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Coral reefs management and decision making tools

Nathalie Hilmi [a, *], Alain Safa [b], U. Rashid Sumalia [c], Mine Cinar [d]

[a] Centre Scientifique de Monaco, 8, Quai Antoine 1er, Monaco
[b] Skill Partners, France
[c] University of British Columbia, Vancouver, Canada
[d] Loyola University Chicago, USA

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ABSTRACT

In this article, we examine the problem of coral reef destruction and discuss various stakeholders who suffer losses from the destruction. We then postulate a stakeholder versus threats matrix and outline an algorithm where public authorities can streamline policy based on expected losses. We also formulate, using local data, divergence between public good and individual benefits and examine the agent behaviour under monitoring. Our examples, using previous estimations on net benefits, give guidelines on how to form public policy and management strategies.

1. Introduction

The importance of coral reefs in terms of shore line protection, hosts for marine habitat and biodiversity as well as an attraction as a tourism destination have been well documented in the literature (e.g., Dixon et al., 1988). Coral reefs are also known to support activities that create jobs the livelihoods of millions of people around the world through the supply of nutritious and healthy food (Hubbell, 1997; Cinner et al., 2012, 2016; Teh et al., 2013). Protection and conservation of coral reefs to add to their resiliency and their ability to protect biodiversity is of primary importance at the local, regional and national levels.

Policymakers in coral reef regions of the world have to make management decisions that weigh the positive externalities or benefits (such as tourism revenues) with the negative externalities or cost of exploitation (natural resource destruction) in order to avoid tragedy of the commons. Biologist Garret Hardin put forth his "tragedy of the commons" idea in 1968. He described a situation in which multiple individuals, acting independently and rationally based on their own self-interest, will ultimately deplete a shared limited resource (Hardin, 1968). Elinor Ostrom believed that if users decide to cooperate with one another, monitoring each other's use of the resource and enforcing rules for managing it, they can avoid the tragedy. For Ostrom (1990), social control mechanisms and collective actions regulated the use of the commons. In her book "Governing the Commons", she demonstrated that informal approaches to managing common property resources are superior to government-enforced ones. Hardin (1968, 1994, 1998) revised his theory and called it "The Tragedy of the Unmanaged Commons". Cooperative behaviour is the key to success when commons are used as a framework for solving environmental problems (e.g., Munro, 1979; Sumaila, 1999, 2013; Bailey et al., 2010). Pomeroy (1995) has also discussed the importance of fishers and other stakeholders to have a say in management as a policy to reduce conflict management in fisheries. The authors note that decentralization and management of these programs will require new institutional arrangements at the local and national levels.

Universe-wide problems such as global warming have to have decisions taken at many different levels, including, global, regional, national and local ones (e.g., Miller et al., 2013). As for coral reefs particularly, stakeholders for reefs and related resources are many (see Bryant et al., 1998; Burke et al., 2002). First of all, coral reefs are a world heritage resource and an important marine habitat which should be sustained and preserved for both current and future generations. Many countries, especially emerging nations, rely on tourism income generated by the resource and by the industries which have horizontal and vertical linkages to it. These linked industries not only generate tax revenue but they also provide

* Corresponding author.
E-mail address: hilmi@centrescientifique.mc (N. Hilmi).

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employment. Health of linked-industry firms, especially small businesses such as hotels, restaurants, etc. are very important to the overall economy since small businesses also provide a minimum of 90 percent or more of employment in national economies. Other industries which would be seriously impacted by the destruction of the marine habitat are fishing (especially artisanal fishing) and marine-related food industries and local communities who rely on marine-based food for their household incomes and livelihoods. Policymakers may be at a loss when it comes to management and benefit/cost analysis of common resources. They have to set strategy within the confines of a solitary game. To give guidelines for policy and decision makers for decision making at local/regional/global levels, we propose a simple explanation as to what is at issue, where we model threats[1] to the reefs and examine them at each stakeholder level. We identify the threats and stakeholders in Section 2.

Some papers have studied the strategies, including uncertainty, in the exploitation of a common-property resource (Antoniadou et al., 2013; Fesselmeyer and Santugini, 2013; Alvarez-Cuadrado, and Van Long, 2011). Our paper focuses on one particular common property resource: coral reefs.

The aim of this study is to propose a method for individual agents and local public officers to find the right strategy by assessing potential damages. For this purpose, we use previously available data on net benefits in the latter part of the paper as an example of what can be done.

2. Theoretical framework: constructing loss matrix of threats versus stakeholders

We use game theory to study strategies in exploiting coral reefs. For individual agents and local public officers, decision making may be hard due to severe short run opportunity costs considerations as captured by the concept of discounting (Sumaila and Walters, 2005). Game theory may be an appropriate mathematical tool for structuring and analysing problems of strategic choices in interactive environments (Cinar et al., 2013; Sumaila, 1999). It models a very wide range of situations between interacting decision-makers who can simulate the players, their strategic options, their preferences and reactions. Nash theorem, taking its root in Leon Walras' General Equilibrium Theory (1874) and John von Neumann's and Oskar Morgenstern's Game theory (1944), make it possible and appropriate to gain insight into protecting a natural resource such as coral reefs (e.g., Munro, 1979; Esteban and Dinar, 2013).

To help in formulating strategy, this study constructs loss matrices to give an idea about the metrics in question for each different strategy for stakeholders. Data for estimated costs of threats and of benefits from the resource are scarce and we use data from the existing literature to illustrate our method. To construct loss matrices, we need to assess the probabilities of losses which are fundamental for all stakeholders. Getting good estimates are crucial and then there are many decision methods. Feasible options of minimizing the maximum (minmax) loss in the matrix are by directing policies aimed at preventing the damage in a particular **cell** or minimizing the maximum loss in the matrix by directing policies aimed at preventing the damage in a particular **row** (stakeholder) or particular **column** (threat). If we can estimate the probabilities for threats and also get estimates for, in monetary terms, of potential damages when the reefs lose their resiliency, we would have a basis for making sounder decisions. We can then construct the expected payoff matrix per stakeholder, by using the information on losses and the probabilities of them happening. Once the policy holders get an estimate of such a table, they can set strategies to minimize the maximum losses.

Since this game is played against nature, having dynamic, sequential games that extend the game over longer time periods is one that the policymakers will need to make for long run decisions. However, there is much to be said for constructing a simple expected loss matrix as described above to get the policies prioritized in the short run.

We can postulate about coral reef stakeholders and the impending threats by constructing a loss matrix for public administrators.

The stakeholders who are going to suffer from the destruction of reefs are at several levels of congregation (see Bryant et al., 1998, 1999; Burke et al., 2002). These are the:

1. Global community: Coral reefs are 'human and world heritage' resources. They are also an important habitat of marine biodiversity (Knowlton et al., 2010; Bellwood et al., 2004).
2. Tourism and related hospitality industries: Tourism agencies, hotels, restaurants are important to regions. Regional and national authorities are impacted by adverse changes in these industries; (Andereck et al., 2005).
3. National governments: Government revenue and employment consequences are of important macro outcomes.
4. Fishing, marine-related food industry and consumers: Fisheries, canning, freezing, marine food export industry, consumer access to marine based food are important to producers, households, their incomes and their diets (Kawarazuka and Béné, 2010; Gross, 1975).

On the other hand, the sources of threats for reefs above can be grouped under four main headings, i.e., (i) carbon dioxide emissions-ocean acidification; (ii) overuse due to tourism or human usage (including pollution), (iii) overfishing by destroying present and future marine life; and (iv) algae that colonize the reefs (Cesar et al., 2003).

ICRI (1995) reports that damages from different sources have already destroyed one-quarter of coral reefs worldwide and CRTF (2000) reports that 60 percent may be under threats that can make them disappear by 2050. The threats come from several sources. There are natural threats, such as disease outbreaks (NMFS, 2001), algae colonizations, and hurricanes and cyclones (Barnes and Hugues, 1999). There are also human-generated anthropogenic threats, such as destructive fishing practices of cyanide fishing, blast fishing, bottom-trawling; (Reeves and Notarbartolo di Sciara, 2006; Gerlak, 2004), overfishing with indirect effects through the food chain and direct effects on the fished species; (Dyck and Sumaila, 2010), unsustainable tourism (diving, snorkelling, waste sewage, dropped anchor), pollution (agrochemicals, industrial waste, oil pollution), sedimentation (erosion of the coasts, increased sediments in rivers), coral mining (coral is used as bricks or cement for new buildings and/or sold to tourists), climate change (coral bleaching and ocean acidification effects) (Bryant et al., 1998; Cheung et al., 2010; Sumaila et al., 2011).

The underlying assumptions about this matrix are that the game we propose for the administrators is a solitary one in that this game is played against nature, that the stakeholders are optimizing over a single period. Since coral reefs can be sustained (Jenkins, 2010), we can get region-specific prevention or replacement costs in the future. We realize that games against nature are long run games and there may be principal agent problems created by the different

[1] The sources of threats to coral reefs can be summarized as due to climate change (carbon dioxide emissions-ocean acidification) and to indirect and direct anthropogenic factors and to colonization by other groups of organisms, mainly algae. It is hard to quantify each of these threats in terms of dollar losses and opportunity costs given the present state of scanty data.