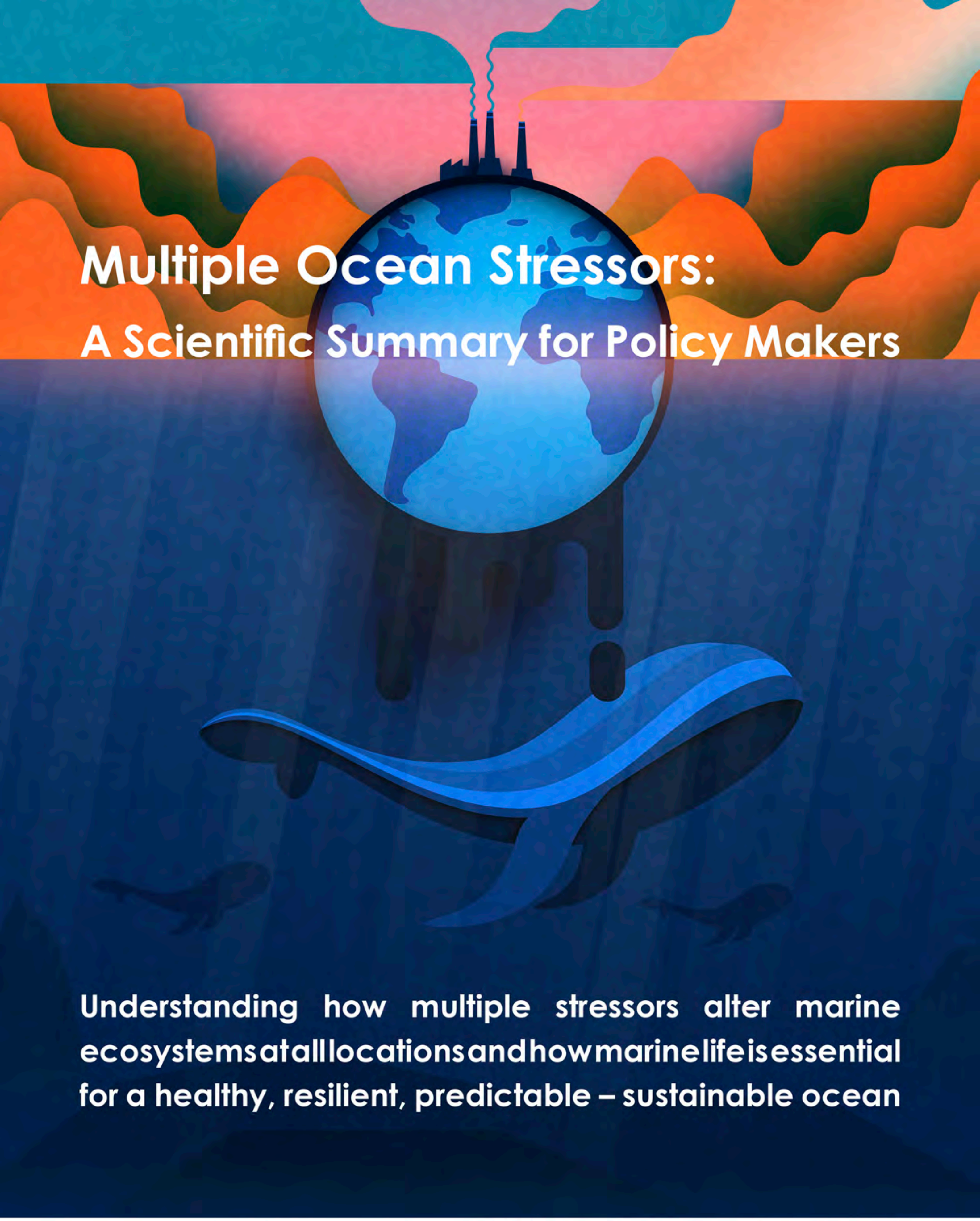

# Multiple Ocean Stressors:

## A Scientific Summary for Policy Makers

**Understanding how multiple stressors alter marine ecosystems at all locations and how marine life is essential for a healthy, resilient, predictable – sustainable ocean**

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

unesco
Intergovernmental Oceanographic Commission

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# Multiple Ocean Stressors: A Scientific Summary for Policy Makers

Understanding how multiple stressors alter marine ecosystems at all locations and how marine life is essential for a healthy, resilient, predictable – sustainable ocean

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2021 2030 United Nations Decade of Ocean Science for Sustainable Development

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# Preface

## Multiple ocean stressors research and Ecosystem-Based Management in support of the UN Decade of Ocean Science for Sustainable Development

This Scientific Summary on Multiple Ocean Stressors for Policy Makers offers a reference for all concerned stakeholders to understand and discuss all types of ocean stressors. This document will help coordinate action to better understand how multiple stressors interact and how the cumulative pressures they cause can be tackled and managed. It is a first step towards increased socio-ecological resilience to multiple ocean stressors (Figure 1).

Ecosystem-Based Management (EBM)[1] recognizes the complex and interconnected nature of ecosystems, and the integral role of humans in these ecosystems. EBM integrates ecological, social and governmental principles. It considers the tradeoffs and interactions between ocean stakeholders (e.g. fishing, shipping, energy extraction) and their goals, while addressing the reduction of conflicts and the negative cumulative impacts of human activities on ecosystem resilience and sustainability. Thus, EBM is an ideal science-based approach for managing the impacts of cumulative stressors on marine ecosystems.

The United Nations Decade of Ocean Science for Sustainable Development (2021–2030; Ocean Decade), which is based on a multi-stakeholder consultative process, identified 10 Ocean Decade Challenges. Challenge 2: *Understand the effects of multiple stressors on ocean ecosystems, and develop solutions to monitor, protect, manage and restore ecosystems and their biodiversity under changing environmental, social and climate conditions* addresses the overall outcomes of the Decade. In particular, outcomes aimed at a clean, healthy and resilient, safe and predicted, sustainably harvested and productive, and accessible ocean, with open and equitable access to data, information and technology and innovation by 2030.

**This Scientific Summary for Policy Makers is also a call to action underlining the urgency to understand, model and manage multiple ocean stressors now. We cannot manage what we do not understand, and we cannot be efficient without prioritization of ocean actions appropriate to the place and time.**

1. The comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity (Altvater and Passarello, 2018).

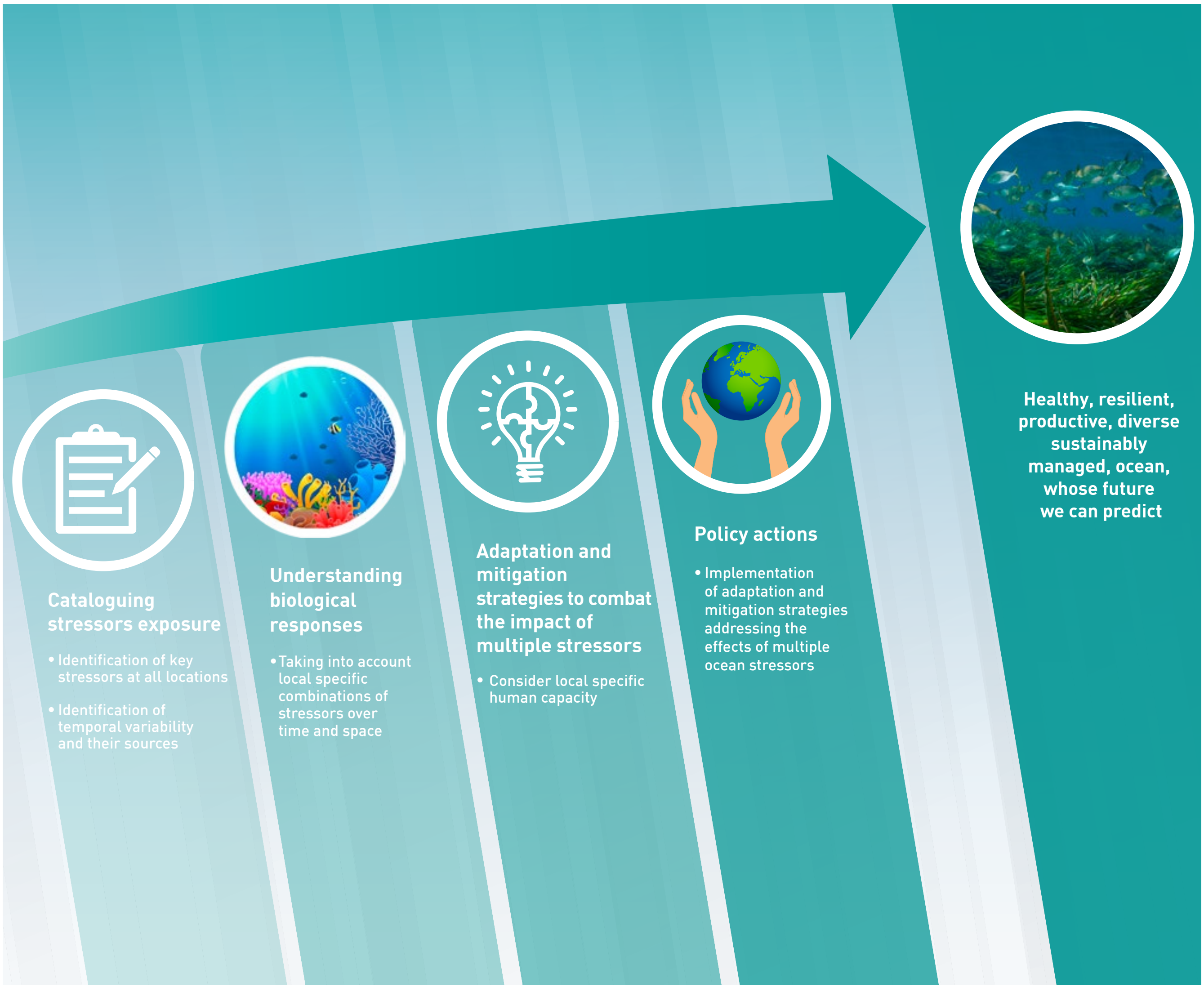


**Figure 1.** Value chain that emerges from addressing questions, helping to structure the development of science into multiple ocean stressors, resulting in increased understanding to inform management strategies and policy action needed to achieve a healthy, sustainable, resilient ocean.

# Setting the scene

Human health and well-being are closely linked to the ocean and the many goods and services it provides. However, the ocean is under cumulative stress from a range of pressures at various scales – local, regional and global (Figure 2). The impact of multiple ocean stressors together and their interplay on marine life and ecosystem function is not well understood, yet it is central to meeting Challenge 2 of the Ocean Decade (UNESCO-IOC, 2021). Improved understanding of how multiple stressors impact the ocean will help society to achieve several expected outcomes of the Ocean Decade, in particular:

- **A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed**. The cumulative threat from multiple ocean stressors is detrimental to the resilience of marine life and reduces ocean health.
- **A productive ocean supporting sustainable food supply and a sustainable ocean economy**. Environmental ocean stressors affect the food supply provided by ocean resources; in parallel fishing and aquaculture can be ocean stressors if not managed sustainably.
- **A predicted ocean where society understands and can respond to changing ocean conditions**. Multiple stressors interact and the underlying mechanisms are complex; ignorance of which hinders prediction of the risks they pose and development of counteractive measures needed to ensure a sustainable ocean.

To ensure a sustainable future for all, it is critical to understand multiple stressors, comprising such as stressors driven by climate change, inefficient use of fertilizers, or over-exploitation of ocean resources, and target efforts at minimizing their impacts to lessen the cumulative pressure on the resilience and health of marine life associated with human activities.

Identifying multiple ocean stressors and understanding the underlying processes causing adverse changes to the open and coastal ocean is complicated and research addressing multiple ocean stressors and associated processes is at an early stage of development. To date, studies often focus on single species or groups of organisms and the influence of a single stressor. This means that information about ecosystem responses to multiple stressors is limited. Innovative science is needed to resolve the complexity (i.e. additive or multiplying effects, amplification or lessening of the effect) of the interplay of stressors and the resulting impacts.

This publication attempts to provide a conceptual overview of multiple ocean stressors, their controls, and potential effects, in each case supported by illustrative examples. The objective is to advance science to enable the transition from passive observation of the problem – impacts of multiple ocean stressors on marine life – to proactive engagement in finding solutions.

Interdisciplinary science addressing multiple ocean stressors is required to mitigate the negative effects they cause and/or to support adaptation strategies that might counteract stressors. A better understanding of the impacts of multiple stressors on marine ecosystems will lead to informed actions. Ultimately, transformative science striving to develop solutions will help to achieve

## Box 1. Definitions to remember

**Drivers:** Environmental properties (e.g. temp-erature) and ecological processes (e.g. grazing pressure) that influence marine life and its productivity and diversity. Drivers can be natural or anthropogenic forces that cause beneficial or detrimental effects. For example, temperature determines growth rates but excessive temp-erature causes stress and eventually mortality.

**Healthy ocean:** The ocean is healthy if and only if it is resilient, productive, and diverse.

**Stressors:** Environmental properties or ecological processes, which at a certain threshold (e.g. excess nutrient supply or over-harvesting) results in detrimental effects to marine life. Stressors, individually or collectively, are directly responsible for a range of significant harmful changes to the biological components, patterns, and relationships in natural systems.

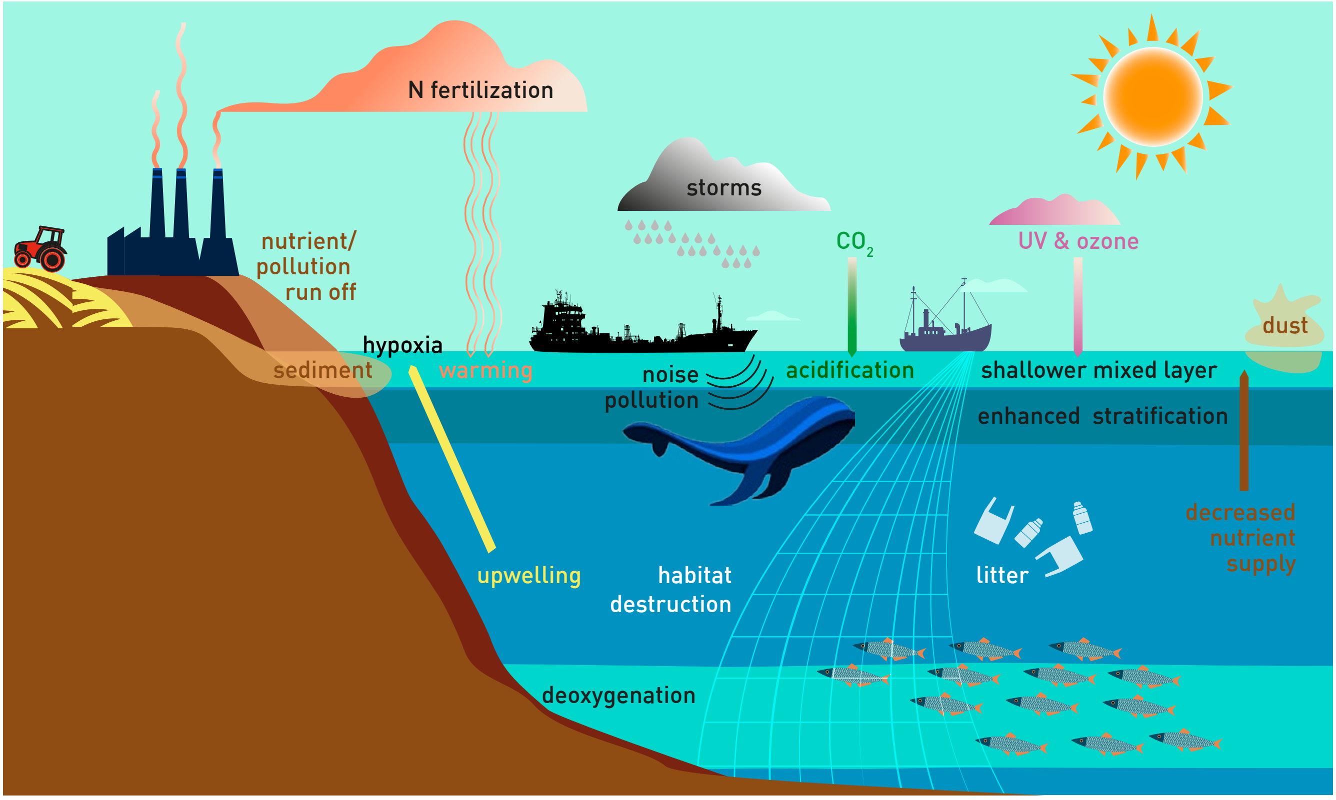


**Figure 2.** Illustrative examples of global (warming, acidification), regional (ozone, litter, atmospheric pollutants) and local (sedimentation, pollution and nutrient runoff) stressors that can affect marine life (adapted from Boyd et al., 2018). Illustrative examples are used here since insertion of icons for all stressors would cover the ocean in this figure. Marine life at each location, from coastal areas to offshore waters, will encounter a unique combination of stressors, and ecosystems may be exposed to concurrent changes to multiple stressors simultaneously.

a healthy, resilient, productive, diverse, sustainably managed ocean, whose future can be predicted.

Key challenges remain to ensure that future generations will be able to rely on the ocean for their health and wellbeing. **Therefore, science priorities for generating the knowledge needed to inform policy and ocean stewardship for the upcoming years are:**

- **Priority 1**: Identification of the most influential, major stressors within each marine ecosystem, their temporal variability, and their controls/source(s).
- **Priority 2**: Improved understanding of the biological impacts resulting from the unique combination of stressors at all locations, along with the degree of exposure to these stressors.
- **Priority 3**: Development and implementation of innovative actions to mitigate the drivers and impacts of multiple ocean stressors at appropriate scales, based on available technological capabilities, human resources, and the degree of threat imposed by multiple stressors on marine ecosystems.

Four groups of guiding questions can be used to structure the development of multiple ocean stressors' science and how application of the findings can help decrease ocean stress.

**1. Better understanding of multiple ocean stressors**

- What are the dominant stressors at each location?
- What are the spatial and temporal scales, as well as timing of these stressors?
- What are the mechanisms by which multiple ocean stressors influence marine life?

**2. Strategies to combat the impact of multiple ocean stressors**

- What is the appropriate scale local, regional or global of strategies? Which combination will work best?

**3. Communication**

- How to ensure the most effective and widespread use of scientific data and information for multi-stakeholder use and application?

**4. Policy actions**

- How best to implement and coordinate strategies to address the effects of multiple stressors?

# Ocean under stress

Intensified human activities on land and in the ocean are increasing, placing stress on the health of marine ecosystems. These activities include excessive harvesting of marine life to feed the Earth's growing population, disposal of a wide range of materials such as pollutants, plastics and excess nutrients, and changes to oceanic conditions due to rising anthropogenic emissions of greenhouse gases (Figure 2). Such alteration of the ocean exposes marine life to conditions that they have not encountered (e.g. new pollutants) or to deviations from the norm (e.g. warming, ocean acidification, deoxygenation, eutrophication, and extreme events such as marine heat waves) resulting in a suite of changes, termed here as multiple stressors (Box 2).

Stressors such as pollution or over-fishing have negative impacts on marine life, while other biologically influential effects – linked to ocean global change – such as increasing temperature and/or altered nutrient supply can, depending on their environmental context, be beneficial, neutral or detrimental. These biologically influential effects can stress marine life and ecosystems directly, through increased food supply resulting in growth (beneficial), or indirectly, through increased temperature leading to low oxygen contents hampering respiration (detrimental), and can be caused by human activities or naturally. Human-driven and natural stressors can also be cumulative.

## Box 2. Stress is relative

Marine organisms are exposed to a wide range of naturally fluctuating environmental conditions such as temperature, salinity, dissolved oxygen and pH conditions that constitute their ecological niche. Because of evolution, an organism is often adapted to its environment and the concept of stress is then relative and dependent on the type of stressor. For example, exposure to a new pollutant can be expected to drive stress following Paracelsus' principle 'the dose makes the poison'. Another source of stress can originate from changes in environmental conditions (e.g. temperature, pH) that are naturally encountered by marine life, and which influence biological processes. In addition to environmental stressors, biological stressors such as invasive species and overfishing contribute to the cumulative pressure on organisms through changes in the abundances or performance of other organisms. These biological stressors result in changes in predator-prey dynamics, inter- and intra-species competition.

Such environmental and/or biological stressors will impact organisms to different degrees. For example, fish species in polar regions are adapted to temperatures that are lethal for tropical species, and vice versa. Stress can then be defined as a *condition evoked in an organism by one or more environmental and biological factors that bring the organism near or over the limits of its ecological niche* (after Van Straalen, 2003; Figure 3). The consequence of a particular stress will depend on its intensity (how much it deviates from normal conditions) and duration (how long it persists for). A robust understanding of environmental and biological conditions encountered by an organism is then necessary to define its niche and establish whether an environmental change is a true stress.

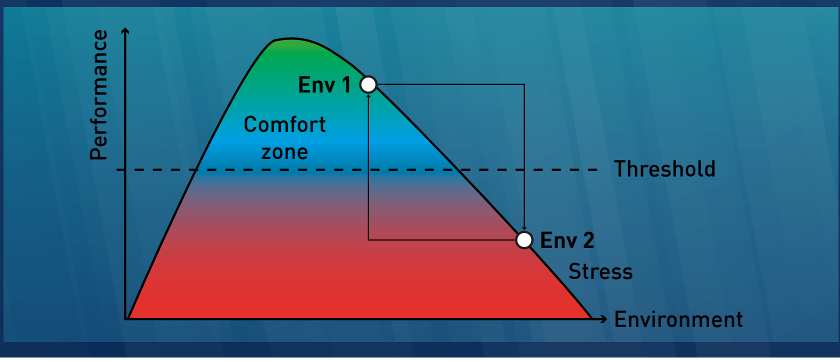


**Figure 3.** Ilustration of how the degree of stress alters with change in environmental conditions leading to a deviation from an optimal (Env1) to an increasingly stressful environment (Env2). The "Comfort Zone" refers to the region of optimal performance by the organism.

## There is an urgent need to determine how multiple ocean stressors combine, and jointly affect ocean health – their cumulative pressure is more complex and often more detrimental than a single stressor.

It is necessary to monitor, understand and quantify the cumulative effects of multiple stressors on marine ecosystems so that research and observation priorities at appropriate time scales can be identified while evaluating tradeoffs and informing management action. Ultimately, this will lead to the development of ecosystem-based management strategies which underpin policy decisions on reducing the sources of stressors in the ocean and its combined effects. Future assessments will need to address the different controls of change to oceanic conditions. Some are local and transient in scale (e.g. episodic nutrient runoff, upwelling events reducing oxygen and pH, accumulation of toxins from harmful algal blooms), while others are global, persistent or even permanent (e.g. ocean warming and acidification; Figure 2) causing ecosystems to be exposed to conditions outside their normal envelope of natural variability and exacerbating the impacts of episodic events. Identifying the timing, duration, extent, and degree of stressors will allow the adaptation of available solutions, and the development of new deployment strategies.

## Identify and implement the best strategies to minimize the impact of multiple stressors and meet local challenges, opportunities and needs.

There is an emerging need to better understand which environmental changes are putting marine life under stress; how organisms respond to this stress; which individual, or combination of stressors are dominant; and how responses to multiple stressors vary among organisms and/or across communities, as well as ecosystems. Only an integrated body of research and observations can provide the knowledge needed to understand how whole ecosystems will respond to long-term changes in the ocean and enable the development of solutions, which ensure a sustainably-managed ocean (Box 3).

### Box 3. Local impacts urge for solutions at local, regional and global scales

At each location, major ocean stressors can be identified by using the interactions between exposure (list of environmental conditions, their variability, intensity, timing and duration) and effects (sensitivity of key species and ecosystems to these conditions, alone and when combined). Depending on the type of stressor, addressing multiple stressors will require a combination of solutions at local, regional and global scales (Figure 4). For example, addressing local effects of ocean acidification requires global (mitigation of $CO_2$ emissions) and local/regional adaptation solutions (e.g. increased ecosystem resilience through regulation of other stressors and/or development of Marine Protected Areas (MPA) or refugia).


Figure 4. Framework for identifying major stressors and research needs to successfully implement solutions to address and minimize the impacts of multiple stressors.

# Cataloguing stressors & their characteristics at the local level

The ocean is changing from the coastal zones to the deep sea (Figure 2). Because of the various influences of local, regional and global anthropogenic stressors, marine life may encounter very different combinations of stressors from location to location.

**The effect of any stressor will be highly dependent on its intensity and duration, the so-called exposure. In order to understand the effects of multiple stressors together, governments supported by scientists should first catalogue each stressor, its intensity and duration, whether it interacts with other stressors (e.g. warming increases the risk that water will contain less oxygen) and, critically, what causes and controls that particular stressor.**

Resident biota, along with their ecological role, should be considered while cataloguing stressors and their exposure, as this will determine where and when observations should be made (Box 4). Understanding the source, timing, spatial extent, intensity, interactions, and likely impacts of driver(s) of each stressor is critical for informing how policies and stewardship can be used to reduce the threat of multiple stressors to marine ecosystems.

## Box 4. Monitoring environmental conditions at the right place(s) and time(s)

Environmental conditions in the ocean vary over space and time. It is therefore critical to gather data at each relevant location. When monitoring, it is therefore of the utmost importance to select sampling sites based on the biology of the resident organism or ecosystem of interest. Some organisms depend on different habitats throughout their life cycle, and their sensitivity to specific stressors may change (Figure 5). Thus, understanding the ecological niche of ecologically and economically important marine species and the environmental conditions that may affect populations of that species requires monitoring in different locations at different times. Marine conditions also differ over time because of variations in season, ocean currents, biology and human activities. To be able to understand the response of marine life to these changes, it is critical to capture natural variability (daily, seasonal) and particularly the environmental extremes.

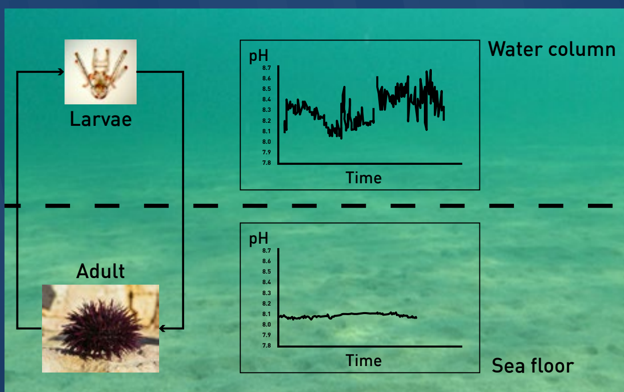


Figure 5. Many marine invertebrates spend their juvenile and adult life cycle on the sea floor while early stages are spent suspended in the water column. This exposes them to different environmental conditions depending on their life cycle stage. For example, sea urchins reproduce by releasing gametes into the overlying water column where larvae develop for several weeks before settling as juveniles on the seafloor. As illustrated above, juveniles and adults on the seafloor are exposed to relatively stable pH conditions while larvae swimming in the water column are exposed to high pH variability. Therefore, fully understanding sea urchin response to ocean acidification requires a pH monitoring in both the water column and sea floor.

At global levels, increasing atmospheric $CO_2$ caused by human activities leads to both atmospheric and ocean warming, and to the occurrence of ocean acidification. In turn, ocean warming increases ocean density stratification where exchange between surface and deeper waters is reduced, thereby decreasing upward nutrient supply and the downward supply of oxygen to deeper layers. The coastal ocean is also subject to confounding effects of many locally-driven stressors (Figure 2) including runoffs linked to excessive fertilizers and biocide loading; inadequate sewage/wastewater treatment (leading to eutrophication); offshore drainage of chemicals from industries; pollution; coastal destruction leading to increased sedimentation and modification in terrestrial runoffs' patterns, and habitat loss; overfishing and temporary; underwater noise (e.g. shipping, surveying/resource exploration, construction of offshore windfarms); shoreline and offshore sand mining and sand extraction.

**Biological responses to multiple stressors are a result of exposure and sensitivity.**

## Box 5. Examples of multi-stressors' cumulative pressures on marine ecosystems

### 1. Gulf of Saint Lawrence, Canada

Over recent decades, episodes of low oxygen concentrations (hypoxia) leading to stress on marine life have been observed more frequently in the Gulf of Saint Lawrence. This is happening in areas with low vertical mixing, where oxygen-rich upper ocean layers are not mixing with deeper oxygen poor layers. At lower layers, available oxygen is consumed by the respiration of marine biota, especially via microbial decomposition of sinking particulate organic matter (Bernier et al., 2018). In parallel, global climate change and the regional input of organic matter from algal blooms – stimulated by high levels of anthropogenically-produced nutrients – contributes to the worsening of hypoxia in the region.

### 2. Jakarta Bay, Indonesia

Marine life in reef systems of Jakarta Bay, Indonesia, is influenced by both global (ocean warming and acidification) and local stressors (eutrophication, pollution, sedimentation, fishing pressure and blast fishing). The stressors are a mix of environmental changes such as acidification and direct human interventions such as blast fishing (Kunzmann et al., 2018). Consequently, reef degradation may increase in the near future as these stressors increase in severity.

'Indonesia's continuing growth in population, especially along the coast, poses severe problems for ecosystems such as coral reefs. Reef degradation due to global and local stressors will eventually cause a loss of ecosystem services that sustain millions of people.' (Kunzmann et al., 2018)

The limited understanding of the joint impact of these combined stressors on local ecosystems in Indonesia hinders the ability to develop strategies for the sustainable management of ocean resources and to make informed policy actions. Scientists in the region advocate for both the study of multiple stressors and their effects on marine life – from species to ecosystems. Researchers also emphasize the need to devise management strategies for developing ways to decrease these anthropogenic pressures via, for example:

i. mitigating greenhouse gas emissions,
ii. increasing efficiency of fertilizers' use globally,
iii. regulating wild and aquaculture fishing practices at the regional level and
iv. implementing local adaptation measures such as establishing MPAs to provide shelter areas for recruitment of marine species.

'Any relief from stressors would help coral reefs and give them the chance to recover thereby securing livelihoods for future generations. However, ocean management can no longer ignore and focus on individual stressors but must incorporate combined stressor effects.' (Kunzmann et al., 2018)

# Effects – biological responses to multiple stressors

**Identifying the main stressors for a selected ecosystem requires knowledge (field observations combined with experimental work) of each stressor at a given location along with the biological response.**

Designing the most effective and tractable mitigation and/or adaptation strategies to combat the worst consequences of an ocean under stress requires knowledge of how sensitive each key marine organism (keystone species, ecological engineers, species that provide key ecosystem services such as for food security) and ecosystem is to the specific clusters of multiple stressors. These effects can be direct (e.g. temperature affecting the physiology of a fish) or indirect (e.g. the combination of stressors leading to the loss of key species, thereby negatively impacting other species that compete with them or rely upon them as a source of food).

Coping with each stressor comes at a cost for an organism and for entire ecosystems. The cost of dealing with each stressor will influence performance, as it may require the diversion of energy needed for other essential tasks to offset a particular stress. Sensitivity to stress is controlled by many factors – some physiological (e.g. the ability to buffer changes in chemistry), others are driven by life history (some life stages are more susceptible to stress), the ability to acclimate (over short timescales) or adapt (over longer timescales) to altered conditions, or by species ecology (organisms at different trophic levels may be more or less vulnerable to a stressor).

**1 + 1 ≠ 2. When two or more stressors act together, their combined effect is often not equal to the sum of the effect.**

One of the major knowledge gaps in the field of multiple ocean stressors limiting our ability to project future impacts and propose science-based solutions is understanding how stressors interact with each other. Biological responses to a single stressor can be manifold (Box 2) and stressors can interact with other environmental parameters, often in complex ways. For example, Figure 6 clearly illustrates that the response of sea urchins to decreased pH is modulated by temperature.

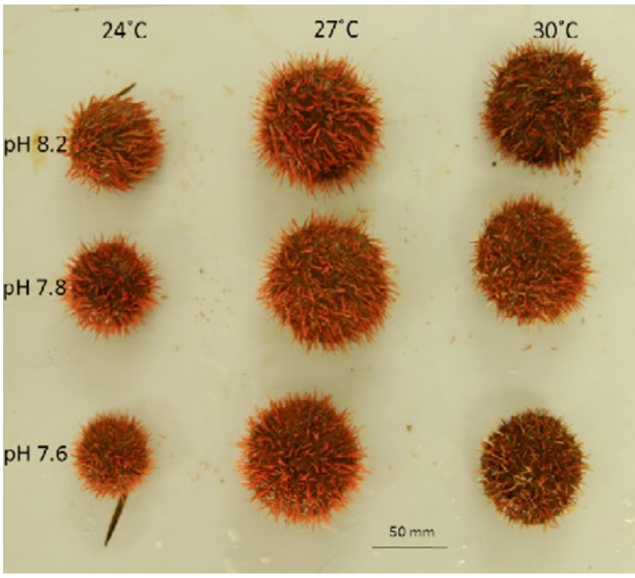


**Figure 6.** Joint influence of temperature and pH on sea urchin growth (adapted from Dworjanyn and Byrne, 2018). At high pH (8.2), urchin size increases with warming. A different trend is observed at lower pH (7.6) as the positive effect of warming on growth is less influential than that observed at the highest temperature. Hence, this is an example of the interplay of two stressors lessening the effect of an individual stressor. In many other cases, multiple stressors can amplify (i.e. a non-linear effect) the effect of individual stressors, such as warming and hypoxia, which further decreases seawater capacity to dissolve oxygen (Box 6).

When looking at natural marine environments, more than two stressors typically affect an ecosystem at the same time. As more stressors are combined, the complexity of tracing their effects and interactions increase (Box 6).

## Box 6. What is an interaction between stressors and why does this matter?

The effect of a combination of stressors on marine life remains an ongoing field of research. Terms such as additivity, synergism or antagonism are commonly used for explaining such interactions but are rarely or poorly defined. For example, in the context of multiple stressors, additivity (i.e. a cumulative effect) cannot be equated with the additivity of effects in the mathematical sense but rather how stressors combine to increase the level of stress (Figure 6 and 7). For example, as presented in Figure 7, the lack of additivity at the effect level (Effect A + Effect B ≠ Effect A+B) does not exclude the possibility of additivity at the stressor level as temperature and pH both have impacts on growth through changes in the allocation of energy.

Additivity of stressors is the simplest combination of stressors to resolve and model. Interactions occur when combined stressors fail the 'additivity expectation' and require collection of more data to model and project cumulative effects.

Resolving cumulative effects of ocean stressors is critical to project their impact and evaluate efficiency of strategies aiming at the mitigation of drivers and adaptation to impacts. It requires an understanding of the modulating mechanisms (mode of action) of an individual stressor and cannot be simply resolved by a single multiple stressor experiment. There are opportunities online to explore the interplay of multiple stressors (Multiple Environmental Driver Design Lab for Experiments – MEDDLE).[3]

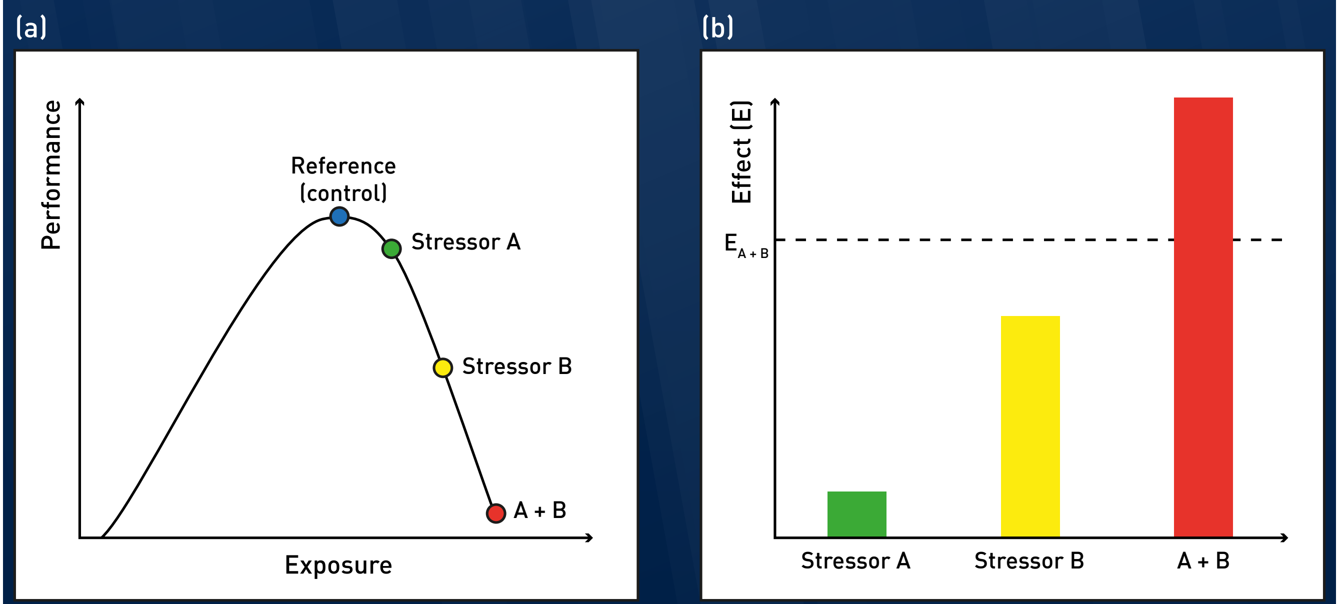


**Figure 7.** Example of additive effects of stressors (adapted from Gianguzza et al., 2014 for pH and temperature) using a performance[2] curve to link exposure to the performance[2] of a marine organism (a). Two different stressors (A & B) act additively (no interaction) on the level of exposure. Their combined effect can be projected as the effect of their combined exposure (addition of effects). However, as the performance curve is not linear, this does not necessarily translate into an addition of the individual effects (b), that is Effect A + Effect B ≠ Effect A+B.

2. Performance: In this instance, performance is a phenotype with a correlation to fitness.
3. Meddle http://www.meddle-scor149.org

# Time to act

**The next steps related to multiple ocean stressors must extend from the implementation of identified research priorities to applying the results in the development of Ecosystem-Based Management strategies and informing policy decisions.**

## Literacy/stewardship

New and innovative research is required to understand the impacts of multiple stressors arising from human activities on ocean health. Explaining the terminologies (e.g. stressor, driver, interactions) in simple terms will raise awareness of the scale and nature of this challenge to policymakers, the private sector, indigenous communities and the general public at large. It will be indispensable to continue identifying the mechanisms and processes behind the impacts of multiple ocean stressors, supported by newly established scientific capacity. Training courses, development of simple and clear best practices guides (e.g. Boyd et al., 2019); improvement of biological and biogeochemical ecosystem modelling, monitoring and mentorship schemes, in close cooperation with relevant existing programmes and networks will allow many to benefit from existing experiences to align observations and encourage the inclusion of multiple stressors in ongoing work. Recent examples to build upon include the Global Ocean Acidification Observing Network (GOA-ON) and the Global Ocean Oxygen Network ($GO_2NE$). The newly gained knowledge will be used to develop and implement strategies to minimize the drivers and impacts of multiple stressors on marine life and move towards sustainable use of ocean resources.

## Research strategy and priorities

- Identification and monitoring of stressors at key locations (e.g. sites of high ecological and economical value, sites with high vulnerability to ocean change, sites with different levels of anthropogenic impact) and temporal scales. A holistic approach of sustained ocean observation, based on best practices, experimentation and modelling should be pursued. Although these efforts often target a subset of stressors (e.g. nutrient inputs in coastal regions, or oxygen/pH changes in the ocean), approaches can build on existing international research communities already monitoring marine conditions (e.g. Global Ocean Observing System (GOOS), GOA-ON, $GO_2NE$, Global Harmful Algal Blooms science programme (GlobalHAB)).
- Development of human scientific capacity should go hand in hand with technological advances (e.g. sensor development).
- Understanding the sensitivity of marine species and ecosystems to stressors and their tolerance thresholds, across a wide range of environmental conditions covering present and future natural variability.
- Developing a mechanistic understanding of the nature of the biological response to each stressor (mode of action) and how stressors may interact to alter the mode of action. This knowledge is critically needed to improve understanding of how different stressors interact and how biological impacts can be projected.
- Research should also focus on identifying and developing solutions to counteract the effects of multiple stressors.

# Sharing data, knowledge and information

- Multiple ocean stressor observation data and research information should be shared with the global community.
- Scientific data and information that identifies multiple ocean stressor interactions and impacts should be managed, easy to locate, openly accessed and disseminated. Efforts should follow the principles of FAIR data: findability, accessibility, interoperability, and reusability. Auxiliary information, including relevant metadata and background information on the calculation of uncertainty, allow management decisions and trade-offs to be evaluated.
- Assessments, knowledge, and decision support tools on local and global stressors, based on the best scientific information available, will enable the development of mitigation and adaptation strategies for the future.

# Management implications/ applications

- The information provided by research on identifying and developing solutions should lead to their implementation at appropriate spatial (local, regional and/or global) and temporal scales.
- Depending on the significance of individual stressors and local capacity, mitigation action might focus on reducing one driver (such as $CO_2$ emissions or sewage treatment), or multi-stressor action (e.g. the establishment of MPAs and efficient food production on land and in the ocean).
- Adaptation action, reducing the stress at local and regional scales tailored to specific combinations of pressures, implemented by various stakeholders such as the industry sectors, governments and local, regional and global organizations should include MPAs, refugia, resistant aquaculture species, coastal protection and EBM.

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# Acronyms and definitions

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| **Adaptation** | In biology and ecology, adaptation refers to the process of adjusting in an organism behavior, physiology, or structure to become more suited to an environment. It may also be defined as the state reached by the biological population undergoing adjustments or changes. It may also pertain to the trait that made the species a better fit for the environment.<br><br>The UNFCCC defines adaptation as human-driven adjustments in ecological, social or economic systems or policy processes, in response to actual or expected climate stimuli and their effects or impacts. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation. |
| **Anthropogenic** | Caused by humans or their activities. |
| **Blast fishing** | Blast fishing, fish bombing, or dynamite fishing is a destructive fishing practice using explosives to stun or kill schools of fish for easy collection. This often illegal practice is extremely destructive to the surrounding ecosystem, as the explosion often destroys the underlying habitat that supports the fish. |
| **$CO_2$** | Carbon dioxide |
| **Drivers** | Environmental properties (e.g. temperature) and ecological processes (e.g. grazing pressure) that influence marine life and its productivity and diversity. Drivers can be natural or anthropogenic forces that cause beneficial or detrimental effects, for example temperature sets growth rates, but excess temperature causes stress and eventually mortality. |
| **EBM** | Ecosystem-Based Management |
| **Ecological niche** | An ecological niche refers to the interrelationship of a species with all the biotic and abiotic factors affecting it. |
| **Evolution** | Evolution is defined as the process leading to a change in the genetic composition of a population over successive generations. |
| **FAIR data** | FAIR data meet the principles of findability, accessibility, interoperability, and reusability. |
| **Fitness** | The extent to which an organism is able to produce offspring in a particular environment. |
| **GlobalHab** | Global Harmful Algal Blooms **http://www.globalhab.info** |

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|---|---|
| **$GO_2NE$** | Global Ocean Oxygen Network **https://en.unesco.org/go2ne** |
| **GOA-ON** | Global Ocean Acidification-Observing Network **http://goa-on.org** |
| **GOOS** | Global Ocean Observing System **https://www.goosocean.org** |
| **Healthy ocean** | The ocean is healthy if and only if it is resilient, productive, and diverse. |
| **Intraspecific competition** | Intraspecific competition occurs when members of the same species compete for limited resources. This leads to a reduction in fitness for both individuals, but the more fit wins the competition. |
| **MEDDLE** | Multiple Environmental Driver Design Lab for Experiments **http://www.meddle-scor149.org** |
| **MPA** | Marine Protected Area |
| **Ocean Decade** | UN Decade of Ocean Science for Sustainable Development |
| **Performance** | Performance is a phenotype with a correlate to fitness. |
| **Phenotype** | Phenotype refers to the observable characteristics of an organism. The organism phenotype includes its morphological, biochemical, physiological, and behavioral properties. The phenotype is the product of both the organism genetic traits as well as the influence of environmental factors and random variation. |
| **Predator-Prey relationship** | An interaction between two organisms of different species in which one of them acts as predator that captures and feeds on the other organism that serves as the prey. |
| **Recruitment** | Process by which new individuals are added to a population, whether by birth and maturation or by immigration. |
| **Stressors** | Environmental properties or ecological processes, which at a certain threshold (e.g. excess nutrient supply or over-harvesting) result in detrimental effects to marine life. Stressors, individually or collectively, are directly responsible for a range of significant harmful changes to the biological components, patterns and relationships in natural systems. |
| **UNFCCC** | United Nations Framework Convention for Climate Change **https://unfccc.int** |

# Multiple Ocean Stressors: A Scientific Summary for Policy Makers

**Understanding how multiple stressors alter marine ecosystems at all locations and how marine life is essential for a healthy, resilient, predictable – sustainable ocean**

***This Scientific Summary on Multiple Ocean Stressors for Policy Makers offers a framework for all concerned stakeholders to understand and discuss all types of ocean stressors. This document will help coordinate action to better understand how multiple stressors interact and how the cumulative pressures they cause can be tackled and managed. It is also a call to action underlining the urgency to understand, model and manage multiple ocean stressors now. We cannot manage what we do not understand, and we cannot be efficient without prioritization of ocean actions appropriate to place and time.***

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