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ECONOMICS OF OCEAN ACIDIFICATION

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OCEANOGRAPHIC MUSEUM, MONACO



Bridging the Gap
between Ocean
Acidification Impacts
and Economic Valuation



**CONCLUSIONS
AND RECOMMENDATIONS
FOR DECISION MAKERS**



OCEAN ACIDIFICATION, THE OTHER CO₂ PROBLEM

Several recent policy briefs and information documents have drawn attention to the effects of increased carbon dioxide (CO₂) on our oceans – a problem that is still generally unknown to policy-makers and the general public. Indeed, few people are aware of the potential consequences of the anthropogenic CO₂ currently entering the world's oceans at a rate of 25 million tons per day.

« The average acidity of the global ocean has increased by 30% »

The average acidity of the global ocean has increased by 30% (equivalent to a decrease in pH from 8.2 to 8.1) since the beginning of the industrial revolution, and is expected to increase by 300 % (equivalent to a decrease in pH to 7.8) by the end of this century if atmospheric CO₂ emissions continue at current rates. The absorption of CO₂ by the oceans contributes to the mitigation of global warming by reducing the increase in atmospheric CO₂, but at a cost: when CO₂ dissolves in seawater, a series of well-understood perturbations occur to the ocean carbonate cycle resulting in an increase in ocean acidity (i.e. decrease in pH). Ocean acidification is a term used to describe these changes in chemistry.

It is anticipated that these chemical changes could have dramatic consequences, potentially including extinction, for keystone marine species. These changes to chemistry are exacerbated when combined with other stressors such as increasing temperature or hypoxia. Organisms that produce a carbonate shell or skeleton have been the focus of scientific research, as calcification partly depends on seawater chemistry. Results have shown that organisms respond

to ocean acidification at variable degrees and that sensitivities differ between species. Other direct consequences, such as changes in growth rates, are mediated through changes in acid-base status or shifts in energy budget. These effects also depend on the species specific capacities to compensate. Additional physiological disturbances have been reported including behavioral changes, reductions in fertilization and reproductive success through development effects to eggs, larvae and juveniles. Projected changes at the ecosystem level include relative shifts in fitness and competitiveness, changes in species interactions, and ecosystem restructuring due to synergistic effects with temperature and changes in species composition and biodiversity. Marine organisms also may be indirectly at risk due to ocean acidification effect on key components of food webs, for example on specific zooplankton such as pteropods that are important in the diets of salmon and whales.

While research on various aspects of climate change has generated a large number of studies, ocean acidification has only recently been recognized as a serious threat for the environment with economic consequences. This new recognition is giving rise to an increasing number of studies on ecological impacts of ocean acidification, but estimates of economic impacts are still almost absent, despite their considerable importance for policy decisions.

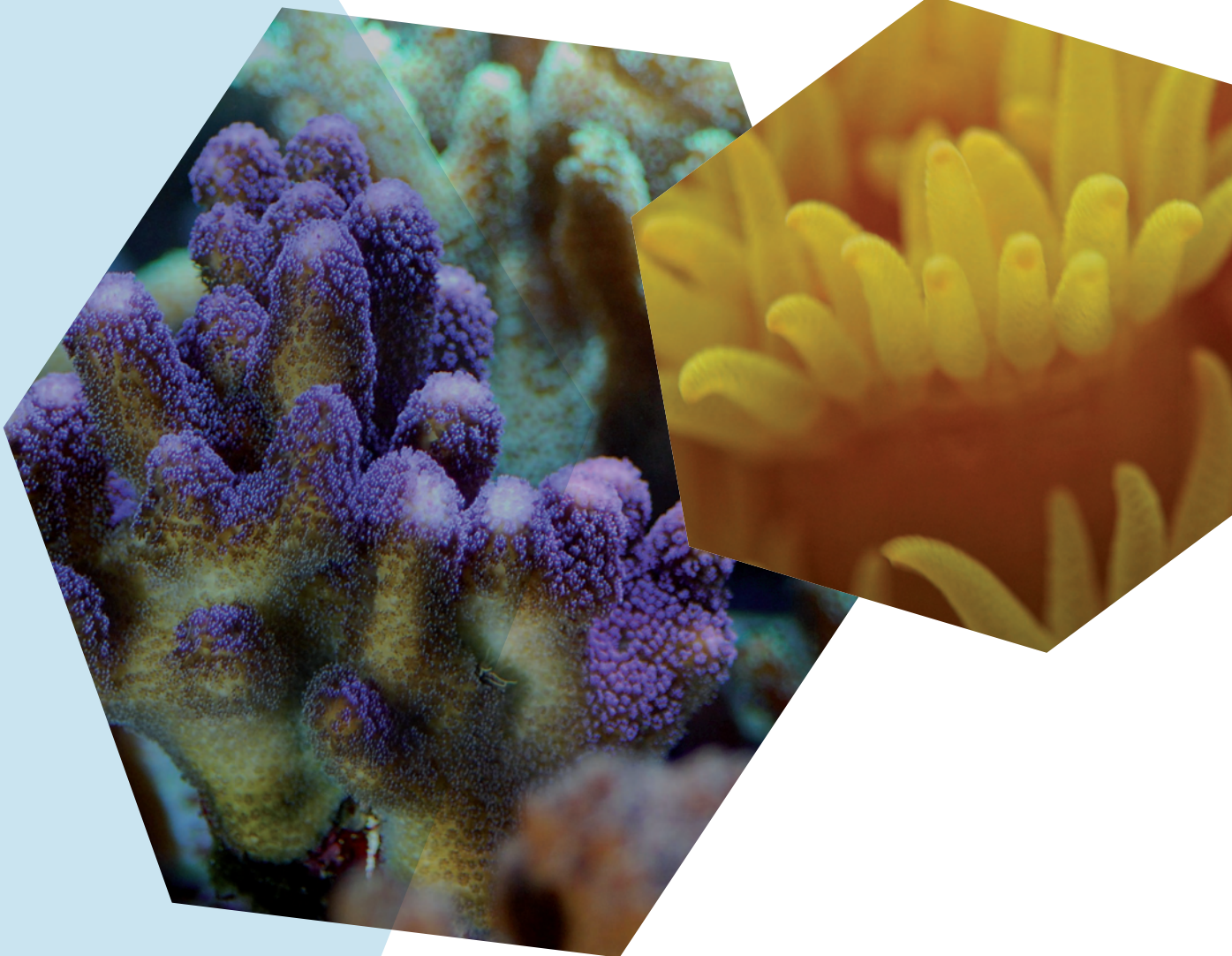
An international workshop, organized jointly by the Centre Scientifique de Monaco and the International Atomic Energy Agency, on the socio-economic impacts of ocean acidification brought together a dozen economists, a dozen natural scientists and representatives of international organizations for 2.5 days in Monaco. This followed the recommendation by 155 scientists from 26 nations in the 2008

Monaco Declaration to build better linkages between socio-economists and life scientists to enable future understanding of the impacts of ocean acidification on society.

Multidisciplinary experts were present at this workshop to facilitate discussions among the different communities and to start building the methodology for integrating knowledge from these different disciplines to better study the economic impact of ocean acidification. This interdisciplinary approach to ocean acidification was successful, stimulating relevant debates and identifying research prospects that are still to be explored. The discussions, rather than being alarmist, identified a positive and constructive

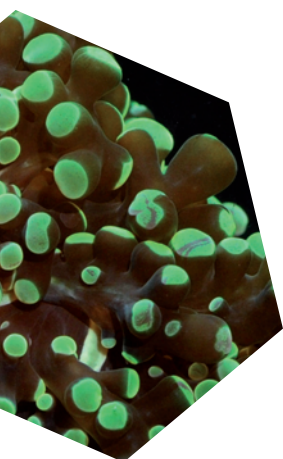
approach to seeking policy-oriented solutions to the threats raised by ocean acidification along with other environmental pressures. Although integrated studies are yet to be developed between the natural sciences and economics, the discussions have already led to recommendations for decision-makers, for both global mitigation and local adaptation to ocean acidification on three topics: natural resources and management, fisheries and aquaculture, and tourism.

« This interdisciplinary approach to ocean acidification was successful »



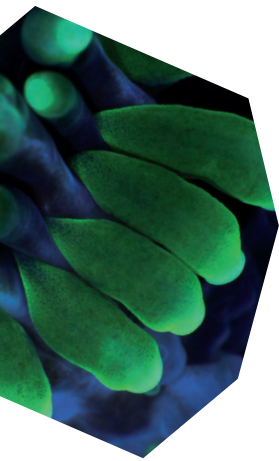
OCEAN ACIDIFICATION MAY AFFECT SEVERAL ECOSYSTEMS AND THEIR ORGANISMS THAT HAVE BIOLOGICAL AND SOCIO-ECONOMIC IMPORTANCE.

SYSTEMS AND ORGANISMS LIKELY TO BE AFFECTED BY OCEAN ACIDIFICATION	BIOLOGICAL IMPORTANCE	SOCIO-ECONOMIC IMPORTANCE	IMPACTS OF OCEAN ACIDIFICATION
CORAL REEFS	<ul style="list-style-type: none"> > Major marine ecosystem Central role in sustaining the biodiversity in the oceans realm (host 1/3 of all marine life) > Nursery for numerous organisms > Carbon export to the open sea Corals as major habitat builders (ecosystem engineer) > Corals as major habitat builders (ecosystem engineer) 	<ul style="list-style-type: none"> > Coastal protection > Provide various resources, including drugs (antibacterial, antimitotic...) > Materials for construction > Food source for about 500 M people > Tourism industry, recreational and leisure > Entertainment (e.g. films and documentaries) > Aquarium market > Recreational and commercial fisheries 	<p>Weakens carbonate skeletons and reduces coral growth, narrows distribution range, exacerbates temperature effects, shifts in species composition,</p>
CORALLIGEN (GORGONIANS, RED CORAL, CRUSTOSE CORALLINE ALGAE...)	<ul style="list-style-type: none"> > High biological diversity > Habitat > Spawning site > Inducer for larval invertebrate settlement (crustose coralline algae) 	<ul style="list-style-type: none"> > Ecosystem maintenance > Recreational fisheries > Recreational diving > Entertainment (e.g. films and documentaries) > Jewelry (red coral) > Use for construction and as a soil conditioner (crustose coralline algae) 	<p>Very few data available, potential effect by reduction of calcification</p>
PELAGIC ECOSYSTEMS	<ul style="list-style-type: none"> > Very large ecosystems (open ocean) > Key element in ocean productivity and food webs > Very large reservoir of marine organisms > Very important carbon reservoir > Nutrient cycling > Biogas production and flux to atmosphere 	<ul style="list-style-type: none"> > Globally important source of Oxygen > Globally important source of primary production supporting major food webs > Source of genes and drugs > Commercial fisheries > Recreational fisheries > Carbon sequestration 	<p>Shifts in species composition, potential effect on plankton growth and productivity</p>
PLANKTON CALCIFIERS SPECIES (FORAMINIFERA, COCCOLITHOPHORES, PTEROPODS)	<ul style="list-style-type: none"> > Major component of the food web > Major component of marine ecosystems > Large primary production > Major elements in the carbon cycle > Major elements for long-term landscape builders (sedimentary rocks) 	<ul style="list-style-type: none"> > Carbon sequestration > Food source for fishes > Genetic resources, drugs... 	<p>Likely important, potential effect by change of calcification and productivity</p>
MACROALGAE AND SEAGRASS MEADOWS	<ul style="list-style-type: none"> > Commercially harvested species > Posidonia beds: spawning site, high biodiversity > Oxygen production > Habitat, high biodiversity > Food supply for large grazers > High productivity > Nutrient cycling 	<ul style="list-style-type: none"> > Food source > Biofuels, alginates and land fertilizer > Oxygen production > Sediment stabilization > Coastal protection (by reducing water currents) > Water purification > Recreational and commercial fisheries > Ecosystem maintenance > Recreational diving 	<p>CO₂ enticement has fertilizing effect but alteration of species composition and biodiversity could occur</p>
ESTUARINE ENVIRONMENT	<ul style="list-style-type: none"> > Interface between land and sea > Important habitat for birds (particularly migratory birds) 	<ul style="list-style-type: none"> > Nursery for commercial fish and invertebrates > Key transport hubs > Commercial, industrial, recreational fisheries > Aquaculture activities > Bird watching > Ecotourism > Most preferred residential locations and harbours 	<p>Vulnerable to multiple stressors including acidification from freshwater input, ocean acidification will be stronger in low salinity waters</p>



SYSTEMS AND ORGANISMS LIKELY TO BE AFFECTED BY OCEAN ACIDIFICATION	BIOLOGICAL IMPORTANCE	SOCIO-ECONOMIC IMPORTANCE	IMPACTS OF OCEAN ACIDIFICATION
DEEP-SEA	<ul style="list-style-type: none"> > Largest (but yet least-known) habitat on earth > Largest store of carbon (apart from rocks) on planet > High biodiversity > Important endemic / specific organisms > Cold-water corals as ecosystem engineer and support of deep-water ecosystems > Important part of food web > Important in remineralization of organic matter and nutrient recycling 	<ul style="list-style-type: none"> > Habits for deep-sea fishes (nursery) > Source of new genes, enzymes, chemicals and drugs > Commercial fisheries > Entertainment (e.g. films and documentaries) 	Weakens carbonate skeletons and reduces coral growth, shifts in species composition
POLAR REGIONS	<ul style="list-style-type: none"> > Original ecosystems with highly specific (endemic) organisms 	<ul style="list-style-type: none"> > Source of new genes and drugs > Tourism, touristic cruise > Commercial fisheries > Entertainment (e.g. films and documentaries) > Home to charismatic species such as polar bears 	Ocean acidification will be stronger in cold waters, but only few data on sensitivity of polar organisms
MOLLUSCS	<ul style="list-style-type: none"> > Second largest marine phylum (about 17% of all the known marine organisms) > Important part of food web > Landscape builders 	<ul style="list-style-type: none"> > Important human food source (sea foods: oysters, mussels, prawns, scallop...) > Jewelry (pearls, mother-of-pearl) > Source of drugs (antibacterial, antifungal, anti-inflammatory, antimiotic...) > Genetic resources > Source of textile fibers > Aquariology 	Weakens carbonate skeletons and reduces growth, shifts in species composition
SEA URCHINS, SEA CUCUMBERS, STARFISH	<ul style="list-style-type: none"> > Important part of food web > Keystone species and ecosystem engineers 	<ul style="list-style-type: none"> > Human food source > Genetic resources > Major animal model for developmental biology and regenerative medicine 	Weakens carbonate skeletons and reduces growth, possible total extinction of some species (brittlestars)
SPONGES	<ul style="list-style-type: none"> > Ecosystem engineer, landscape formation > Water filtration 	<ul style="list-style-type: none"> > Sponge culture > Important source of drugs > Recreational diving > Genetic resources, enzymes antibacterial compounds 	Weakens carbonate skeletons and reduces growth
CRUSTACEANS (CRABS, PRAWNS, LOBSTERS, CRAYFISH...)	<ul style="list-style-type: none"> > First largest animal phylum > Important part of food web 	<ul style="list-style-type: none"> > Important human food source > Use in aquaria > Source of drugs and chitin 	Inhibition to stimulation of growth according to species, shifts in species composition
MARINE MAMMALS (WHALES, DOLPHINS, SEALS...)	<ul style="list-style-type: none"> > Important part of food web as plankton-eaters and source of carbon for deep-sea ecosystems (carcass) 	<ul style="list-style-type: none"> > Cultural role (charismatic species) > Whale watching > Entertainment (e.g. films and documentaries) 	Possible indirect effects by change in the food web
FISHES (HERRINGS, SARDINES, ANCHOVIES, TUNAS, CODS, FLOUNDERS, SHARKS...)	<ul style="list-style-type: none"> > Important part of food web, > Some are top predators 	<ul style="list-style-type: none"> > Commercial fisheries > Human food (almost 80% of the world catch) > Oil production > Fish meal provision > Recreational fisheries > Cultural role (charismatic species) > Entertainment (e.g. films and documentaries) 	Effects uncertain, disturbances reported in development, behaviours
BACTERIAL COMMUNITY	<ul style="list-style-type: none"> > Drivers of major biogeochemical cycles (decomposition of organic matter, nutrient regeneration...) > Some are major actor in O₂ production and marine productivity > Food source for small heterotrophic zooplankton and benthic feeders 	<ul style="list-style-type: none"> > Ecosystem maintenance > Sewage treatment > Source of new genes and drugs 	Potential alteration of microbial processes, potential impact on biogeochemical cycles and climate regulation
JELLYFISH	<ul style="list-style-type: none"> > Important part of food web > Biological model for medical research 	<ul style="list-style-type: none"> > Competitors with fishermen > Obstacle for beach activities, no swimmers > Genetic resources > Source of drugs and medical compounds 	Few contrasting data available, possible indirect effects





OCEAN ACIDIFICATION WILL IMPACT HUMAN WELL-BEING MAINLY THROUGH THREE ECONOMIC SECTORS.

NATURAL RESOURCES & MANAGEMENT

Biodiversity represents the unique relationships between individuals of a species, between different species and all of their interactions with the environment. A large range of social and economic benefits flow from the processes and functions of biodiversity (e.g. nutrient cycling, production of oxygen, construction of resilient habitat...) and the ecosystems services that they generate, such as climate regulation, waste remediation, coastal protection, food supply and security, provision for cultural environment and the availability of natural compounds for medicine. Degradation of the marine environment as a consequence of acidification may result in losses in these specialized ecosystem services or may require increased cost and efforts to avoid them.

AN EXAMPLE: Bioremediation of waste, defined as the removal of organic and inorganic pollutants through their storage, transformation and burial by marine bacteria, occurs through diverse processes. The impact of ocean acidification on marine bacteria may have an effect on the bioremediation of waste. Substantial changes to their activities, and of organisms responsible for the burial of waste products, may change the amount of waste that is locked away in seafloor sediments.

FISHERIES AND AQUACULTURE

Fisheries and aquaculture are major economic activities based on natural marine resources that support local and regional economies. These marine resources are part of the “blue revolution” that would need to occur in order to satisfy the food requirements of the growing world population in the coming decades given the projected shortfall in agricultural production.

AN EXAMPLE: Molluscs make up the second largest animal phylum on earth. They are a high-quality food source for

many of the world’s population. Several of the ecologically and economically important molluscan species may be challenged under future ocean acidification conditions, leading to reductions in growth that may have important socio-economic impacts on food security and poverty.

TOURISM

Ecosystem services provide opportunities for material and non-material benefits such as leisure and recreation, cultural heritage, education, training and research (i.e. cognitive development). Cultural ecosystem services also contribute to the non-material benefits that people obtain from the environment such as aesthetic information, spiritual experience, and inspiration for culture, art and design.

AN EXAMPLE: A future change in the prevalence of harmful algal blooms in a more acidic ocean may potentially lead to restrictions on recreational activities due to a reduction in water quality; this may alter the health benefits obtained from marine recreation. In addition, ocean acidification may impact charismatic species (e.g. corals, whales) or species that have some religious or spiritual meaning (e.g. totems used by native Australians) or recreational value (e.g. through ecotourism and wildlife watching activities), changing the contribution of these cultural services to human well-being.

RECOMMENDATIONS

The most obvious mitigation strategy for ocean acidification is the reduction of anthropogenic CO₂ emissions to the atmosphere. Ocean acidification is therefore a powerful additional argument to that of climate change for policy discussions on global CO₂ emission reduction.

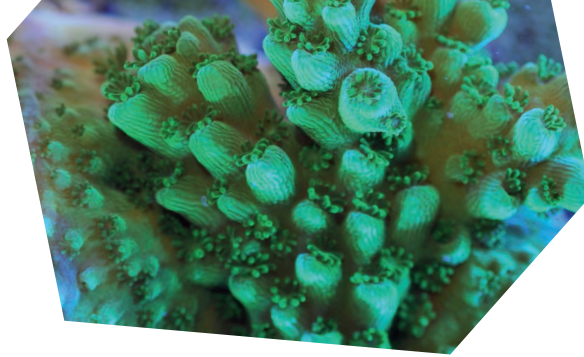
Participants to the workshop put forward the following recommendations to decision-makers.

MANAGEMENT OF THE MARINE ENVIRONMENT

- > Promote natural capital by sustaining healthy marine ecosystems to increase resilience to ocean acidification.
- > Recognize the non-monetary value of marine ecosystems services.

« Fisheries and aquaculture are major marine economic activities »

OUTCOMES OF THE WORKSHOP



DEVELOP THE SYNERGIES between natural and social sciences through education, training and interdisciplinary research to understand the biological and socio-economic impacts of ocean acidification.

ENSURE COMMUNICATION of research results and decision support to policy makers.

IDENTIFY PUBLIC PERCEPTION to ocean acidification and integrate it in policy decision.

DEVELOP THE PUBLIC UNDERSTANDING of the goods and services provided by the ocean. Develop public awareness to ocean acidification

IDENTIFY LOCAL SUCCESS STORIES OF MARINE MANAGEMENT, analyse the reasons for their success, and develop incentives and tools for a wider implementation.

OBTAIN ESTIMATES OF COSTS AND BENEFITS of rebuilding of degraded areas. Estimate the monetary values of marine ecosystem services and incorporate them in national accounts and cost-benefit models.

IDENTIFY THE ENVIRONMENTAL STRESSORS that interact with ocean acidification.

DESCRIBE HOW ECOSYSTEM SERVICES by species vulnerable to ocean acidification may be affected.

INCLUDE OCEAN ACIDIFICATION in other existing policy areas. Minimise duplication and contradictory policies, and making it more relevant to poverty reduction, rural and agricultural development, and the energy sectors.

INCREASE MANAGEMENT EFFICIENCY by identifying and obtaining measurable indicators of success and failure.

CREATE MORE MARINE PROTECTED AREAS and develop the local monitoring.

USE NEW TECHNOLOGIES to monitor and communicate the effectiveness of protected area management to encourage wider stakeholder engagement and to provide feedback to investors.

IDENTIFY THE RESISTANT/TOLERANT SPECIES to ocean acidification that can be used in aquaculture.

IDENTIFY THE MOST VULNERABLE GEOGRAPHICAL REGIONS and prioritize them. Elaborate a global socio-economic map of ocean acidification vulnerability.

FOR DECISION-MAKERS

- > Establish officially recognized international networks for efficient management of marine protected areas to maintain or restore marine ecosystems and increase their resilience to ocean acidification.
- > Services through effective mechanisms by reducing other stressors which may increase vulnerability to ocean acidification.
- > Introduce mechanisms to diversify aquaculture production and select resistant/tolerant species. Support the shellfish aquaculture industry to conduct monitoring of seawater chemistry and develop adaptations they implement.

SPECIFIC POLICIES

- > Include ocean acidification in global climate change policy discussions in addition to increasing temperatures, sea level rise, point and non-point pollution, living resources overexploitation and introduction of alien invasive species.
- > Develop mechanisms to maintain marine biodiversity because loss of species impacted by ocean acidification may disrupt the food web (predator- prey relationships).
- > Incorporate stakeholders by engaging the private sector in ocean acidification actions.
- > Develop consensus and commitment mechanisms across public and private sectors to build resilient marine ecosystems.

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