack of political will to address the problem, and lack of transparency and control against transnational criminal networks.

In addition to the obvious economic, social, and food security impacts, unsustainable, and particularly IUU, fisheries are likely to present greater risk to the environment due to destructive fishing practices and improper waste management.

## Recommendations

1. **Use large-scale ocean observations to prioritize areas and species for most urgent action.**
2. **Implement a comprehensive global approach to fisheries management through understanding of habitats and food chains and monitoring of fishing stocks.**
3. **Provide for widespread use and availability of modified fishing gear that reduces impacts to seafloor beds, minimizes bycatch, and biodegrades.**
4. **Employ remote-sensing and monitoring technologies to enable enforcement of existing regulations and inform the creation of new regulations.**
5. **Provide for traceability throughout the sea-food supply system.** Digital "traceability in the food supply chain can be defined as the ability to track and follow food production at all stages of production, processing, and distribution" (Center for Food Safety and Applied Nutrition, "Tracking and Tracing of Food"). "Traceability along the seafood supply chain is necessary to combat IUU fishing and achieve healthy fisheries and aquaculture." Consumers can also make informed decisions on how and where their seafood is being harvested or cultivated.

6. **Coordinate policy and regulation, i.e., the rapid adoption and implementation of Marine Stewardship Council (MSC) and Aquaculture Stewardship Council (ASC) requirements that certify the sustainable harvest and farming of seafood** (MSC, 2019).

## Case study

*This information is given solely for the convenience of users of this document as examples of case studies that were known at the time of publication, and does not constitute an endorsement of any company, product, service or organization by the IEEE or IEEE Standards Association (IEEE SA).*

1. Farhan et al. Calculation Model of Economic Losses Due to Illegal Fishing Activities in Indonesian Territorial Waters. 2018.

## Further resources

1. European Commission. "Illegal Fishing." Sustainable Fisheries, Rules.
2. UN Food and Agriculture Organization (FAO). *International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing*. Rome: UN FAO, 2001.
3. Global Dialogue on Seafood Traceability (website).
4. Naibaho, Nicolaus. *Strengthening the Role of Ports in Combating Illegal, Unreported and Unregulated Fishing in Indonesia*. New York: Division for Ocean Affairs and the Law of the Sea, Office of Legal Affairs, United Nations, 2017.

# Issue 4: Destruction of important biodiverse and climate-resilient habitats

## Background

Changes are needed in development and resource extraction to reduce or prevent destruction of key habitats such as seagrass meadows, kelp forests, tidal marshes, and mangroves, causing a loss of marine biodiversity, coastal erosion, flooding, and ocean warming.

From seagrass meadows to kelp forests to tidal marshes and mangroves to deep sea ecosystems, our ocean and coasts provide key habitats for a multitude of plants, animals, and other organisms all over the world. Biodiverse environments are more resilient to climate fluctuations; therefore, the protection and restoration of these areas is crucial to maintaining a livable planet. These important habitats are being damaged by resource extraction, coastal urbanization, pollution, introduction of invasive species, storm surges, and sea-level rise.

The loss of biodiversity in the ocean is causing major reductions in available fishery stock, affecting livelihoods and increasing food insecurity globally.

These habitats also play an important role in ocean–atmosphere interaction. Seagrass meadows and kelp forests capture significant amounts of carbon dioxide absorbed by the ocean each year. The continued loss of seagrass meadows and kelp forests will further increase atmospheric levels of GHGs.

The destruction of tidal marshes and mangroves is destabilizing coastlines by increasing erosion and flooding, causing governments and coastal communities millions of dollars a year.

Deep sea ecosystems are poorly understood yet could be threatened by increased fishing and future deep-sea mining.

There has been a rapid increase in the establishment of marine conservation areas (MCAs) globally. However, the lack of ecological monitoring and enforcement has called into question the effectiveness of many of these areas in meeting conservation goals.

## Recommendations

1. **Balance manufactured, that is, human-made structures, against using natural approaches to resilience.**
2. **Implement more marine protected areas (MPAs) and marine conservation areas (MCAs), including robust monitoring programs and adaptive management practices, that meet the 30 × 30 goals (30% of the ocean protected by 2030) and that include key habitats and prioritize biodiversity.** Take localized impacts on stakeholders into consideration, especially in the case of "no take" zones where all fishing activities are prohibited. This approach would also include the development of an open-access database allowing for MPA/MCA managers, researchers, and stakeholders to access and share best practices and *any* data (from oceanographic to economic and everything in between relating to these areas).
3. **Establish sophisticated monitoring and noninvasive technology (moorings, buoys, eDNA, underwater remote-operated vehicles, autonomous underwater vehicles, and sensors) to better**

**understand the overall dynamics and detect changes in the ocean's ecosystems**. Understanding the ecology and processes of these habitats will provide valuable information on their integral importance and further inform evidence-based decision-making for management needs.

4. **Use machine-learning technology to process and synthesize monitoring data.** These analyses should enable adjustments to conservation goals and faster implementation of direct action.
5. **Implement widespread use and accessibility of mechanical restoration technologies, such as seeding buoys and vessels designed to mechanically plant seagrass and kelp seedlings**.
6. **Establish living seawalls with 3D-printed structures.** Designed to mimic naturally occurring substrates, these seawalls allow for a variety of invertebrates, fish, and seaweeds to live or grow on them, while protecting coastlines from storm surges and erosion.

## Case studies

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1. Living Seawalls

   *"Sydney Harbour has shown that after 1-2 years Living Seawalls already support at least 36% more species than plain, unmodified seawalls, with as many as 85 species of invertebrates, seaweeds and fish living and growing on the panels."*

2. Monitoring of Marine-Protected Areas

   *"eDNA as a metabarcoding tool for monitoring marine protected areas"* (Gold et al., 2021).

# Issue 5: Urgency of preventing coral reef bleaching and die-offs

## Background

Without intervention, increases in coral reef bleaching and die-offs will continue, which will threaten large ecosystems that provide many services, from food security to ecotourism.

More than half a billion people depend on coral reefs for resources and protection. Coral reefs protect coastlines from storms and erosion and provide economic opportunities and ecosystem services. They also remove large amounts of carbon annually from the ocean.

Coral reefs are threatened by pollution, harmful fishing practices, and climate change impacts such as increased ocean temperatures and acidification.

Many of these threats can stress reef ecosystems, leading to bleaching and possible death. Bleaching is when stressed corals may expel the symbiotic algae—their main food source—living within them, thus, putting the coral at risk of dying. Many coral bleaching or mass mortality events have occurred over time; however, the largest recent one was the 2014 to 2017 global coral bleaching event, in which warm waters affected approximately 70% of coral reefs worldwide (Scott & Lindsey, 2018).

## Recommendations

1. **Consider bioengineering of heat-resistant corals.**
2. **Convert the more than 10,000 (**Masterson, 2024) **offshore oil and gas rigs into living substrates or artificial reefs as fossil fuels are phased out**. Beware, however: Some believe this process will provide oil conglomerates a loophole to dump unwanted debris as a cost-saving measure.

## Further resources

1. Blue Latitudes. "Rigs-to-Reefs."
2. International Coral Reef Initiative. "Coral Reef Restoration Guidelines."

# Issue 6: Ocean pollution due to offshore extraction and processing of fossil fuels, and the difficulties associated with attributing damage to specific polluters

## Background

The exploration and processing of raw hydrocarbons, along with the spills of raw hydrocarbons, petroleum products, and their related compounds, and everyday use of petroleum products has led to widespread and persistent pollution of the marine environment. Continued exploration for, extracting, processing, and using petroleum products demands a substantial change in engineering and behaviors to help reduce or eliminate controlled releases and uncontrolled releases of hydrocarbons into the ocean.

Petroleum pollution of the marine environment is well known and has been documented for decades. The most visible impact is that of oil spills[6,7]. One key issue making fingerprinting of oil spills intractable, even major ones, is the potential prevalence of natural oil seeps within the same region. These seeps make it challenging to detect small or early leakage of oil spills and to hold petroleum companies accountable for the long-term effects of major oil spills. Furthermore, a related issue is the difficulty of assessing effective long-term remediation for petroleum and petroleum-derived products in the ocean.

## Recommendations

1. **Build a road map for ocean energy transition: all the technical, economic, and human issues related to decommissioning existing offshore infrastructure, building new infrastructure, and meeting society needs for energy while reducing CO2 emissions and other environmental impacts**.
2. **Encourage knowledge exchange and collaboration between existing offshore oil and gas practitioners and newer offshore wind developers**. Existing petroleum-sector knowledge could accelerate development, and infrastructure may be repurposed for clean energy solutions. All current functional platforms should be required to develop plans to modify their existing offshore infrastructure and operation toward sustainable energy alternatives—wind, wave, solar—within the next 20 years.
3. **Study marine pollution in the context of the environmental interaction of potentially hundreds of hydrocarbons that make up the complex mixture of petroleum** (different for different sources of petroleum.
4. **Assess effective remediation strategies for ocean pollution due to petroleum and related products like oil spills or slow leaks** (e.g., oil booms, skimmers, and sorbents). Bioremediation should also be of interest (i.e., using algae and bacteria to break down oils).

[6] For example: DeepWater Horizon-BP Gulf of Mexico Oil Spill, 10 Apr. 2010. https://www.epa.gov/enforcement/deepwater-horizon-bp-gulf-mexico-oil-spill.

[7] For example: Exxon-Valdez Oil Spill-Prince William Sound, Alaska, 24 Mar. 1989. https://darrp.noaa.gov/oil-spills/exxon-valdez.

5. **Consider limiting the development and construction of new offshore petroleum extraction platforms to reduce petroleum reliance across society.**
6. **Require all extraction/processing platforms to monitor the natural hydrocarbons in their region so that spills can be detected and mitigated early.**
7. **Require platforms to contribute to a regional management fund that can use tools such as satellite monitoring and tracking to trace the sources of natural hydrocarbons and of spills from other sources to improve accountability.**
8. **Investment should be made in ocean-based renewable energy systems using energy from wind, waves, currents, and geothermal, ion exchange, and the sun**.

## Case studies

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1. Satellite oil spill detection and case study

   Sea Empress was grounded near the town of Milford Haven, Wales, on 15 Feb. 1996.

## Further resources


1. Agarwal, Mayur. "10 Methods for Oil Spill Cleanup at Sea." Marine Insight, Marine Environment. 30 Apr. 2021.
2. Illuminem (website).
3. Leporini, Mariella, Barbara Marchetti, Francesco Corvaro, and Fabio Polonara. "Reconversion of Offshore Oil and Gas Platforms into Renewable Energy Sites Production: Assessment of Different Scenarios." *Renewable Energy* 135 (May 2019).
4. Löw, Fabian, Klaus Stieglitz, and Olga Diemar. "Terrestrial Oil Spill Mapping Using Satellite Earth Observation and Machine Learning: A Case Study in South Sudan." *Journal of Environmental Management* 298 (Nov. 2021).
5. Rajendran, Sankaran, Fadhil N. Sadooni, Hamad Al-Saad Al-Kuwari, Anisimov Oleg, Himanshu Govil, Sobhi Nasir, and Ponnumony Vethamony. "Monitoring Oil Spill in Norilsk, Russia Using Satellite Data." *Scientific Reports* 11, no. 3817 (Feb. 2021).

# Issue 7: Influx of excess nutrients is polluting the ocean environment

## Background

Food security, biodiversity, and the safe management of coastal and ocean ecosystems cannot be maintained without better monitoring and more effective control of pollutants: Nitrates and phosphates cause eutrophication, fish die-offs, and ecosystem changes and may increase harmful algal blooms (HABs) in coastal waters.

The presence of pollution in the ocean, particularly in the form of nitrates and phosphates, is becoming ubiquitous, with significant effects on marine life and human health. The complete picture of pollutants is complex, and there are not sufficient data available to fully characterize all sources and effects, but there are well-established major causes. These causes include agricultural runoff, impacts of inefficient aquaculture practices, effluent discharges from urban and industrial areas, and the modification of natural river flows, which disrupts sediment transfer processes.

Pollutants cause a change in the ratio of important nutrients and temporarily stimulate plant growth, causing or exacerbating localized "*dead zones* where" decaying "organic matter consumes oxygen faster than" is exchanged with "the oxygen-rich" sea "surface" (UNESCO, *State of the Ocean Report 2022*). These hypoxic conditions directly affect commercial fish stocks, alter food webs, and may be a major contributor to habitat and biodiversity loss (see issues elsewhere in this chapter on coral reefs, seagrass meadows, and coastal wetlands).

The changes in nutrient ratios due to human activities may also contribute to the sudden, rapid growth of certain phytoplankton species—known as HABs—which present health risks to food chains, commercial fisheries, and humans, as well as related economic effects.

## Recommendations

1. **Develop and widely adopt low-cost technology for real-time monitoring of temperatures, nutrients, pollutants, and suspended sediment in all waterways**. The fit-for-purpose ocean observation system is a cross-cutting theme. For this issue specifically, monitoring of pollution outflows from rivers and cities is essential, including submarine groundwater discharge.
2. **Support and deploy direct measurements of water movement and its chemical composition** (for example, with gliders equipped with dissolved $CO_2$ and nitrous oxide sensors). The resulting data are necessary to validate detailed computer models, which can then help predict hazards and conduct what-if testing of various technical or policy mechanisms. These measurements should result in a wide range of actions, from changing regulations on farming and aquaculture practices to timing the operation of dams and spillways, to minimize harmful effects on ocean chemistry.
3. **Improve remote-sensing methods to help monitor and provide timely warnings to mitigate the immediate effects of HABs.** Improvements could be new sensors on new satellites but more likely will include improved machine learning algorithms to automate the processing and analysis of existing—near real-time—remote-sensing data.

4. **Work toward a long-term healthy ocean solution that would see the establishment of more regenerative agriculture practices and better urban wastewater management, including biofiltration systems and blue-green roof technology for storm water runoff.**
5. **Develop and implement corrective measures that protect the ocean mirroring those linked to land—this also impacts seafood production.** Sodium tripolyphosphate (STPP) is used in laundry detergents and on farmed shrimp and fish to retain water to add weight (not banned in most places). STPP contains phosphate and can cause eutrophication and algae bloom if wastewater merges into water bodies without the right treatment.
6. **Encourage citizen scientists to provide cost-effective water quality data on temporal and spatial scales that would otherwise not be possible**.

## Case studies

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1. Use of Biochar to remove toxins from different harmful algal blooms

   "Biochar May Help Fight Against Harmful Algal Blooms"
2. Nanobubble ozone technology (NBOT) to control cyanobacteria and their toxins
3. Case studies of biofiltration systems from the Minnesota storm water manual
4. Blue-Green Roof technology
5. The development of smartphone applications (Apps), which can be used by citizen scientists to cost-effectively measure and record surface reflectance, water color, and water quality parameters
6. Environmental Protection Agency Participatory Science Water Projects

## Further resources

1. Aliaga, Bernardo, Ward Appeltans, Rick Bailey, Julian Barbiere, Mathieu Belbeoch, Aileen Bohan, Elisabetta Bonotto, et al. Edited by Henrik Enevoldsen, Kirsten Isensee, and Ikroh Yoon. *State of the Ocean Report 2022*. Paris: UN Educational, Scientific and Cultural (UNESCO) Intergovernmental Oceanographic Commission, 2022.
2. Busker, Tim, Hans de Moel, Toon Haer, Maurice Schmeits, Bart van den Hurk, Kira Myers, Dirk Gijsbert Cirkel, et al. "Blue-Green Roofs with Forecast-Based Operation to Reduce the Impact of Weather Extremes." *Journal of Environmental Management* 301 (Jan. 2022).
3. Metcalfe, Anya N., Theodore Kennedy, Gabriella A. Mendez, and Jeffrey D. Muehlbauer. "Applied Citizen Science in Freshwater Research." *Wiley Interdisciplinary Reviews (WIREs): Water* 9, no. 2 (Jan. 2022).
4. San Llorente Capdevila, Anna, Ainur Kokimova, Saunak Sinha Ray, Tamara Avellán, Jiwon Kim, and Sabrina Kirschke. "Success Factors for Citizen Science Projects in Water Quality Monitoring." *Science of the Total Environment* 728 (Aug. 2020).

5. United Nations. *Groundwater: Making the Invisible Visible*. Paris: UN Educational, Scientific and Cultural Organization (UNESCO) World Water Assessment Programme (WWAP), 2022.

6. Yang, Feikai, Dafang Fu, Chris Zevenbergen, and Eldon R. Rene. "A Comprehensive Review on the Long-Term Performance of Stormwater Biofiltration Systems (SBS): Operational Challenges and Future Directions." *Journal of Environmental Management* 302, pt. A (Jan. 2022).

# Issue 8: Unsustainable marine transportation industry operations

## Background

The shipping industry is already on the edge of two major and simultaneous revolutions: *nature of trade* and *nature of shipping*. The nature of trade is where major gains can be made as trade is rearranged in terms of "what is carried" and "where it is carried" to reduce the total amount of shipping and use inherently more efficient ship types. For instance, the transport of feed stocks or materials for additive manufacturing is easier to carry than finished goods. Port facilities and access, driven by the nature of trade, will directly influence the effects of erosion and other coastal access issues. The nature of trade is a distinctly external set of characteristics that drives the shape of shipping.

The nature of shipping is about the mechanics of shipping in terms of ship propulsion types and operations, operating structure of shipping, construction, and repair of ships. It is a distinctly internal set of characteristics to shipping itself. Step changes can be made in zero/low-emissions powering and noise and vibration abatement.

Commercial shipping, for the purposes of this discussion, can be divided into "international" shipping between countries and "local" shipping within a single country. International shipping is effectively governed for safety and environment through the International Maritime Organization (IMO), a UN body that produces codes such as MARPOL or SOLAS that are endorsed and enforced by the maritime flags and ports. One distinct characterization of the IMO is that its codes are uniformly adopted worldwide without consideration of such groups as "developing nation" status or other fragmentations. Local shipping is effectively governed solely by the locality of the vessel, although many localities adopt general IMO codes in part or full. Commercial shipping represents an opportunity or major problem depending on one's viewpoint. Both international and local shipping issues provide two of the best opportunities for general decarbonization and industry leadership.

Commercial shipping is an ancient endeavor and has evolved to move "90% of everything" around the world. It accounts for around 3% of the world's GHG emissions (Figueres, 2020), making it approximately the fifth largest emitter if it were a country and, if left unchecked, will grow to around 16% of the world's emissions by 2030.[8] Commercial shipping is tightly integrated into the world's economies and is a key enabler in the creation and sustainability of supply webs and geopolitical stability that span the world. Shipping, while much more efficient compared to other modes of transport such as road, rail, pipeline, or airborne, should also be part of the overall solution of tackling climate change.

Shipping is also a major contributor to human-made subsea noise and vibration and local erosion/coastal changes in the way of harbors or channels where vessels are active.

Shipping is characterized by long-lived assets with asset lives ranging from 20 to 50 years, causing changes to occur over a period of time. Ships are acquired and operated based on having a full life with minimal retrofit for any type of regulation. Hence, there is a strong lobbying effort from the established operators to delay or minimize the effect of potential new regulations.

[8] Projections for the future of $CO_2$ in shipping under different policies are found at: Bryan Comer, "Choose Wisely: IMO's Carbon Intensity Target Could Be the Difference between Rising or Falling Shipping Emissions This Decade," *The International Council on Clean Transportation (ICCT)* (blog), 18 May 2021.

IMO regulations are the primary policy driver for shipping, related merchant marine, and many naval requirements. Policy in the form of IMO regulations, while slow in formulation and full implementation, are thorough. One example is the phasing out of single hull tankers following the 1989 *Exxon Valdez* spill in Alaskan waters. The United States adopted OPA 90 in 1990, making the United States the first country to adopt double hull requirements followed by the IMO in 1992. Single hull tankers were fully phased out in 2015 in general worldwide trade with several intermediate steps. Profound change can happen even though it takes time, and it can be messy, especially in the earlier stages. The inherently slow and measured process of IMO work further limits the extent of what may be drafted and adopted by IMO; that said, IMO requirements, once established, are sticky and force change because it is the primary policy driver of the shipping industry.

## Recommendations

1. **Implement step changes toward in zero/low-emissions powering for "local' and "international" shipping.** Commercial shipping represents an impactful opportunity for decarbonization of marine transportation.
2. **Reduce unnecessary transportation.**
3. **Optimize the use of shipping vessels and routes.**
4. **Work with the IMO to develop regulations for more sustainable shipping.**
5. **Support abatement of human-made sub-sea noise and vibration caused by shipping**.

# Issue 9: Path to decarbonization for new and existing ships is unclear

## Background

Ships are a significant source of GHGs, and gaps in scalable technology and enforceable policy make the pathways to reach zero emissions ambiguous.

Fuel used in commercial shipping results in the emission of harmful pollutants, including $CO_2$, nitrogen oxide (NOx), sulfur oxide (SOx), particulate matter (PM), and unburned hydrocarbons.

There is an ongoing effort to regulate marine pollutants, most notably led by the IMO's Convention for the Prevention of Pollution from Ships (MARPOL). However, these efforts are incremental and long because of the nature of regulations developed by consensus followed by ratification and implementation. Vessels that do not trade internationally are not subject to IMO/MARPOL; hence, the local regulations may be stronger or weaker than the IMO.

Individual nation-states can, and occasionally, adopt higher standards, but the jurisdiction is limited to vessels working within the waterways of the nation-state.

Fuel used in commercial shipping results in the emission of harmful pollutants, including GHGs (like $CO_2$, NOx, SOx, and PM). Studies are ongoing to measure the emissions levels and their impacts for many of these areas. For instance, 3% of global GHGs (Figueres, 2020) are attributed to shipping, and emissions are expected to rise by 16% by 2030 (Comer, 2021) if there are no changes made.

There is an ongoing effort to regulate marine pollutants, most notably led by the IMO's Convention for the Prevention of Pollution from Ships (MARPOL). However, these efforts fall short due to issues such as variations in regulations in different flag and port states, the high cost of refitting the large proportion of older vessels to meet modern standards, limited availability of truly clean energy solutions, and challenges in measuring and tracking the impact of any operational or equipment adaptations at an appropriate scale. The inherently slow and measured process of IMO work further limits the extent of what may be drafted and adopted by the IMO.

## Recommendations

1. **The cost of emissions from the operation of vessels (and their embodied energy) should be higher than the cost of clean technologies.** This effort should be supported both through regulation (tracking of emissions and levying of fines) and by subsidizing technology development and adoption (policy, corporate).
2. **Support research and scaling of transformative technologies of ships' propulsion systems.** Although incremental improvements like liquid natural gas (LNG) fuels can be considered in the short term, transformative technologies will be needed, including propulsion innovation (e.g., hydrogen fuel, wind assist, and long-duration electric) and route optimization (e.g., data analytics, weather forecasting, and autonomous navigation).

3. **Consolidate localized studies, initiatives, and oversight to capture global trends and expectations in shipping.** International bodies should work and cooperate to provide a consistent regulatory environment (interoperable regulations between jurisdictions) across borders to help prevent local regulations (e.g., speed limits, green corridors, emissions limits, and clean fuel standards) from being bypassed as a ship transits from one regulatory regime to another. The industry should not force one region to bear the brunt of emissions as others enforce higher standards.
4. **Measurement of impact of a ship's operations on a smaller and more frequent scale should be enabled so that change (negative or positive) can be recognized and timely adjustments can be made.** This measurement can include emissions monitoring in ports that every ship can use to establish its baseline levels without additional cost.
5. **Build mechanisms to publicize *wins* and critique *losses* so that reputational factors (with respect to a vessel or a shipping company) further drive reduced emissions.** These mechanisms can include expanding programs that recommend, verify, track, and publicize metrics and industry members who meet them.
6. **Educate and inform the public about the embodied energy of goods.** Customers should be allowed to choose the right shipping option for their needs. This choice might include the option of slower shipping in exchange for reduced carbon footprint.

## Case studies

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1. Voluntary certification programs
   a. Green Marine (North America)

      *"The Green Marine program demonstrates year after year its ability to encourage its participants to go beyond regulatory requirements." (*Green Marine, "Certification, Results")

   b. First Movers Coalition (Global):

      *"The FMC is a coalition of companies using their purchasing power to create early markets for innovative clean technologies across eight hard to abate sectors. These in-scope sectors are responsible for 30% of global emissions–a proportion expected to rise to over 50% by mid-century without urgent progress on clean technology innovation."* (World Economic Forum, "First Movers Coalition")

2. Marine protected areas

    a. Mongabay—MPA Impact Review (US-based non-profit)

    *"To find out if marine protected areas achieve their environmental and socioeconomic goals, we read 42 scientific studies and talked to seven experts. Overall, marine protected areas do appear to help marine animals recover within their boundaries. But a lot more rigorous research is needed. The effects of marine protected areas on socioeconomic outcomes and fisheries are less clear."* (Dasgupta, 2018)

    b. PEW—The Case for MPAs (Charitable trust)

    *"In 2016, members of the International Union for Conservation of Nature, a global authority on the status of the natural world, adopted a motion recommending that nations protect 30 percent of their waters from all extractive activities by 2030. Safeguarding ocean space in marine protected areas (MPAs) has been proved to help conserve marine life and associated habitats. Creation of MPAs can improve ocean health and provide multiple benefits to the people whose lives and traditions are linked to these waters." (Pew Charitable Trusts, "The Case for Marine Protected Areas")*

    c. WWF Effects of MPAs (World-wide conservation organization)

    *"WWF scientists collaborate on a geographically expansive, long-term study to quantify the impacts of marine protected areas on both people and nature."* (Morgan, 2016)

3. Future fuels and propulsion

    a. Lloyd's Register—Zero-carbon fuel readiness monitor (Marine classification society)

    *"Zero-emissions solutions have so far only been deployed in niche applications, solutions for large scale ocean shipping are not yet established."* (Lloyd's Register, "Zero-Carbon Fuel Monitor")

    b. International Transport Forum—Market Forces Driving Decarbonisation (Intergovernmental organization)

    *"This chapter spells out the drivers and barriers of decarbonisation and the conditions under which it could be achieved. One of these conditions is strong financial incentives, such as carbon pricing. The chapter concludes with implications for regulation."* (Kirstein, Halim, & Merk, 2018)

c. Bureau Veritas—Challenges and Impact of Adopting Wind Propulsion (Marine classification society)

> *"In addition to turning to low- and zero-carbon fuels, many owners are researching alternative propulsion methods as a way to limit their impact. Among developing options, wind-assisted propulsion is considered a strong contender for achieving significant emissions reduction. As a free, clean energy source available worldwide, wind can power ships renewably through the use of sails – both advancing the shipping industry and returning it to its roots. However, much of the technology needed to support wind-assisted propulsion systems is still in the early stages of development. While a handful of pilot projects are underway, several environmental, technical, design and financial challenges remain before widespread adoption of wind-assisted systems is possible."* (Bureau Veritas, "Powering Marine Decarbonization")

## Further resources


1. Comer, Bryan. "Choose Wisely: IMO's Carbon Intensity Target Could be the Difference Between Rising or Falling Shipping Emissions this Decade." *The International Council on Clean Transportation (ICCT)* (blog), 18 May 2021.
2. Hussain, Iftikar, Haiyan Wang, Muhammad Safdar, Quoc Bang Ho, Tina D. Wemegah, and Saima Noor. "Estimation of Shipping Emissions in Developing Country: A Case Study of Mohammad Bin Qasim Port, Pakistan." *International Journal of Environmental Research and Public Health* 19, no. 19 (Sept. 2022).
3. Kadwa, Farheen. "How Canada's Shipping Industry Can Reduce its Climate Change Impacts." WWF-Canada, 24 Nov. 2021.
4. Moldanová, Jana, Ida-Maja Hassellov, Volker Matthias, Erik Fridell, Jukka-PekkaJalkanen, Erik Ytreberg, Markus Quante et al. "Framework for the Environmental Impact Assessment of Operational Shipping." *Ambio* 51 (July 2022): 754–769.
5. Pavlenko, Nikita, Bryan Comer, Yuanrong Zhou, Nigel Clark, and Dan Rutherford. *The Climate Implications of Using LNG as a Marine Fuel.* Working Paper 2020-02. International Council on Clean Transportation (ICCT), Jan.2020.
6. Reinsch, William Alan, and Will O'Neill. "Hydrogen: The Key to Decarbonizing the Global Shipping Industry?" Center for Strategic and International Studies (CSIS), 13 Apr. 2021.

# Issue 10: Increased noise from ships is destroying underwater habitats

## Background

Increasing demands for fast shipping and tourism to remote habitats is causing a larger number of ships to operate along established shipping routes, as well as into areas where ships did not previously transit frequently. Aquatic species, and especially marine mammals, are sensitive to the underwater noise generated by these ships, causing them to change their behaviors or abandon critical habitats to avoid shipping traffic.

Ships are powered by large engines and driven by large propulsors, which results in significant vibration of the structure and results in both airborne and underwater noise and vibration resulting from mechanical and hydrodynamic phenomena. Barnacles and other biofouling on ships are another source of underwater noise. Underwater ambient noise levels have doubled each decade since the 1970s, and reductions are unlikely to be achieved by 2030 when the next generation of ships start being delivered. Studies are ongoing to measure the emissions levels and their impacts for many of these areas.

Due to the discomfort and harm caused to humans on noisy vessels, as well as onshore, there are standards in place to control airborne noise and structural vibration in crew areas. However, underwater noise does not have the same controls in place. Currently, there are actively mandated noise and vibration abatement programs, including design practices and specific technologies that have existed for many decades and have been routinely applied in various vessel types (naval, oceanographic, cruise, etc.) However, our ocean and coasts remain extremely noisy places for marine life.

## Recommendations

1. **Fund the research needed to determine what noise levels are harmful in key shipping locations.** This research should include determining what species are present in locations, what their hearing thresholds are, and whether a limit on specific and/or total shipping activity is needed.
    a. Consolidate local studies and Indigenous knowledge and encourage industry leaders to collaborate in the work to build expertise among decision makers for the need to control underwater noise levels.
2. **Employ insights resulting from underwater noise studies and stakeholder cooperation (policy, academia, corporate, industry associations, Indigenous and other local stakeholders) to generate underwater noise emissions standards for individual vessels, as well as soundscape standards for shipping lanes, ports and harbors, and critical habitats.**
3. **Put noise management plans in place for all existing vessels that identifies their noise levels under different operating conditions and provides the vessel operators with guidance on what operating conditions are appropriate in areas where they may interact with noise-sensitive species.**
4. **Design new vessels to meet incoming underwater noise standards and follow a noise management plan once they become operational.** This effort should be supported both through regulation (tracking of emissions and levying of fines) and by subsidizing technology development and adoption (policy, corporate).

5. **Develop and implement the use of improved nontoxic antifouling coatings.**
6. **Measure the impact of underwater noise reduction approaches more frequently so that change (negative or positive) can be recognized and timely adjustments can be made.** This measurement can include noise monitoring in ports that every ship can use to establish its baseline levels without additional cost. There should also be mechanisms to publicize *wins* and critique *losses* so that reputational factors further drive reduced emissions (policy, industry associations).
7. **Support research in transformative technologies, including cavitation reduction, active and passive noise control in structures and spaces, antifouling coatings, and maintenance protocols** (policy, academia, corporate).

## Case studies

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1. Marine protected areas (see Issue 9 of this chapter)
2. URN target setting and mitigation measures
   a. BC Ferries—URN Mitigation Study (Passenger Ferry Industry)

   *"Key learnings for other vessel operators considering the implementation of underwater radiated noise targets: Obtain baseline measurements of your fleet to determine where your starting point is before setting underwater noise reduction goals; Make design decisions in consideration of the larger system. Underwater radiated noise is a function of many complex interactions within a vessel, and as such, it is important to design the propeller and propulsion systems in concert with the hull design to account for functional requirements; Engage an underwater radiated noise expert to assess design impacts and conduct trade-off analysis. Make expertise available for working closely with the selected shipyard throughout the detailed design and build process; Anticipate conflicting requirements as a part of the design optimization process. For BC Ferries, for example, meeting underwater radiated noise reduction requirements while achieving improved energy efficiency is a balancing act that requires careful consideration."* (Peterson, 2021)
3. Incentive programs
   a. Port of Metro Vancouver—EcoAction Program (Port Authority)

   *"Through the port authority's EcoAction Program, shipping companies can qualify for up to 75% off their harbor dues fees by taking voluntary measures to reduce their environmental impact, such as by using renewable energy to reduce air emissions, installing propeller technologies that reduce underwater noise, or obtaining third-party environmental designations."* (Port of Vancouver, "EcoAction Program")

b. Santa Barbara Channel—Speed reduction incentive program (National Marine Sanctuary and Port)

*"Commercial shipping is the dominant source of low-frequency noise in the ocean. It has been shown that the noise radiated by an individual vessel depends upon the vessel's speed. This study quantified the reduction in source levels (SLs) and sound exposure levels (SELs) for ships participating in two variations of a vessel speed reduction (VSR) program. SLs and SELs of individual ships participating in the program between 2014 and 2017 were statistically lower than non-participating ships ($p < 0.001$). In the 2018 fleet-based program, there were statistical differences between the SLs and SELs of fleets that participated with varying degrees of cooperation. Significant reductions in SL and SEL relied on cooperation of 25% or more in slowing vessel speed. This analysis highlights how slowing vessel speed to 10 knots or less is an effective method in reducing underwater noise emitted from commercial ships."* (ZoBell et al, 2021)

4. Impact of noise on aquatic species

a. Measuring Impact on Cetaceans (Canadian Conservation)

*"This report presents an analysis of high-risk areas in Canadian waters where shipping activity poses an elevated threat to cetaceans, and it is founded in in-depth interviews and a literature review of four working groups developing mitigation measures to manage impacts of shipping on cetaceans in the country. … Based on these case studies, we summarize best practices and draw the following recommendations: 1. Where possible, separate ships from cetaceans by modifying routes or designing vessel exclusion zones in high-risk areas. 2.Where it is not possible, apply speed restrictions in known sensitive cetacean habitats, such as feeding aggregation or nursing areas. 3.Evaluate the co-benefit of speed restrictions for cetacean conservation and for the environment in general to better quantify benefits versus costs. 4.Consider all endangered, threatened and protected species when designing mitigation measures. 5.Apply best practices to create an effective and collaborative structure to coordinate communication between relevant stakeholders, and base management decisions on the best available knowledge (scientific, local and Indigenous). 6.In areas where place-based measures are not enough, encourage certification or port-led incentive schemes and the development of quantifiable noise-reduction targets and/or noise thresholds to regulate shipping."* (Dalili, Ushio, and Cosandey-Godin, 2020)

b. Managing Noise Impacts—Context and Monitoring Approach (US-based Ocean Noise Strategy Roadmap)

*"This case study provides a place-based context for examining recommendations …expanded focus and attention to NOAA-managed and acoustically sensitive fishes and invertebrate species, …. extended use of existing authorities to address noise impacts to acoustic habitats for sensitive fish and invertebrate species, and … prioritized development of NOAA-maintained long-term passive acoustic monitoring capacity."* (Gedamke, Harrison, & Hatch, 2021)

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2. Moldanová, Jana, Ida-Maja Hassellov, Volker Matthias, Erik Fridell, Jukka-PekkaJalkanen, Erik Ytreberg, Markus Quante et al. "Framework for the Environmental Impact Assessment of Operational Shipping." *Ambio* 51 (July 2022): 754–769.
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# Issue 11: Waste streams and emissions from ships in the ocean are difficult to trace

## Background

Ships generate many waste streams that have traditionally been dumped into the ocean with limited traceability. This has changed over many decades and addresses treatment of overboard waste streams and retaining waste until discharge at a receiving terminal. But lingering issues remain, such as antifouling coatings, ballast water, and transfer of invasive species.

In addition to emissions from fuel, commercial shipping and other vessels emit other harmful pollutants in many forms, including bilge water, scrubber water, and ballast water; wastewater and food; metals from bio- and antifouling coatings; and invasive species. These waste products can result in algae blooms, damage habitats by releasing cleaning products or metals that can poison key parts of ecosystems and/or introduce new species into locations where they have no natural predators, causing them to dominate over local species. These pollutants are particularly challenging as damage occurs quickly and traceability is impossible due to the vast spatial dimensions, the multitude of pollutants, and the traffic volume.

## Recommendations

1. **Develop regulations for controlling emissions, including mechanisms for levying fines, when needed.** These regulations should apply to vessels throughout their routes to help prevent the storage of waste to be dumped in areas with fewer regulations (policy, industry associations).
2. **Provide funding for the development and adoption of new technologies for reducing the volume of waste, cleaning or processing waste waters onboard the vessel, and supporting the handling of waste in ports.** Funding is also needed for research into transformative technologies to mitigate invasive species in ballast tacks, and nonleaching antifouling coatings (policy, academia, industry associations).
3. **Support the development of meaningful metrics for these waste emissions and mechanisms for tracing their sources when dumped illegally**.
4. **Introduce transparency programs that publicize companies who do and do not act in good faith so that reputational factors further drive compliance** (academia, policy).
5. **Address technology gaps.** Develop and implement solutions with respect to:
    a. Anti-invasive species in ballast tanks
    b. Safe antifouling coatings
    c. Monitoring equipment and software (for consistent reporting)
6. **Conduct better monitoring of large areas for dumping** (e.g., satellite oil dumping detection).

## Case studies

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1. Marine protected areas (see Issue 9 of this chapter)
2. Invasive species
    a. Lake Tahoe—Multi-jurisdictional Coordination (US-based conservation)

    *"Biological invasions are increasing in frequency and the need to mitigate or control their effects is a major challenge to natural resource managers. Failure to control invasive species has been attributed to inadequate policies, resources or scientific knowledge. Often, natural resource managers with limited funds are tasked with the development of an invasive species control program without access to key decision-support information such as whether or not an invasive species will cause damage, and what the extent of that damage may be. Once damages are realized, knowing where to allocate resources and target control efforts is not straightforward. Here we present the history of invasive species policy development and management in a large, multi-jurisdictional and multi-use aquatic ecosystem. We present a science-based decision-support tool for on-the-ground aquatic invasive species (AIS) control to support the development of a sustainable control program. Lastly, we provide a set of recommendations for managers desiring to make an AIS control implementation plan based upon our development of novel invasive species research, policy and management in Lake Tahoe (USA). We find that a sustainable invasive species control program is possible when science, coordination and outreach are integrated."* (Wittmann et al., 2015)

3. Cruise ships
    a. Cruising Tourism Environmental Impacts (Marine tourism Dubrovnik, Croatia)

    *"Cruise tourism is new economic, social and environmental phenomena with potential serious impacts on the three pillars of sustainability. This paper will look into the environmental impacts in order to disclose potential hazards in port of Dubrovnik. Subsequently, existing mechanisms to deal with the hazards will be analyzed to determine their effectiveness to mitigate the impacts. This process will use direct pollution costs calculations to enable cost benefit analysis. Other impact analysis will be conducted in form of environmental (pollution) foot printing that compare environmental loads of cruise tourist vs. local inhabitant. The two (cost benefit analysis and environmental foot printing) analysis will provide information on general aspects of cruise tourism carrying capacity and its current direction of development. Finally, the discussion will point to key pollution management issues, possible solutions to some of the pollution aspects, and stress other direct ecological threats." (Carić, 2011)*

b. Cruise Ships Wastewater Pollution (Marine tourism Adriatic Sea):

*"The global growth of cruise tourism has brought increasing concern for the pollution of the marine environment. Marine pollution from sanitary wastewater is a problem especially pronounced on large cruise ships where the number of people on board may exceed 8,000. To evaluate future marine pollution in any selected period of time it is necessary to know the movement of ships in the Adriatic Sea. This paper presents the problem of marine pollution by sanitary wastewater from cruise ships, wastewater treatment technology and a model of cruise ship traffic in the Adriatic Sea considering MARPOL Annex IV areas of limited wastewater discharge. Using the model, it is possible to know in advance the routes of the cruisers and retention time in certain geographic areas. The data obtained by this model can be used as input parameters for evaluation model of wastewater pollution or for evaluation of other types of pollution from cruise ships."* (Perić, 2016)

c. Cruise Ship Waste Generation and Management (Marine tourism in Aegean Sea)

*"In a medium-sized cruise ship, 140808 m3 of all types of waste is produced annually. A high amount of the waste volume (90 %) is legally discharged at sea. Minor quantities are disposed to port reception facilities (8 %) or incinerated (2 %). The waste management infrastructure at land in the Caribbean area is poor. Management of ship generated waste is a prerequisite for sustainable cruising."* (Kotrikla, 2021)

## Further resources


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2. Moldanová, Jana, Ida-Maja Hassellov, Volker Matthias, Erik Fridell, Jukka-PekkaJalkanen, Erik Ytreberg, Markus Quante et al. "Framework for the Environmental Impact Assessment of Operational Shipping." *Ambio* 51 (July 2022): 754–769.
3. Kalnina, Renate, Ieva Demjanenko, Kristaps Smilgainis, Kristaps Lukins, Arnis Bankovics, and Reinis Drunka. "Microplastics in Ship Sewage and Solutions to Limit Their Spread: A Case Study." *Water* 14, no. 22 (Nov. 2022): 3701.

# Issue 12: Ubiquitous presence of micro- and macro-plastics in the ocean

## Background

One of the biggest issues within ocean conservation is plastic pollution. It directly threatens marine life, affecting biodiversity and human health. According to the UN Environment Programme (UNEP), 8 million tons of plastic waste end up in the ocean every year and this could double by the year 2025 if drastic action is not taken (Torkington, 2011). Plastic is floating in rivers. Plastic can even be caught and collected out on the ocean. But there is more than just visible plastic waste. There is macro- and micro-plastic. Macro-plastics are objects visible to our eyes. Microplastics, however, are particles smaller than 5 mm (NOAA, "What Are Microplastics?"). They come either from clothing fibers or are a result of larger plastic items breaking down. These tiny particles are floating throughout the ocean and are even found in the ocean´s tiniest creatures, like plankton.

Plastic makes up 80% of marine debris and is caused by mismanaged plastics. One source is land based, typically from areas with poor waste management without a recycling system (TONTOTON). Single-use plastic items make up half of all plastics produced annually and likely form the largest part of the plastic pollution problem. The largest pollution coming from marine sources are from fisheries (ghost-gear), aquaculture, and nautical activities (UNESCO, 2021). A recent study in the Great Garbage Patch shows that around 80% of plastic waste originates from fishing activities (Egger, 2022).

Marine plastic debris is a direct threat to animal health and, therefore, impacts biodiversity, food safety and quality, human health, and coastal tourism. Plastic waste also contributes to climate change through the potential release of carbon dioxide when incinerated.

It can be difficult for an Individual to understand the full impact of their decisions on the ocean/environment. Considering the complete lifecycle of a product can also help measure the benefits of changes that might appear too expensive without a full understanding of the cost of the status quo: the financial, environmental impact, disposal impact etc, and other costs. This approach should be captured in two ways: by making companies responsible for the full lifecycle cost of products/materials they produce and profit from, and by making consumers aware of the impact of their use of products.

## Recommendations

4. **Overhaul the use of plastics and management of waste to reduce the prevalence of macro- and micro-marine plastics, which directly threaten marine life, affecting biodiversity and human health**.
5. **Control urban waste to prevent plastic waste from entering bodies of water, including the ocean.** Urban waste management is a key issue for preventing plastic waste reaching the ocean carried by river systems and through direct coastal runoff to be carried to the ocean.
6. **Investigate the potential of bacteria for plastic waste treatment.** Plastic-eating bacteria may be able to decrease the microplastic waste (Cornwall, 2021).
7. **Prioritize waste management in municipalities and invest in regulations to support proper waste collection and disposal**.

8. **Model pollution drifting to determine where to focus both mitigation and cleanup efforts.** Modeling will help in understanding the impacts of plastics on human health and planetary health.
9. **Monitor fishing gear to prevent the loss of equipment and save costs and fuel while searching for it.**
10. **Carry out lifecycle analyses (LCAs) for plastics-based products and services, including their potential impact on the ocean**.
11. **Make consumers aware of the impact of the use of their products, as well as encourage them to participate in appropriate reuse/recycling programs at the end of use of their items.**
12. **Encourage and support collaboration and cooperation between countries.** Countries should join forces. Currently, too many different organizations promote ocean literacy. There should be a way to combine and interchange the knowledge of new and improved technologies as well as processes and data in an efficient, transparent and reliable manner. This should lead to faster adoption of more environmentally beneficial technologies and protocols.
13. **Further develop biodegradable fishing lines/gear (Bland, 2023).**
14. **Update policy and regulation in a timely and effective manner as newer more environmentally friendly technology becomes available** (e.g., biodegradable fishing gear and effective environmentally safe antifouling paint).
15. **Investigate the impact of microplastics.** A better understanding of the impact of microplastics is needed, especially related to the food chain (human health vs. planetary health).
16. **Consider a global treaty banning plastics or other measures that will ultimately stop** (non-biodegradable) **plastic waste from entering the ocean**.
17. **Research into alternative plastics should be encouraged** (e.g., biodegradable “plastic” solutions such as this one made from seaweed; see Canadian Plastics, “This Non-Toxic Biodegradable Plastic Film Is Based on Seaweed”).
18. **Intercept, collect, and remove plastic pollution in runoff, ditches, streams, and rivers, preferably using low-cost, low-tech solutions.**
19. **Develop, implement, and enforce common standards and regulations for recycling, collection, treatment, and composting of end-of-use plastics across communities, states, and countries**. In addition, data collection methodologies (like block chain) need to be developed to report on these activities: plastic waste reduction, recycling rates and other waste reduction measures. Moreover, producers should assume/share responsibility for supporting effective end-of-use material handling programs.

## Case studies

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1. The Great Bubble Barrier

   *"Bubble Barriers capture plastic in waterways with bubbles. We create a bubble curtain by pumping air through a perforated tube on the bottom of the waterway. The bubble curtain creates an upward current which directs plastic to the surface. By placing the Bubble Barrier diagonally across the river, the natural flow of the water will push the plastic waste to the side and into the catchment system.*

   *The catchment system is designed to work in harmony with the bubble curtain to collect and retain plastics. Following collection, it will be removed for processing and reuse.…*

   *The Bubble Barrier comprises three main components: the bubble curtain, the compressor, and the catchment system. The three components are designed to work together to create the optimum solution for each location."* (The Great Bubble Barrier website)

2. Plastic Fischer

   Installing a boom system in rivers can be up to 300 times more cost-effective than fishing plastic out of the ocean.

3. Lonely Whale

   Lonely Whale has trained thousands of young leaders across dozens of countries and engaged tens of thousands more through the OH-WAKE Media Network at ohwake.org.

4. NextWave

   This organization focuses on considering plastic no longer as waste, but a valuable raw material for the circular economy. "Keeping plastics in the economy and out of THE ocean."

5. Global Plastic Innovation Network

   An innovative network to crowdsource innovations of high potential innovators to tackle plastic pollution.

6. Mi Terro

   Sustainable and durable bio-based materials for packaging, textiles, contact lenses, and other applications. Using biomaterials that can be returned to nature after used, reducing harm to the environment.

## Further resources

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2. *Blueprint for Ocean Climate Action: Recommendations for the Ocean Policy Committee.* June 2022.
3. Global Plastic Action Partnership (GPAP) (website).[9]
4. Incubation Network (website).[10]
5. Ocean Literacy (website).

[9] GPAP is a multi- stakeholder platform dedicated to translating commitments to reduce plastic pollution and waste into concrete action.
[10] The Incubation Network sources, supports, and scales innovative solutions that tackle plastic pollution.

# Issue 13: Management and the lack of global ocean data

## Background

Most, if not all, solutions to key ocean issues are hindered by an enormous gap between the available data and the data needed to support management, evidence-driven policy, and responsible economic and technology development. High-quality data collection is essential to making effective and efficient marine operations easier, as well as to predicting ocean related hazards through modeling (Canada's Ocean Supercluster, "Port Integration").

Data have always been essential, especially for evidence-based decision-making. Data on sound, weather and GHG monitoring, salinity, current, and temperature can show the impact of climate change on the ocean (NESDIS). The most important issue regarding ocean data is to find a balanced way to collect and share data (HUB Ocean, "Data Catalog"). Thus, even if data get collected, there has to be a way to translate it into a common language so that every sector (science, technology, industry, policy) has access and can make use of the data. With increased levels of technology-based approaches to addressing sustainability challenges, there is an even greater need for data. For example, machine learning algorithms highly depend on high-quality ground-truth data to use to design the algorithms. Remote-sensing (aerial and satellite) data of the sea surface, combined with complex ocean models, have provided large improvements in understanding of ocean systems over the past few decades. Still, the fact that electromagnetic waves (light, radio, etc.) do not penetrate water well has left the interior of the ocean vastly undersampled. Remote sensing of ocean properties, from bathymetry to physical properties, to chemical and biological cycles, depends on local sampling methods. Even advanced autonomous systems rely on physically coming to the surface to communicate. All methods of underwater communication are extremely slow, short range, or both. Even above the ocean, there is no parallel to the vast sampling of the atmosphere over land.

As a result, large parts of the climate and ocean system depend on modeling based on sparse data.

## Recommendations

1. **Urgently narrow the data gap about the ocean.**
2. **Prioritize the collection of relevant ocean data points.**
3. **Use open-source data repositories, or if need be, create a common language for data sharing, for example, the IEEE Data Port.**
4. **Train scientists in how to collect and mine relevant and useful marine data.**
5. **Build machine learning models to recognize potential solutions and unseen problems.**
6. **Design causal learning models.**
7. **Invest in computational capabilities and make these resources more accessible.**

## Case studies

*This information is given solely for the convenience of users of this document as examples of case studies that were known at the time of publication, and does not constitute an endorsement of any company, product, service or organization by the IEEE or IEEE Standards Association (IEEE SA).*

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2. The Ocean Data Platform—HUB Ocean: Data: An open collaborative tool that unlocks and aggregates ocean data to encourage scientific collaboration, industry transparency, and layered analysis.
3. Port Integration and Enhancement of Data Project—Canada's Ocean Supercluster: Shows the importance of data through artificial intelligence to support economic growth both as an ocean transport hub and as a software hub.
4. Ellipsis Earth Ltd: To detect patterns of litter behavior through detailed monitoring and the ability to identify more than 47 types of litter. This technology identifies trends, measures impact, and targets critical hotspots. It can help to demonstrate direct success or failure of solutions by allowing for more efficient spending with less wasted time and money and eliminating greenwashing.

## Further resources


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