WORKSHOP SUMMARY FOR POLICYMAKERS

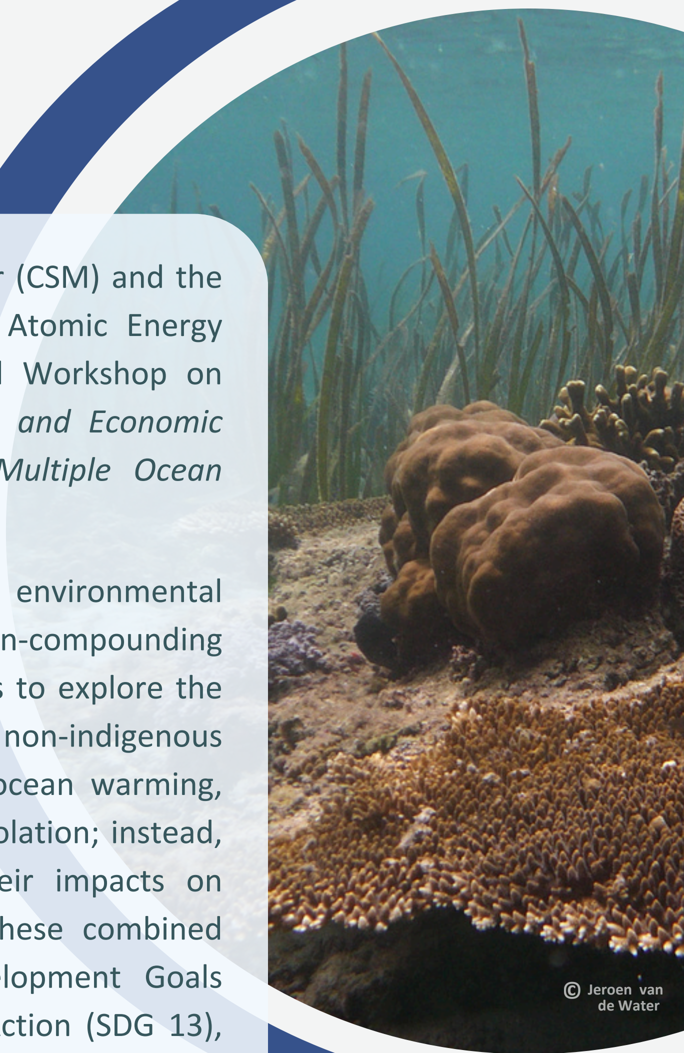
CENTRE SCIENTIFIQUE DE MONACO

IAEA

SIXTH INTERNATIONAL WORKSHOP

BRIDGING THE GAP BETWEEN OCEAN ACIDIFICATION IMPACTS AND ECONOMIC VALUATION

AN INTERDISCIPLINARY APPROACH TO ADDRESS MULTIPLE OCEAN STRESSORS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In October 2024, the Monaco Scientific Center (CSM) and the Marine Environment Laboratories of the International Atomic Energy Agency (IAEA) jointly organized the Sixth International Workshop on *Bridging the Gap Between Ocean Acidification Impacts and Economic Valuation: An Interdisciplinary Approach to Address Multiple Ocean Stressors.*

This interdisciplinary workshop addressed various environmental stressors to coastal marine ecosystems and their often-compounding impacts to ecosystem services. The overarching goal was to explore the complex interactions between local stressors (pollution, non-indigenous species, plastics, eutrophication) and global stressors (ocean warming, ocean acidification). These stressors do not operate in isolation; instead, they often occur in parallel, which may intensify their impacts on biodiversity, ecosystem services, and human health. These combined challenges hinder progress towards Sustainable Development Goals (SDGs), including, Life Below Water (SDG 14), Climate Action (SDG 13), Responsible Consumption and Production (SDG 12), Clean Water and Sanitation (SDG 6), No Hunger (SDG 2) and No Poverty (SDG 1).

Examining the connections between these multiple stressors provides insights into the economic and societal costs of inaction and potential solutions to address them. This workshop convened an interdisciplinary group of 26 experts from 12 countries, equally distributed between the Global South and North, and included balanced gender representation. Participants formed four working groups to discuss key local stressors (i.e., pollution, plastics, eutrophication, and non-indigenous species) in the context of co-occurring global stressors driven by greenhouse gases emissions (GHGs). The groups identified solutions grounded on research evidence and formulated policy recommendations that reflect the need for an integrated approach to achieve ocean sustainability.

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POLLUTION UNDER GLOBAL CHANGES

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I. Summary of Impacts

- **Environmental:** Pollution threatens the marine environment and poses a risk to marine food chains. Pollutants include plastics, untreated wastewater, nutrient runoff, and chemicals. Among the 350,000 chemicals registered for production and use, approximately 1,000 are classified as Contaminants of Emerging Concern (CECs). The vast majority of chemicals are untested and their risks are not well understood. Co-occurring global stressors such as ocean acidification and ocean warming can increase toxicity and bioaccumulation of pollutants, especially at higher trophic levels.
- **Socio-economic:** Pollution, intensified by global stressors, negatively impacts the functioning of marine ecosystems, hence reducing ecosystem services. This compromises the blue economy, and increases costs for restoration and pollution control efforts (e.g., Inaction on ocean pollution could cost the U.S. $838m annually in fisheries revenue, while proactive measures could boost revenue by $117m, according to *The Invisible Wave* report by The Economist Impact).
- **Health:** Direct impacts of pollution include exposure to contaminated seafood, leading to food safety and security issues; this disproportionately affects communities with limited resources. The accumulation of toxins in seafood can be exacerbated by global stressors (e.g., ocean warming increase methylmercury concentration in tuna). Additionally, the release of antibiotics from agriculture, healthcare, and industry operations to the marine environment promotes the development of antibiotic-resistant bacteria (ARB).

II. Solutions and Policy Recommendations

- **Mitigation and adaptation efforts:** Reduce pollution by developing affordable treatment technologies (e.g., septic tanks to curb nutrient runoff), promoting green chemistry, enhancing waste management and raising pollution awareness, especially in areas with poor sanitation. Encourage local actions aimed at increasing biodiversity and ecosystem resilience to co-occuring global stressors such as ocean acidification (e.g., coral reef restoration; restoration of seagrass meadows and saltmarshes, which also play a vital role in filtering water pollution).
- **Governance:** Enforce global pollution monitoring, implement stronger regulations to reduce CO_2 emissions and curb environmental pollutants (e.g., sewage, fertilizer runoff, and plastics), as this is critical for fostering SDG 13 on Climate Action. Enforce the 'polluter pays' principle and involve communities in designing metrics for sustainable practices. Align local regulations with international legal instruments to mitigate these overlapping challenges.
- **Economic:** Eliminate subsidies for polluting industries (e.g., fossil fuels, transport, agricultural fertilizers, manufacturing & construction), and reallocate funds to support sustainable industries. This shift can help reduce pollution, ocean acidification and warming. Use tools such as green bonds, emissions trading, and contingent valuation, to inform policymakers and track environmental metrics.
- **Research:** Focus on combined effects of threats, including chemical mixtures, global stressors, and emerging contaminants, and prioritize actionable Research and Development. Identify cases where knowledge is already sufficient to address single-stressor impacts. Design research on multiple stressors with a clear goal of identifying solutions rather than resolving the combined effects of thousands of pressures in unique combinations.

III. Case Study: Hong Kong's Harbor Area Treatment Scheme (HATS) improved water quality

Water quality in Victoria Harbor, Hong Kong, was greatly improved by the installation of sewage tunnels that prevent the continuous discharge of 1,000 tons of sewage sludge daily. This has reduced levels of fecal bacteria (i.e., *E. coli*) by over 90%, reduced levels of ammonia and nitrogen by 50%, and increased oxygen concentration in the water by 12%. As a result, mussels are now safe for consumption and 35 coral species have returned to the area. The restoration of benthic biodiversity has also revitalized fisheries and benefited local fishermen's revenues.

NIS UNDER GLOBAL CHANGES

I. Summary of Impacts

- **Environmental:** A subset of non-indigenous species (NIS) become invasive, known as aquatic invasive species (AIS) in the marine environment. AIS cause biodiversity loss and disrupt habitats, a phenomenon known as biopollution. Ocean warming, ocean acidification, and expanded commercial shipping routes accelerate the spread of adaptable NIS (e.g., blue swimming crabs in the Mediterranean). Ocean acidification may benefit fleshy seaweeds, harmful phytoplankton, and organisms without calcareous skeletons, such as jellyfish. Ocean warming enables some species to migrate and establish themselves in new areas, disrupting local ecosystems. These global stressors also alter species interactions by giving invaders a competitive advantage over native species, which may be more sensitive to changes in temperature or pH. AIS do especially well in disturbed or man-made environments, such as harbors and other artificial structures.
- **Socio-economic:** AIS outcompete native species, which can affect tourism (e.g., invasion of jellyfish in swimming areas) and impact communities dependent on fisheries. AIS impose substantial economic burdens (e.g., aquatic invasions have cost the global economy US$345 billion), straining public budgets due to costs for eradication efforts, monitoring, ecosystem restoration, and maintenance of water treatment facilities.
- **Health:** Non-indigenous pathogens (e.g. *Vibrio cholerae*; algal blooms) directly impact food security, and biopollution from AIS indirectly compromises water quality.

II. Solutions and Policy Recommendations

- **Mitigation and adaptation efforts:** Develop NIS tracking, monitoring and early detection systems especially for high-risk areas, and implement biopollution assessment procedures. Restore habitats by reintroducing native species to foster SDG 14 on Life Below Water; integrate NIS control into Marine Protected Area (MPA) policies. Implement ecosystem-based management strategies that incorporate both climate change and invasive species management to create synergies.
- **Governance:** Include AIS in regional cooperation agendas and advocate for strict aquaculture regulations. Enforce robust biosecurity measures to manage key transmission pathways (e.g., canals and ballast water). Strenghten legal frameworks to facilitate the removal of AIS and establish thresholds for assessing the effectiveness of management strategies.
- **Economic:** Develop a supply chain that integrates AIS into business strategies to offer alternative products, to foster public engagement and support local economies. Employ methodologies (e.g., cost-benefit analysis) to quantify the economic benefits provided by intact ecosystems vs. the costs of NIS management.
- **Research:** Foster international partnerships to share data and strategies for managing NIS, conduct localized studies on regional impacts, and monitor harmful algal blooms and pathogens to mitigate health risk. Allocate funding for research on complex interactions between NIS and global stressors, an underexplored area crucial for developing effective management strategies, and on restoration techniques for affected ecosystems.

III. Case Study : The invasive lionfish in the warming Mediterranean

Recent regional ocean warming has facilitated the rapid spread of tropical lionfish in the Mediterranean from the Red Sea. As a strategy to control this invasive species, Cypriot restaurants have created lionfish dishes and boosted customer demand through tastings. This effective approach supports both ecological balance and local economies. Cyprus also successfully implemented control measures for lionfish (e.g., regulated spearfishing, removal action teams, and community competitions) within Marine Protected Areas.

PLASTIC UNDER GLOBAL CHANGES

I. Summary of Impacts

- **Environmental:** Plastics contribute to climate change as greenhouse gases are emitted during production, transport, and energy intensive recycling. Additionally, plastics have direct negative impacts on the marine environment. Over 1,500 marine species have been documented ingesting plastics, resulting in physical harm and contamination of the food chain. Impacts of plastics vary with their size and include trapping, strangulation, the accumulation of garbage patches, and the disruption of photosynthesis on coral reefs obscured by macroplastics. The most harmful impact of plastics on coral reefs is smothering, which reduces water flow and leads to anoxia. Plastic debris can also serve as a raft for bacteria, facilitating biofilm formation and the growth of harmful pathogens, while ocean acidification further alters microbial interactions with plastics. Moreover, microplastics particles can attach themselves to marine snow, thus slowing the displacement of carbon from the surface to the depths. Finally, plastic can take up to 1000 years to decompose : this long-term contamination in snow and ice can decrease the albedo, which accelerates melting of polar and mountain ice.
- **Socio-economic:** The economic burden of plastic pollution include cleanup expenses, public health costs, and negative impacts on coastal tourism. There is disproportionate impact on developing countries and Small Island Developing States (SIDS), despite their relatively low contribution to plastic production. Projections indicate that the costs of plastic pollution will range between $13.7 trillion to $281.8 trillion by 2040 if no action is taken.
- **Health:** harmful plastics additives (e.g., bisphenol A) and plastic microparticles directly impact human reproductive, cardiovascular, immune and developmental health, particularly in children. Other vulnerable populations, including fenceline communities near landfills, workers in the fossil fuel and plastics industries, and waste pickers, are disproportionately exposed to severe health risks. Indirect impacts include the combined effects of plastic pollution, climate change, and ocean acidification (e.g., high CO_2 conditions alters plastisphere communities living on plastic waste, increasing pathogen abundance). Ocean warming accelerate the breakdown of plastics, leading to an increase in microplastics that provide more surfaces for bacteria to attach to, thereby enhancing bacterial virulence, raising infection risks, and contributing to antimicrobial resistance (AMR).

II. Solutions and Policy Recommendations

- **Mitigation efforts:** Enforce producer responsibility, reduce plastic production and implement taxes to discourage its use as a cheap manufacturing option, ban harmful chemicals, improve waste management, prohibit single-use plastics.
- **Governance:** Recycling plastic waste in developing countries can generate income, but international cooperation is needed to avoid shifting waste burdens. Prioritize 'no-regret' actions with co-benefits when developing policies.
- **Economic:** Create incentives to make recycled plastic more financially competitive than using virgin materials and limit fossil fuel subsidies. Develop a circular economy (Reuse, Repair, Refill) by creating markets for recycled plastics, setting content targets, and investing in advanced recycling technologies to foster SDG 12 on Responsible Consumption and Production.
- **Research:** Address urgent need for standardized methods and harmonized protocols to analyze microplastics. Assess the impact of alternative materials and the effectiveness of current recycling approaches. Investigate the synergistic effects of plastic pollution, climate change, and ocean acidification, as their interconnected impacts are not yet fully understood.

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III. Case Study: Zero Single-Use Plastic Waste Policy in Monaco (2016)

The initiative, supported by strong community engagement, exemplifies cooperation in the progressive ban of single-use plastics, including tableware, polystyrene containers, plastic tea bags, fruit packaging, salad boxes, and straws. Businesses were supported with guides and reusable alternatives to ensure a smooth transition.

EUTROPHICATION UNDER GLOBAL CHANGES

I. Summary of Impacts

- **Environmental:** Eutrophication is the excess growth of aquatic biomass driven by high nutrient concentrations (i.e., surplus nitrogen and phosphorous), often originating from agricultural fertilizers and untreated municipal and industrial wastewater. Nutrients may enter the marine environment through point sources (e.g., rivers, creeks) or indirectly through groundwater and atmospheric depositions. Eutrophication can decrease water oxygen levels through increased oxygen demand during the decomposition of the surplus biomass, resulting in 'dead zones' that devastate marine biodiversity and disrupt food webs. During hypoxic or anoxic conditions, potent greenhouse gases (e.g., N_2O; CH_4) are released from the seafloor, intensifying climate change. Eutrophication and ocean warming can increase the intensity of harmful algal blooms, which may release biotoxins and can be detrimental to marine organisms. Eutrophication exacerbates ocean acidification as CO_2 is released during decomposition of the surplus biomass. Marine coastal ecosystems may be less resilient to multiple stressors; the combination of eutrophication with ocean warming or ocean acidification results in species being more vulnerable to pollution or invasive species, potentially leading to ecosystem change.
- **Socio-economic:** Eutrophication can incur significant costs by damaging fisheries, shellfish farming and aquaculture; it can also affect tourism due to compromised seafood safety and beach quality (e.g., estimated annual losses of up to 4.4 billion euros across all sectors in the Baltic Sea). Biodiversity loss and reduced fish stocks create economic risks for dependent coastal populations, hindering SDG 1 on No Poverty, SDG 2 on No Hunger, SDG 3 on Good Health and Well-Being, and SDG 6 on Clean Water and Sanitation.
- **Health:** Harmful algal blooms (HABs) may affect water quality and increase the risk of seafood poisoning (e.g., amnesic, paralytic, diarrheic). This poses a risk to both coastal populations and also the broader population reliant on the global seafood market, threatening food safety and security. Toxic blooms drive up healthcare costs and strain local communities dependent on fisheries.

II. Solutions and Policy Recommendations

- **Mitigation and adaptation efforts:** Improve wastewater treatment and agricultural practices (slow-release fertilizers; reduced application; advanced technologies). Implement Nature-based Solutions (NbS) such as constructed wetlands and protect/restore coastal vegetated ecosystems to filter nutrients . These ecosystems harbor multiple benefits (support biodiversity; provide a vital breedings ground for marine life; increase carbon sequestration; combat OA ; protect coastlines).
- **Governance:** Reduce nutrient pollution and involve stakeholders in local nutrient management plans to minimize impacts on vulnerable communities. Strengthen policy enforcement (e.g., EC Common Agricultural Policy; Common Fisheries Policy).
- **Economic:** Eliminate harmful subsidies for agriculture and fisheries, and create adequate pricing systems for both sectors to support environmental policies. Reallocate funds to invest in wastewater treatment and provide technical assistance for sustainable practices. Foster a circular economy and nutrient recycling from waste, to reduce reliance on synthetic fertilizers, and generate economic benefits.
- **Research:** Study how fertilizer use and prices are impacted by geopolitical factors. Research how eutrophication interacts with other environmental stressors to develop comprehensive risk assessments.

III. Case Study: Seaweed Mariculture in Xiangshan Bay (East China Sea)

Kelp mariculture mitigates eutrophication by absorbing excess nutrients, reducing nitrogen, alleviating acidification, and enhancing phytoplankton diversity. This shows how macroalgal aquaculture can be a viable Nature Based Solution for water quality improvement.

TAKE AWAY MESSAGE

The combined effects of ocean acidification and ocean warming weaken the resilience of marine ecosystems to a variety of local stressors, such as eutrophication, mixed pollutants, and invasive species, compromising the ecosystem services they provide to humanity. The cumulative impacts of these environmental stressors can amplify economic disparities, particularly in low- and middle-income countries where there may not be sufficient technology to remove toxic substances. Moreover, political and economic barriers, including reluctance from agricultural lobbies in the case of eutrophication, hinder the implementation of sustainable solutions such as reduced fertilizer use and eco-friendly farming practices. To address this, coordinated funding, transdisciplinary research on potential solutions, and science-based knowledge transfer for informed policy-making are required. Recommendations can support locally co-designed mitigation and adaptation strategies, based on empirical indicators that consider biodiversity, rather than solely relying on GDP.

In conclusion, the combination of global ocean warming and acidification with pollution, plastics, eutrophication, and non-indigenous species places significant strain on marine environments and the blue economy. These pressures threaten food security, challenge industries reliant on marine resources, and disproportionately affect vulnerable populations. These factors also create additional costs for management and restoration efforts, undermining multiple Sustainable Development Goals and causing habitat destruction, biodiversity loss, and water contamination. Given their interconnected nature, these stressors require continuous monitoring and a cross-sectoral systems thinking approach that links chemical control, waste management, nutrient reduction strategies, and invasive species management. Thus, coordinated governance, international cooperation, innovative research, and the implementation of Nature-based Solutions will be critical to safeguarding ocean health and protecting coastal economies.

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