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POLICY BRIEF

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In support of decision-making: Assessing and monitoring the social and ecological vulnerability of coral reef-dependent socio-ecosystems

A scientist studying coral reefs in the Virgin Islands National Park (© NPS Climate Change Response).

SUMMARY

Although they provide essential services to local populations, coral reefs are threatened by the impacts of a multitude of human activities. Through the notions of social and ecological vulnerability of socio-ecosystems dependent on coral reefs, it is possible to develop a risk management framework that enables us to identify and prioritize the issues at stake. In other words, the human, economic and environmental value of elements exposed to the risks of adverse events. This framework makes it possible to assess the possibilities for actions that lead either to reducing vulnerability by reducing hazard or exposure, or that lead to reinforcing response or adaptation capacity. In this policy brief, we explain the concepts of social and ecological vulnerability, and share examples of indicators for assessing and monitoring them, as well as examples of their use in identifying action plans.

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Are pressures from human activities threatening the coral reef ecosystem services on which societies depend?

How dependent are societies on coral reef ecosystem services?

The services provided by coral reef ecosystems are important for livelihoods, fisheries, tourism, coastal protection and provide essential compounds for the development of new drugs, notably for the treatment of cardiovascular disease, ulcers, leukemia and skin cancer (figure 1). Overall, coral reefs provide ecosystem services worth three hundred and seventy-five billion dollars per year. At least one billion people obtain fish protein from coral reefs, and half a billion people depend on coral reefs for their livelihoods. Around one hundred and fifty thousand kilometers of coastline in one hundred countries benefit from some form of coastal protection from the reefs, as a natural barrier.

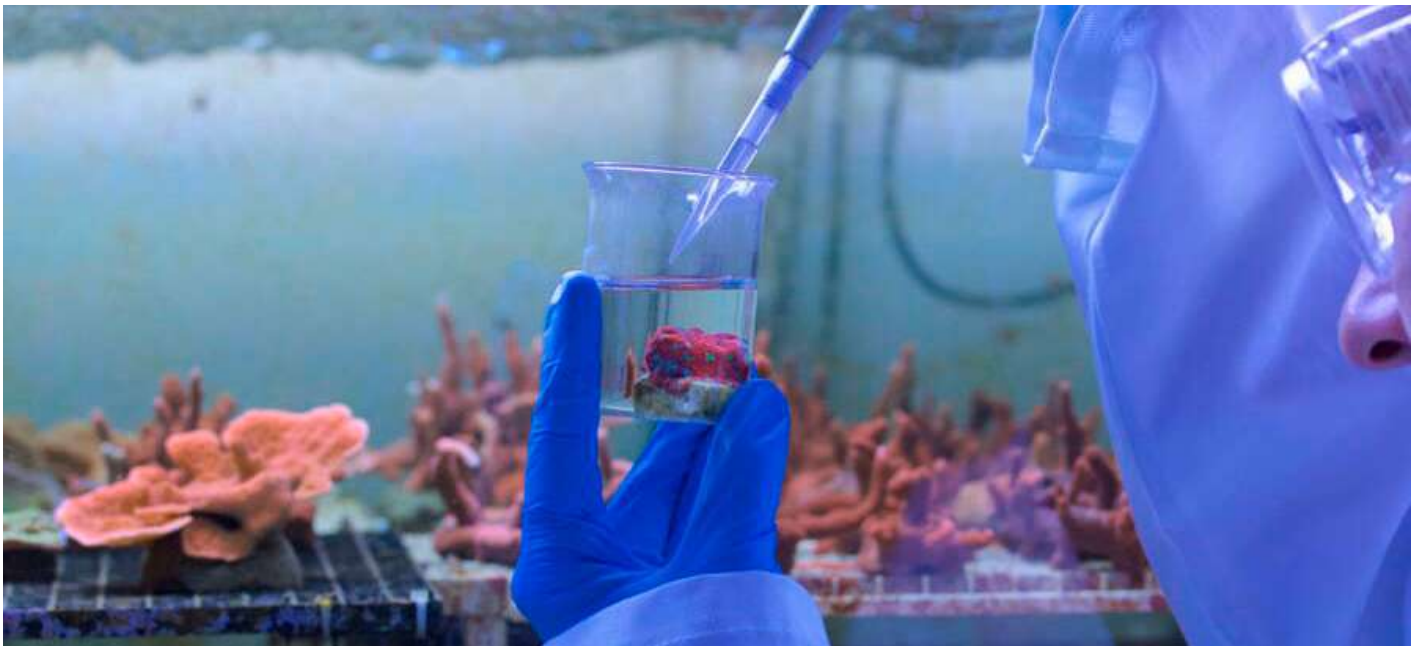

Figure 1. Corals grown for cancer treatment in Marseille (© Coral Biome, 2019)

Reefs are often linked to traditional, spiritual and cultural values of populations living close to these ecosystems. Most coral reef-dependent countries are small island states in the Pacific and Caribbean. Studies show that, on average, countries with coral reef-related industries derive more than half their gross national product from these activities.

What pressures do human activities exert on coral reefs?

Coral reefs undergo multiple threats from human activities, including overfishing, destructive fishing methods, leisure/recreational activities and tourism, coastal development, port construction, dredging, pollution from agricultural land, land clearing for building construction, and sewage and plastic discharges. Illegal wildlife trade and invasive species also threaten coral reefs. The effects of climate change, including rising ocean surface temperatures, ocean acidification, sea-level rise, and storms, are therefore accumulating with this set of pressures.

What is the impact of these pressures linked to human activities on coral reef ecosystem services?

Overfishing of certain species can affect the ecological balance and biodiversity of the reef. For example, overfishing of herbivorous fish can lead to important algal growth. Destructive fishing methods can damage large areas of coral reef habitats, reducing the region's productivity and impacting fishing. Recreational activities can induce physical damage caused by careless swimmers and divers, misplaced boat anchors, shallow coral crossing or abandoned fishing gear. Runoff from land, as well as harbor construction and dredging, induce sedimentation, reducing light and thus coral growth, and an increase in nutrients, allowing algae to proliferate on the coral. Microplastics are ingested by the reefs, increasing the risk of disease due to transported pathogens.

Damage caused by invasive species includes altered ecosystem dynamics and loss of biodiversity. Lastly, climate change is leading to a loss of biodiversity and the spread of disease. Coral bleaching affects their growth, while acidification reduces the corals' ability to build their calcareous skeleton, making them much more vulnerable to erosion (figure 2).

Figure 2. Data collection on coral bleaching in the Virgin Islands (© John Melendez, The Nature Conservancy)

Why analyze the vulnerability of socio-ecosystems that depend on coral reefs?

What is the vulnerability of socio-ecosystems dependent on coral reefs?

According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), vulnerability is defined as the propensity or predisposition to be affected. In the case of the impacts of human-related pressures on coral reef ecosystem services, vulnerability encompasses a variety of elements, including exposure to human impacts - are impacts likely to affect coral reefs locally? - and the lack of capacity of ecosystems and local populations to cope with these impacts - do ecosystems and local populations have the capacity to adapt?

Why assess the vulnerability of socio-ecosystems dependent on coral reefs?

Vulnerability analysis provides elements for developing key actions to minimize the impact of an event. The analysis enables the development of a risk management framework, namely prevention policies and tools, and protection and repair measures adopted and implemented by the various competent authorities. In particular, it helps identify and prioritize the issues at stake, i.e. the human, economic and environmental value of the elements exposed to the potentially dangerous hazard whose intensity and probability of occurrence we are trying to estimate. Stakes are what we risk losing (Table 1).

Vulnerability linked to human value, in other words the endangerment of population exposed to a threat, is non-negotiable: it is based on the principle of collective responsibility, particularly that of the State. A more material vulnerability, involving financial and/or patrimonial stakes, may be subject to monetary evaluation, linked to the search for a compromise between the advantages and disadvantages of collective or individual economic, urban or social development projects that involve taking risks. Differentiations of this kind provide the basis for prioritizing issues to support the definition of action plans.

Table 1. Summary of stakes (Hénaff and Philippe, 2014)

TYPES OF STAKES
Protecting human life
Constructions
Activities, uses
Vulnerable infrastructure and equipment
Essential networks
Strategic equipment
Natural environments
Historical heritage

What is the social and ecological vulnerability of socio-ecosystems dependent on coral reefs?

What is social vulnerability?

Social vulnerability provides a framework for risk management. Its aim is to better understand the fragility of a system as a whole, and its capacity for reconstruction. It aims to identify psychological, social, cultural and environmental factors, living conditions (proximity and experience of risks) and the relationship with the area where people live.

Social vulnerability is the result of the sensitivity of social systems to ecological vulnerability, and society's ability to adapt to impacts (figure 3). Ecological vulnerability represents the exposure of socio-economic ecosystems to hazards. For example, for fishing communities dependent on the ecosystem services of coral reefs, ecological vulnerability refers to the extent to which the resource on which they depend will be affected by change.

Social vulnerability enables us to understand the dependence of social systems on coral reef ecosystem services. For fishing communities, social sensitivity can be captured through their level of dependence on marine resources or the sensitivity of their catch composition to hazards. Adaptive capacity reflects the population's ability to anticipate and react to change, and to minimize and recover from the consequences of change. Adaptive capacity can depend on a wide range of factors, such as access to credit, professional and geographic mobility, debt levels and lifestyle.

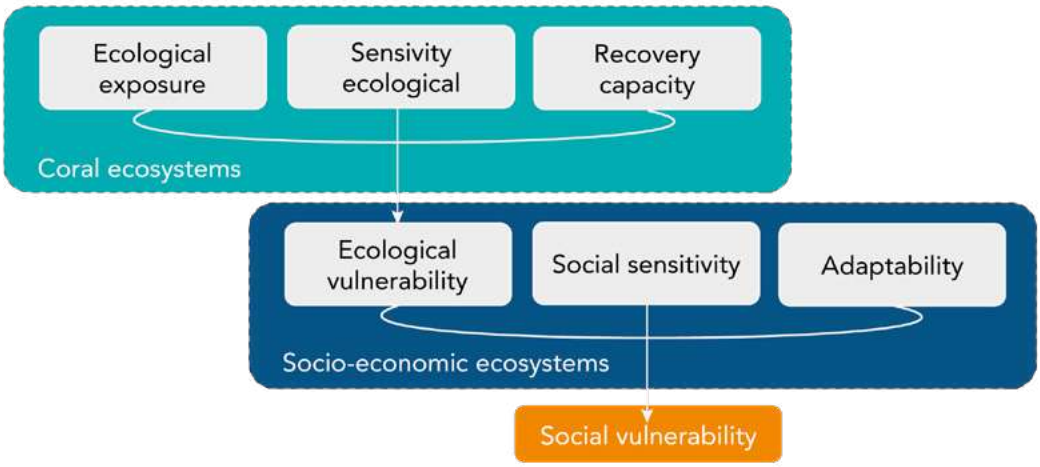

Figure 3. Integrated framework for analyzing social and ecological vulnerability (own elaboration based on Marshall et al., 2013)

How is the vulnerability of socio-ecosystems dependent on coral reefs assessed?

What is ecological vulnerability?

Ecological vulnerability is the risk associated with natural hazards. It is a function of ecological exposure, ecological sensitivity and ecological resilience. Ecological exposure is linked to the frequency, intensity and duration of a given type of hazard, and therefore to the probability of events occurring. For example, ecological exposure to coral bleaching can be defined using a model that identifies the environmental conditions such as temperature, light, currents, chlorophyll and water quality that lead a site to be impacted by bleaching.

Ecological sensitivity is the susceptibility of a component of a natural ecosystem to be exposed to a hazard. For example, it may depend on physiological tolerances to change or variability in physico-chemical conditions such as temperature or pH. Some coral species are highly sensitive to increases in seawater temperature, while others are more tolerant.

The ecological resilience will depend on the hazards to be assessed, as well as the issues at stake, i.e. the socio-economic activities and/or regions targeted by the action plans, and available data. An exhaustive analysis would take into account all the hazards to which the stakeholders are exposed.

What are the social indicators of vulnerability?

Table 2 illustrates examples of social sensitivity and adaptive capacity indicators for fishing activities in Kenya's coral reefs, in the face of climate change impacts. To assess the combined effect of these factors, it is possible to assign a standardized score to each indicator, between zero and one for example, and aggregate them with weightings based on expert opinion, into three indices: ecological vulnerability (see next paragraph), social sensitivity and social adaptive capacity. Social vulnerability is then calculated by adding ecological vulnerability and social sensitivity, and subtracting social adaptability.

Tableau 2. Examples of social vulnerability indicators for Kenya's coral reef fisheries in the face of climate change impacts (Cinner et al., 2013)

SOCIAL SENSITIVITY INDICATORS
Dependence on marine resources
Sensitivity of catch composition to hazard
ADAPTABILITY INDICATORS
Capacity for action on marine resources
Access to credit
Professional mobility
Multiple professional positions
Social capital (number of community groups)
Material lifestyle
Fishing gear diversity
Community infrastructure
Trust (in members of society, in the state)
Ability to change livelihoods
Household debt

What ecological indicators of vulnerability?

Table 3 illustrates examples of indicators of ecological sensitivity and resilience for fishing activities in Kenya's coral reefs to the impacts of climate change. Ecological exposure in this framework is determined by a multivariate model that identifies sites likely to be impacted by climate change. With this model, a higher value implies that sites are more likely to experience coral bleaching.

To assess the combined effect of these factors, it is possible to assign a standardized score to each indicator, for example between zero and one, and aggregate them with weights based on expert opinion into three indices, namely ecological exposure, ecological sensitivity and ecological resilience. Ecological vulnerability should then be calculated by adding ecological exposure and ecological sensitivity, and subtracting ecological resilience.

Tableau 3. Examples of ecological vulnerability indicators for Kenya's coral reef fisheries to climate change impacts (Cinner et al., 2013)

ECOLOGICAL SENSITIVITY INDICATORS
Sensitivity to coral bleaching
Fish sensitivity to bleaching
RECOVERY CAPACITY INDICATORS
Coral cover
Coral overgrowth versus macroalgae
Calcifying versus non-calcifying coating
Coral size distribution
Coral richness
Fish biomass
Ecological metabolism
Herbivore rate in relation to algal production
Fish species richness
Substrate complexity (roughness)
Fish size distribution
Functional diversity of herbivores

How useful are public perception surveys?

Population surveys enable us to provide a qualitative analysis of the local knowledge that influences their ability to adapt and provide solutions in the face of environmental change before suggesting actions to reduce the vulnerability of socio-ecosystems dependent on coral reefs. These surveys can also help improve understanding of how changes in the coral ecosystem, specifically corals, fish, invertebrates and algae, are perceived, as well as threats to coral reefs. This information can complement and qualify quantitative indicators, as well as shed light on the most appropriate actions for the specific local context.

What can be done to reduce the vulnerability of socio-ecosystems dependent on coral reefs?

How useful are vulnerability maps?

To analyze the actions that reduce the vulnerability of socio-ecosystems dependent on coral reefs, it is useful to visualize the different components of social and ecological vulnerability indicators to be able to prioritize issues, that is the human, economic and environmental value of elements exposed to the hazard in different sites. In this way, vulnerability maps can be used to prioritize issues according to various criteria, and remain a tool for risk management of social-ecological systems (Figures 4 and 5).

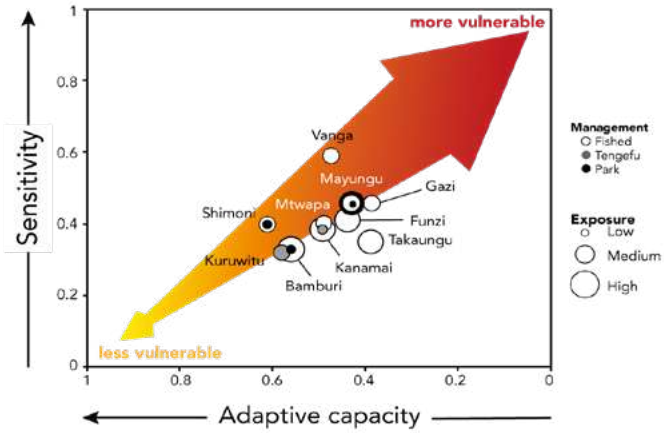

Figure 4. Map of social vulnerability of coastal communities in Kenya according to management systems (open access fished, controlled access tengefu, and protected park) to the impacts of coral bleaching for coral reef fisheries (Cinner et al., 2013)

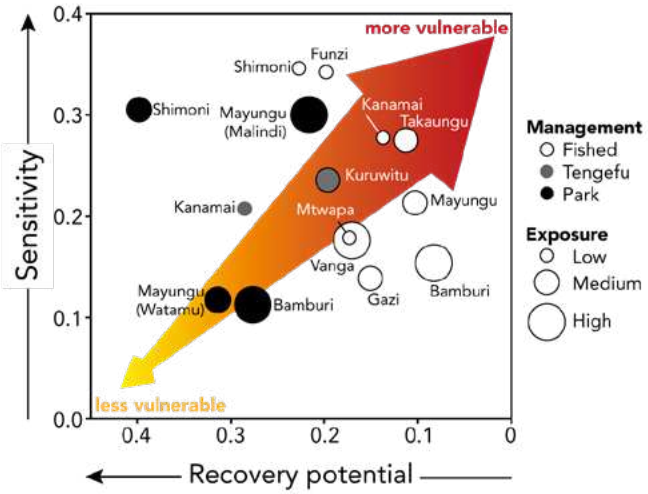

Figure 5. Ecological vulnerability map of coastal communities in Kenya according to management modes (open access fished, controlled access tengefu, and protected park) to the impacts of coral bleaching on coral reef fisheries (Cinner et al., 2013)

What measures can be taken to reduce the social vulnerability of socio-ecosystems dependent on coral reefs?

These vulnerability maps make it possible to visualize which components contribute most to a site's social vulnerability, so that appropriate local actions can be implemented. Thus, in figure 4, the Takaungu site has a high level of social vulnerability due to high social exposure and low adaptive capacity, while social sensitivity is not very high. Actions at this site could focus on improving adaptive capacity, as it is more difficult to implement actions that reduce social exposure.

Table 4 presents possible actions to influence the various components of the social vulnerability of fishing activities in Kenya's coral reefs to the impacts of climate change. For the Takaungu site, micro-credit programs and infrastructure development projects could have a significant influence on their social adaptive capacity. To a lesser extent, education and support for community initiatives and organizations could improve adaptive capacity.

In view of figure 4, the Vanga site is vulnerable mainly because of its high social sensitivity. Actions to reduce the social vulnerability of this site could focus on reducing this social sensitivity. In Table 4, we see that the most suitable actions for reducing social vulnerability at this site focus firstly on developing additional livelihood activities, and secondly on promoting the use of fishing gear less likely to be adversely affected by coral bleaching, such as handlines.

What are the prospects for implementing this approach?

What type of information should be produced?

We need to teach ecological vulnerability, that is prioritize and characterize the main sources of degradation of a reef. It would also be necessary to inform social vulnerability through economic indicators such as fishing turnover, or physical indicators such as the number of tourists and share of protein intake for consumption subsistence. This would make it possible to define the dependence of the local population.

There are many more physical indicators than monetary ones. However, monetary indicators are sometimes key. For the ecosystem services of coastal protection, the question arises of characterizing

Table 4. Possible actions to influence the different components of the social vulnerability of fishing activities in coral reefs in Kenya to the impacts of climate change (Cinner et al., 2013)

VULNERABILITY COMPONENT	POTENTIAL FOR INFLUENCE	POSSIBLE ACTIONS
Social exposure (or ecological vulnerability)		
Social exposure	**Medium**	Develop local management to increase ecological resilience and sensitivity (e.g. through marine protected areas and gear-based management).
Social sensitivity		
Dependence on marine resources	**High**	Develop additional livelihood activities
Sensitivity of catch composition to hazard	**Medium**	Promote the use of fishing gear less likely to be adversely affected by coral bleaching, such as handlines.
Social adaptability		
Capacity for action on marine resources	**Medium**	Education and participation in research
Access to credit	**High**	Microcredit programs, support for community savings groups
Multiple professional positions	Low	Support for economic growth
Social capital (number of community groups)	**Medium**	Support for community initiatives and organizations
Fishing gear diversity	Low	Training, equipment supply
Community infrastructure	**High**	Infrastructure development projects in rural areas
Trust (in members of society, in the State)	Low	Eradicating corruption
Ability to change livelihoods	Low	Skills and capacity building
Wealth (lifestyle, debt)	Low	Poverty reduction plans and growth policies in favor of the poor

the risk if the reef no longer exists. In this case, we would need monetary indicators to assess the cost of replacing the reef with an artificial barrier.

These indicators are used to measure the effects of interdependency and the scales of that dependency. We can then anticipate that with the disappearance of one activity, others, downstream, will also disappear. These indicators make it possible to identify which social groups depend on ecosystem services, and with what degree of intensity, as well as the relative importance of this group in relation to the weight of economic activities.

When do you need to produce this type of information?

We need to characterize and document the indicators. First of all, we need to look for indicators that already exist and also set up dispositifs to monitor this vulnerability. Monitoring ecological and social vulnerability is only of interest if there is also an evaluation to indicate pressures. There are pressures on which we can act at the local level, and others on which we cannot. Indicators on pressures make it possible to look at levers for action (see the integrated approach DPSIR (drivers, pressures, status, impacts, responses)). Characterizing vulnerability indicators involves a fairly laborious procedure, which is justified when these indicators enable the development of action programs. Reefs in developed countries can benefit from the development of these indicators and also certain regions such as the Caribbean because of the local economic stakes.

Developing these indicators is justified in order to put science at the service of action. This in part of an ecosystem management approach of the reef socio-ecosystem. This framework is part of the work initiated in Europe with the Marine Environment Framework Directive, based on the DPSIR ecosystem approach. Under this Directive, there are six-year cycles of assessment and action plans. The first action plan is currently being evaluated, and proposals are being put forward for the third-cycle action plan. The action plan for the second cycle has just been adopted. This framework will enable us to rethink our monitoring programs, so that they are better adapted to the needs of public policy-making. This has transformed marine monitoring programs.

The trend towards developing programs to monitor socio-economics effects is new. Until now, there was only biological monitoring. We also need to characterize socio-economic changes in relation to the environment through socio-economic or blue economy observatories. We must not only monitor the state of the environment, but also observe the evolution of this state of the environment in relation to pressures , and human activities linked to reefs.

All countries in the European Union had to develop a strategy, and an action plan as part of the Directive. This information is published and accessible to all regions in continental Europe. The European Commission has left it up to the Member States to extend this Directive to the outermost regions, with a debate on the subject underway in France. Regions with coral reefs could draw inspiration from this European initiative for reef management to set up a DPSIR framework for ecosystemic management. The problem raised is the lengthy and complex nature of the procedure and the resources to be allocated.

Sources and further reading

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OCEAN UNIVERSITY INITIATIVE

The Ocean University Initiative was initiated by the local authorities in Brittany. It is implemented by the University of Brest (UBO) with the aim of creating the conditions for establishing in France of an institute of the United Nations University dedicated to the ocean and the coasts, and with the means to carry out pioneering work in three areas: research, training and communication.

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