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Decision making tools: How to best manage the coral reefs?

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Abstract: In this article, we examine the problem of coral reef destruction and discuss various stakeholders who face the 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.

Key words: Coral reefs, decision making, management, protection

Introduction

When the biologist Garret Hardin put forth his "tragedy of the commons" in 1968, he assumed that multiple individuals, acting independently and rationally consulting their own self-interest, will ultimately deplete a shared limited resource. Nobel Prize-winning economist Elinor Ostrom believes 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, social control mechanisms and collective actions regulate the use of the commons. In her 1990 book "Governing the Commons", she demonstrated that informal approaches to managing common property resources are superior to government-enforced ones. Hardin revised his theory and called it "The Tragedy of the Unmanaged Commons". Cooperative behaviour is the key of success when commons are used as a framework for solving environmental problems.

In fact, private sector institutions in a nation cannot solve alone universe-wide problems such as global warming. The decision has to be taken at different levels. That is why we think that the game theory is an appropriate mathematical tool for structuring and analysing problems of strategic choices in interactive environment. It models a very wide range of situations between interacting decision-makers who are supposed to enumerate the players, their strategic options, their preferences and reactions. Nash theorem took its root in Leon Walras' General Equilibrium Theory (1874) and John von Neumann's and Oskar Morgentern's Game theory (1944). Is it possible and appropriate to reach a Nash equilibrium when the goal is to protect a natural resource, as coral reef?

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 (Dixon et al., 1994). Protection and conservation of coral reefs to add to their resiliency and protection of biodiversity is of primary importance to both the local, regional and national authorities as well as to humankind.

Some papers have studied the strategies including uncertainty in the exploitation of a common-property resource (Antoniadou et al., 2007 or Fesselmeyer and Santugini, 2011 or Long, 2011). Our paper focuses on one particular common property: coral reefs.

To give guidelines for policy makers for decision making at local/regional/global levels, we propose a simple construct as to what is at issue and as to costs (loss of revenue) involved, where we model threats to the reefs and examine it at each stakeholder level.

Material and Methods

Enumerating Threats to Coral Reef Resiliencies

Damages from different sources have already destroyed one-quarter of coral reefs worldwide (ICRI, 1995) and 60 percent may be under threats to disappear by 2050 (CRTF, 2000). The threats come from several sources. There are natural threats, such as disease outbreaks (NMFS, 2001) and hurricanes and cyclones (Barnes and Hugues, 1999). There are also human-generated anthropogenic threats, such as destructive fishing practices (cyanide fishing, blast fishing, bottom-trawling, …), overfishing (with indirect effects through the food chain and direct effects on the fished species), careless tourism (diving, snorkelling, waste sewage, dropped anchors…), 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) and ozone depletion (increased intensity and nature of ultraviolet radiation).

Figure 1 below reports a 1998 estimate of coral reef areas in different regions in the world and the associated degrees of destruction risk. The estimated risks differ from 41% (Pacific) to 82% (Southeast Asia).

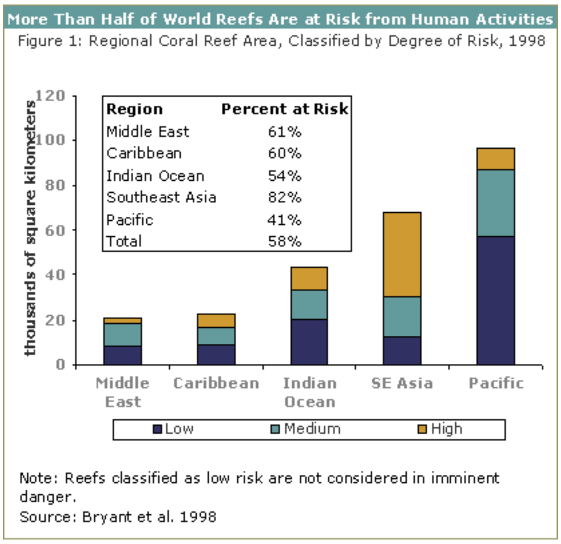

FIGURE 1: Regional coral reef area, classified by degree of risk, 1988

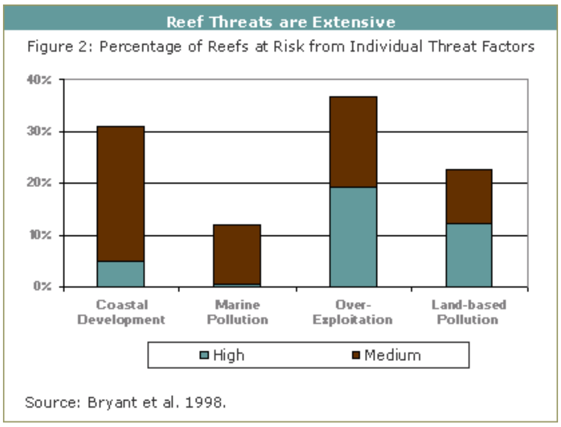

FIGURE 2: Percentage of reefs at risk from individual threat factors

Figure 2 above gives an estimate of sources of threats for the reefs. According to World Resource Institute which published "Coral Reefs: Assessing the threats", that for 1998,

"Significant regional differences exist regarding the degree of risk that coral reefs face. The reefs of Southeast Asia, which are the most species-diverse in the world, are also the most threatened, with more than 80 percent at risk, including 55 percent at high or very high risk. On the other hand, the reefs in the Pacific region, which contains more reef area than any other region, face comparatively less risk. Forty-one percent of Pacific reefs were classified as threatened, and just 10 percent face a high risk. This ongoing assessment suggests that overexploitation (overfishing and destructive fishing practices) and coastal development pose the greatest potential threat to reefs, with each of these threats affecting about one third of all reefs (Bryant et al. 1998:6)".

In the meantime, renewal efforts for coral reefs have paid off. Jenkins (2010) reports about successful coral nursery farms off the coast of Florida by Florida Keys which have been successful in propagating multiple genotypes of corals in 30 feet down underwater nurseries.

Stakeholders for Coral Reef Survival

The stakeholders who are going to suffer from the destruction of reefs are at several levels of congregation. These are

1. Global community: Coral reefs are 'human and world heritage' resources. They are also the habitat of marine biodiversity.
2. Tourism and related industry communities: Tourism agencies, hotels, restaurants are important to regions. Regional and national authorities are impacted by adverse changes in these industries.
3. National Governments: Government revenue and employment consequences are of important macro outcomes.
4. Fishing and food industry and consumers: Fisheries, canning, freezing, food export industry, consumer access to marine based food are important to producers, households, their incomes and their diets.

The sources of threats for reefs are well documented and can be grouped under four main headings. These are from carbon dioxide emissions-ocean acidification, overuse due to tourism or human usage (including pollution), overfishing by destroying present and future marine life and reefs and algae that attacks the reefs. We can postulate about coral reef stakeholders and the impending threats by constructing a revenue loss matrix. The underlying assumptions about this matrix are that the stakeholders are optimizing over a single period time frame and that since coral reefs are now a renewable resource ever since successful underwater coral farming has started (Jenkins, 2010), we can get region-specific prevention or replacement costs in the future. Table 1 below reports such a matrix where arbitrary symbols are used for potential revenue losses.

STAKEHOLDERS ON REEF SURVIVAL AND RELATED REVENUES	CO2	TOURISTS	OVERFISHIN	ALGAE
GLOBAL	A	B	C	D
NAT/LOCAL TOURISM INDUSTRY	E	F	G	H
NATIONAL REVENUE	I	J	K	L
FISHING AND FOOD INDUSTRY	M	N	O	Q

TABLE 1: REVENUE LOSS MATRIX OF THREATS VERSUS STAKEHOLDERS THREATS

Suppose we assign V, damages, to be suffered in lost revenue from each of the threats by assessments and forecasts, where V≤ 0.

The loss in values (V) for each stakeholder unit may be different. For example, the loss in values to **global** stakeholders from tourism (cell B, V(B)) and fishing (cell C, V(C)) are not as important as the CO2 (cell A (V(A)) and algae growth (cell D, V(D)). This would not be true for **local** stakeholders. Note also that while algae, and physical destructions are observable to local authorities, long term CO2 destruction may not be visible in the same time frame. Therefore, V(A) may be minimum to the local, regional and national policy makers. We may, depending on the region, we may find V(A)=V(D)=V(I)=V(E)=V(M) and that V(F), V(N). V(O), V(Q), V(J), V(K) to be the highest in this matrix to local policy makers. The size and relative importance of these losses to GDP will depend on the region and the time (besides the intrinsic loss of a beautiful natural resource). For policy makers in a nation, Tourism and Fishing/Food industry values may be the most important.

Results: Assessing Damages with Uncertainty

In this section, we model a one-period revenue matrix with uncertainty. We find assign probabilities to the 4 threats for a particular region as explained below:

P (O)= probability of carbon dioxide damage to reefs (therefore, (1-P(0)) is the probability that the reef will be resilient

P(AL)= probability of algae damage to reefs

P(T)= probability of unsustainable tourist and consumer use that damage the reef

P(F)= probability of fishing related damage to the reef

Then, if Z values are the enumeration of **expected** losses (L) per stakeholder or per threat, we get

GLOBAL: EXPECTED LOSSES: L(G)= (A)(P(O)) +(B)(P(T))+(C)(P(F)) +(D)(P(AL)) = Z1

NAT/LOCAL/TOURISM INDUSTRY=EXPECTED LOSSES=L(NLT)= (E)(P(O)) +(F)(P(T))+(G)(P(F)) + (H)(P(AL)) = Z2

NATIONAL REVENUE: EXPECTED LOSS=L(NR)= (I)(P(O)) +(J)(P(T))+(K(P(F)) +(L)(P(AL))= Z3

FISHING, FOOD INDUSTRIES: EXPECTED LOSS=L(F)= (M)(P(O)) +(N)(P(T))+(O(P(F))+ (Q)(P(AL))= Z4

Expected losses per each source of threat can also be (values of Z5-Z9)

CO2: EXPECTED LOSSES; L(CO2)=(P(O))(A + E +I +M) = Z5

UNSUSTAINABLE TOURIST/HUMAN RELATED DAMAGE: EXPECTED LOSSES; L(UT)=(P(T))(B +F+J +N)= Z6

OVERFISHING: EXPECTED LOSSES; L(OF)=(P(F))(G +E+K +O)=Z7

ALGAE: EXPECTED LOSSES; L(AL)=(P(AL))(D)+H+L)+Q)=Z8

The sum of row and column sums will equal each other, that is,

Z1+Z2+Z3+Z4= Z5+Z6+Z7+Z8

Discussion: Policy Decisions on Coral Reefs

What should the policy makers do? There are many decision methods. Let us examine two feasible options:

1. Minimize the maximum loss in the matrix by directing policies aimed at preventing the damage in a particular **cell**.
2. Minimize the maximum loss in the matrix by directing policies aimed at preventing the damage in a particular **row** (stakeholder) or particular **column** (threat).

We can show some options by giving a specific numerical example for a particular reef n a region. Suppose we are given the following probabilities for threats:

P (O)=10%
P(AL)=20%
P(T)= 50%
P(F)= 40%

Suppose we are also given estimates , in currency, of potential damages of revenue to the region when the reefs lose their resiliency. Such a set of numbers are given in table 2 below.

STAKEHOLDERS ON REEF REVENUE	CO2	TOURISTS	OVERFISHING	ALGAE
GLOBAL	-10	-10	-10	-10
NAT/LOCAL TOURISM INDUSTRY	-5	0	-30	-60
NATIONAL REVENUE	0	-100	-20	-20
FISHING AND FOOD INDUSTRY	0	-10	-30	-30

TABLE 2: ESTIMATES OF REVENUE LOSS MATRIX FOR STAKEHOLDERS IN A PARTICULAR CURRENCY THREATS

We can then construct the expected payoff matrix per stakeholders by estimating the Z values, by using the information in currency loses and the probability they will happen. Below are the construction of Z values per stakeholder.

GLOBAL: EXPECTED LOSSES: L(G) = (-10) (0.10)) + (-10) (0.50) + (-10) (0.40) + (-10) (0.20) = Z1= -1-5-4-2= **-12**

NAT/LOCAL/TOURISM INDUSTRY=EXPECTED LOSSES = L(NLT) = (-5) (0.10)) + (-30) (0.4) + (-60) (0.2) = Z2 = -0.5 -12 -12 =**-24.5**

NATIONAL REVENUE: EXPECTED LOSS=L(NR)= (0) (0.10)) + (-100) (0.5) + (-20 (0.4) + (-20) (0.2) = Z3 = -50-8-4= **-62**

FISHING, FOOD INDUSTRIES: EXPECTED LOSS=L(F) = (-0) (0.10) + (-10) (0.5) + (-30(0.4) + (-30)(0.2)= Z4= -5-12—6=**-23**

MATRIX TOTAL: -121.5

Same calculations can be also made per threats to resiliency:

CO2: EXPECTED LOSSES; L(CO2) = (-0.10) (-15) = Z5= **-1.5**

UNSUSTAINABLE HUMAN USE: EXPECTED LOSSES; L(UT)=(0.5)(-120)= Z6= **-60**

OVERFISHING: EXPECTED LOSSES; L(OF) = (0.4)) (-90) = Z7 = **-36**

ALGAE: EXPECTED LOSSES; L(AL) = (0.20) (-120) = Z8 = **-24**

MATRIX TOTAL= -121.5

We can show the results in Table 3 below:

STAKEHOLDERS ON REEF REVENUE	CO2	TOURISTS	OVERFISHING	ALGAE	**Total Stakeholder Damages**
GLOBAL	-1	-5	-4	-2	**-12**
NAT/LOCAL TOURISM INDUSTRY	-0.5	0	-12	-12	**-34.5**
NATIONAL REVENUE	0	-50	-8	-4	**-62**
FISHING AND FOOD INDUSTRY	0	-5	-12	-6	**-23**
Total Threat Damages	**-1.5**	**-60**	**-36**	**-24**	**-121.5**

TABLE 3: EXPECTED LOST REVENUE MATRIX OF THREATS VERSUS STAKEHOLDERS THREATS

Once the policy holders get an estimate of Table 3, one can set strategies to minimize the maximum losses. In this particular example, maximum damages are by unsustainable tourism and human use (-60) and by overfishing (-36).

One should note that the coral reef game is one played against nature. Having dynamic, sequential games that extend the game over longer time periods is one that the policy makers will need to make long run decisions. However, there is much to be said for a simple expected loss matrix such as Table 3 above to get the policies prioritized in the short run.

Different strategies for increasing the resiliency of coral

The International Coral Reef Initiative has recognized the necessity to protect reefs through integrated coastal management (ICRI, 1995). Governments and communities began to protect and restore the reefs through planning, management, education, law enforcement and legal protection. The objective is to protect the reefs from the different stressors, to conserve end to maintain the existing coral reefs and to restore the reefs resilience and create reefs farms to replace the died corals. Marine protected areas can help to reach effectively those objectives by putting in place management strategies.

There are national marine sanctuaries, parks and wildlife refuges with coral reefs. Integrated coastal management is very important to develop Marine Protected Areas (MPAs) (Towfighi, 1994). The management strategies should be focused on the control of harvesting activities, the recreational use of the reefs (Marion and Rogers, 1994), water pollution and coastal development. Resource restoration is possible thanks to (often very costly) programs improving water quality, restore depleted fish and shellfish and repair coral damages. Monitoring is very important to implement the right strategy in the right place and at the right moment (Rogers et al., 1994).

Natural resource management concerns both people and natural resources management. Conley and Moote (2003) propose to evaluate the collaborative natural resource management that are incorporated into policies. Coral reefs are considered as a common property and their management is peculiar: it is a community-based natural resource management. The implication of local communities with their cultural norms, local history and political expedience is one of the keys of management success (Argrawal and Gibson, 1999). Community natural resource management enables biological conservation and socio-economic development (Kellert et al., 2000).

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