Carrying Capacity of Coral Reefs

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Introduction

When we begin to talk of coral reefs, several things spring to the mind forthwith. One is the high biological productivity, highest among all tropical marine ecosystems, they sustain, the second is the largest biological diversity associated with them, the third is the richness of their inorganic (coral blocks, debris, sands, ornamental corals, molluscan shells) and organic (food fishes, aquarium fishes, marine algae) resources, the fourth is the biomedical prospects the reef dwellers hold, the fifth is the aesthetic value of the reefs and the tourism potential, and so on. At the same time we also become conscious of the need to manage the reefs in a sensible way if we are to draw benefits from their resources over a long term. The distinction is obvious: no reef resource can be brought under total protection, especially when the local population depends on them for sustenance. The next best alternative is 'have your cake and eat it too' - adopt a sustainable use policy, be it for extractive (e.g. fishing) or invasive but non-extractive (tourism) uses.

This brings us to the concept of carrying capacity of the reef. In a sense it is analogous to what constitutes the biological and environmental (including fishing effort) factors that go into an assessment of the sustainable yield of a commercially exploited fishery. Such parameters with a reef, however, are vastly diverse - size, location, species diversity, productivity, type of extractive activities (fishing, mining, dredging), onshore developmental activities (that lead to industrial and sewage pollution), susceptibility to natural disasters, interactions with adjacent ecosystems (e.g. coral reefs and mangroves), current level of tourism and future prospects of it, and a host of others including as test sites for nuclear explosions. This presents us with a wide choice of parameters to assess the carrying capacity of a reef and monitor it.

I may define the carrying capacity of a reef as its ability to support a range of extractive and invasive uses without perceptible changes and/or degradation of its biological productivity and species diversity over a reasonable period of time. I wish to emphasize here that this definition is not restrictive to tourism-related activities but is intended to cover all those activities (e.g. waste assimilation capacity) which have a potential for expansion and exceed the reefs' ability to cope up with these. The time parameter, naturally, is subjective but not the 'perceptible changes'. Enough literature exists as such to enable us to recognize them and the indices with which we can do that.

My aim is here to summarize these indices and provoke, in doing so, an useful discussion. Easily said than done as the diversity of such indices become obvious as we progress.

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Indices of productivity:

Environmental and biotic changes can both decrease and increase the productivity. Changes in both directions can be easily assessed from a diel oxygen balance (which measures the reef community metabolism as a whole and hence is ideal for situations with a range of auto- and heterotrophs as in a reef). Decrease in P/R (production/ respiration) ratio or a shift to negativity in it would suggest a degradation of the community. P/R ratios may also vary seasonally, if the reefs experience unfavourable conditions during a part of the year. These effects, however, could easily be removed from interannual variations in P/R ratios by time-averaged ratios or by restricting the measurements to specific periods of an year.

As an ecosystem tends to be in a steady state increase in the productivity also is a cause for concern and it is very often as a result of eutrophication. As the reefs are ecologically tuned to survive in low-nutrient waters by efficiently recycling the nutrients within the ecosystem, the effects of eutrophication manifest in a dramatic increase of benthic macroalgal production. This does not augur well for the reef since the proliferation of the algae is often at the expense of corals (competition for space and light). While appearing to benefit the reef initially this will, in the long run, transform a coral reef to an algal ridge with attendant reduction in biodiversity and change in trophic structure. Indices of eutrophication - inorganic nutrients, among which nitrogenous nutrients are the most important, and the organic matter load - are easy to recognize and measure in the field.

Indices of pollution

While at eutrophication we may also dwell with pollution of other sorts, since it is conceivable that developmental activities lead to both. The latter come in the form of oil, heavy metals, thermal effluents and high suspended inorganic load, among others. While all of these may affect a reef gradually and chronically, the very fact that these occur in reefs close to sites of onshore and coastal developmental activities and hence subjected to EIA monitoring regulations (in most of the countries), would render it easy to keep track of them. The indices that we may have to watch out for are heavy metals that may be accumulate in reef biota, petroleum hydrocarbons, and suspended solids that may reduce light penetration and smother the corals.

Indices of biodiversity

The diversity of the reefs is greatest of all the marine ecosystems and it would be practically impossible to monitor the whole or even part of it all the time. Instead changes in abundance and zonation of corals can be better indices of the changes in the carrying capacity of the reef. This also brings us to the usefulness of indicators species. They fall into two categories: environment-type indicators and environment-change indicators. The latter,

of more pertinence to us, can be grouped into indicators of component (communities), structural (functional relationships) and process (rate, direction) changes.

Though none is known with any certainty, several of the reef dwellers, because of their stenotypic nature and specificity to reefs hold a potential as indicator species of carrying capacity.

Indices of harvest practices

Besides the effects of overharvesting, as with any marine resource, harmful harvest practices also tend to affect markedly the carrying capacity of a reef. Such practices are collection of ornamental corals and shell, dynamite fishing, poison fishing, mining and dredging. Destructive fishing methods cause irreversible damages to the carrying capacity of the reef and need to be totally discouraged. As far as overharvesting is concerned, it can be regulated by application of fishery yield models (as is available for the red coral fishery), quotas, closure seasons, and rotation of the zones. Again, the response of the carrying capacity may not be the same with respect to overharvest of organic and inorganic resources: restoration of it may be rapid in the case with organic than inorganic resources. For example, the Gulf of Kachchh (India) reefs which lost more than 50% of the reef cover and biota following commercial dredging of coral sands, are yet to return to 'normalcy' even 20 years after the extraction of coral sands has been discontinued.

This also brings us to the question of whether the carrying capacity will be affected even at level of unorganized harvest of resources. It is quite possible. For example, in the Lakshadweep islands, until recently, the coral blocks served as building materials. With the increase in construction of individual houses, the damage to the reefs and the shoreline as a result of mining became substantial. This could not be stopped for the simple reason that the management practices did not foresee provision of alternate building materials at affordable costs. The lesson is that enhancement of carrying capacity, at least in third world countries, will succeed only when the dependence of the local population on reef resources is alleviated in a manner economically satisfactory to them.

Indices of interactions with adjacent ecosystems

Coral reefs occur quite often in association with other ecosystems, especially the mangroves, and the changes in the latter often entrain damaging effects on coral reefs. For example, in the Gulf of Kachchh, the extensive deforestation of mangroves has led to an increased flux of coastal sediments onto the fringing reefs, so much so that almost every reef in this area lies partly covered with mud. In fact, this is probably a major cause for the reduction in the abundance of corals on the reefs. In this instance, the impairment to the carrying capacity of the reef cannot be remedied without remedying the situation in the mangroves.

Indices of tourism

Tourism is increasingly being advocated as a means of increasing the economic returns from the use of the reefs with minimal damages. However, in several reef areas the carrying capacity has been exceeded by the tourist activities, especially at sites which are very popular with easy access. Though the major impact is predicted to be generally on the reef biota, the fallout of tourism will cover all factors that might otherwise strain the carrying capacity of the reefs: these will include constructional activities on or near the reefs, boat traffic and oil spills, pollution with sewage and non-degrading material (plastic bags, soft drink cans), abandoned or lost diving and reef-walking accessories and so on.

For many third world countries tourism to reefs is a novel and lucrative way of earning money and is likely, in the process, to be oversold. It would prove to be a sensible idea if the management action plans for reef areas are mandated to include projected growth of tourism to reefs and contain it within the estimated carrying capacity of the reef.

Conclusion

Adjusting the diverse reef-related activities to confine within the limits of the carrying capacity of a given reef or a reef region will necessitate a knowledge of the activities the reef is (and expected to be) subjected to and the intensity of the likely impacts. A use and impact chart, as the one prepared for the Gulf of Kachchh reefs (annex), may prove to be useful in summarizing and quantifying them. This is only a part of the game. It would not be a healthy practice to recognize that the carrying capacity has been exceeded only when it indeed occurs. Instead it would be more sensible and practical if the entire concept of the carrying capacity, as I have defined, is brought under a model form: then it would be possible to recognize the trends and contain the activities on the reefs long before they reach the limits of the carrying capacity. Ecosystem modelling is not a new concept - basic models and EIA models exist: adopting them to the specific needs of defining and setting the limits of carrying capacity of the reefs and managing them would be rewarding in the long run.

Use and impact chart for the Gulf of Kachchh coral reefs

Use category	Existent or not	Level of use	Nature of damages
A. Living resources			
1. Commercial fishing within reef areas	NE		
2. Commercial fishing in offshore waters	yes	high	Sustainable catch
3. Subsistence fishing in reef areas	yes	moderate	Habitat destruction
4 . Recreational fishing	N.E.		
5. Commercial coral collection	Yes	Was high. Presently controlled	Live coral cover loss. Habitat destruction. Increase in sediment load leading to further coral mortality.
6. Commercial shell collection	Yes	Was high for pearl oysters. Presently at low level for other pecies.	Overexploitation and failure of pearl oyster fishery. For others, no perceptible damage
7. Aquarium fish collection	N.E.		
8. Aquaculture	N.E.		
9. Turtle hunting	Yes	Modest	Damage to recruitment
10. Bird hunting	Yes		
11. Plant harvesting-terrestrial	Yes	High	Severe erosion of shore-line and transfer of silt and clay into the coastal waters.
12. Plant harvesting-marine	Yes	Modest	
13. Other resources	N.E.		
14. Destructive fishing methods	N.E.		
B. Non-living resources	N.E.		
1. Oil and gas mining			
2. Limestone mining	Yes	High	Habitat destruction
3. Extraction of construction material	Yes	Moderate to high	Habitat destruction
4. Other minerals	N.E.		

Use category	Existent or not	Level of use	Nature of damages
C. Developmental activities			
1. Discharge of effluents	Yes	Low to moderate	Pollution
2. Onshore mining	N.E.		
3. Dams/river flow modifications	Yes	Tidal power plant proposed	Might affect circulation pattern and the coral reefs
4. Harbor/navigational works (dredging, blasting, filling etc.)	Yes	High	Erosion, topography changes, pollution, habitat destruction
5. Domestic sewage	Yes	Less	Localized algal growth
6. Industrial sewage	N.E.		
7. Reclamation	Yes	Less	No visible damage
8. Solid waste dumping	Yes	Less	Dumping of dredged material can kill corals
9. Research and development	Yes		Encouraging Formul-ations of measures for conservation
10. Offshore navigation and oil spills	Yes		Occasional mortalities of corals
D. Non-extractive uses			
1. Resident tourism	Yes	Modest	Visible damage (Ex. Pirotan is.)
2. Sea-borne tourism	N.E.		
3. Air-borne tourism	N.E.		
4. Water sports (SCUBA, snorkeling etc.)	N.E.		
5. Reef walking	N.E.		
6. Constructional activities related to tourism	Yes	Modest	No visible damage