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Viewpoint

Management of coral reefs: We have gone wrong when neglecting active reef restoration

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ABSTRACT

The current best management tools employed in coral reefs worldwide do not achieve conservation objectives as coral reefs continue to degrade. Even improved reef management helps, at best, to reduce the degradation pace, whereas the worsening global changes foretell a dismal fate for coral reefs. The assertion made here is that the prospect for reefs' future is centered on omnipresent acceptance of restoration, an 'active' management instrument. A recent promising such tool is the 'gardening concept', influenced by the well-established scientific discipline of terrestrial forestation. This notion is supported by a two-step protocol. The first step entails rearing coral "seedlings", in specially designed underwater nurseries, to transplantable size, before applying the second step, out-planting into damaged areas of the nursery-farmed coral colonies. Only the establishment of large-scale nurseries and transplantation actions, together with conventional management tools, will be able to cope with extensive reef degradation on the global scale.

1. Conservation management of coral reefs – the 'passive' approach

Coral reefs provide vital sustenance to hundreds of million of people worldwide. When continuously degraded, coral reefs lose original biological and ecological properties, in many instances, without any prospects of recovery. In view of global changes, it has been predicted that some coral reefs would undergo phase shift rather than disappear completely (Bruno and Selig, 2007; Hughes et al., 2003). The ominous consequences of the continuous global reef deterioration have attracted increasing attention from scientists, NGOs, the public and officials, further raising awareness of the urgency in promoting an array of environmental management measures. Regrettably, environmental management that should have reflected the work of professionals, more often than not reflects ulterior and political compromises based on non-scientific practices (Sale, 2008). The notion for marine environment conservation, although above dispute for its moral, aesthetic, cultural, economic, and other inherent values (Owens, 2008), is based on other than science-driven decisions, with less than effective mitigating success.

Coral reefs, while boast exceptional species diversity, are poorly protected, highly degraded, and exposed to multiple persisting threats (Bruno and Selig, 2007; Shafir and Rinkevich, 2008). However, apart from being less meticulously defined, there is nothing distinctive about coral reef conservation, ragarding rationale and needs, compared with terrestrial conservation. This argument is founded on the assertion that coral reefs are often portrayed as "the rain forest of the sea" (Connell, 1978) due to both ecosystems' high primary productivity, high biodiversity, and above all, the functions of corals/trees as the building blocks of ecosystem frameworks. Additionally, both organisms are common ecological-engineering 3-D structures, harboring numerous inhabitants, defining local biological and environmental conditions (Connell, 1978; Goreau et al., 1979; Epstein and Rinkevich, 2001; Epstein et al., 2003; Shafir and Rinkevich, 2008). However, apart of the above commonly accepted claim, the coral reefs have gained very little from the rich literature, rationales, debates and protocols associated with management of corresponding terrestrial ecosystems.

Coral reefs are of major importance to human livelihood and deserve special consideration. While covering less than 1% of the oceanic area (Hughes et al., 2003), they support almost one third of the world's marine fish species (Newton et al., 2007), providing around 10% of the total fish consumed by humans (Pauly et al., 2002). They have become a major focus for the tourism industry (i.e., Ahmed et al., 2007). Despite all conservation management measures implemented, the coral reefs annual decline had reached about 1% before 1997, and this increased to 2% between 1997 and 2003 (Bruno and Selig, 2007). As stated (Sale, 2008), the major coral reef management measure focused upon and practiced by NGOs, conservationists, scientists, managers and decision making authorities, has been the tool of marine protected areas (MPA) with associated measures (increasing MPA number, adaptive legislation, various

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enforcement acts, involvement of stakeholders, reducing exploitation of reef resources, etc.). This instrument treated most urgent management issues, particularly evident in developing countries (Roberts et al., 2001). I would define all above measures associated with the notion of MPA as 'passive' management tools. However, it is difficult to give too much credence to these 'passive' management tools, because, despite all the attempts and measures implemented, reef ecosystem services and resources keep disappearing alarmingly quickly. Considering the anticipated scale of global impacts on coral reefs, I would claim that without equally embracing 'active' management tools (Rinkevich, 2005a), the currently applied tools will not achieve the desired goals.

2. MPA- a great idea a with limited success

The boom in the MPA number and total area protected under MPA legislation is not exclusively confined to marine ecosystems. The 1990 total number of worldwide protected areas (6,931) quadrupled within just a decade to 28,442, whereas the total area protected within the protected areas' boundaries increased from 803 to 1115 million hectares (World Resources Institute, 2005). Ironically, efforts to establish many of these protected areas exacerbated the threats to 'protected' biodiversity that they aimed to alleviate (Wittemyer et al., 2008). Furthermore, despite the popularity of MPA as a management tool, increasing evidence shows that many fail to achieve conservation objectives (Parnell et al., 2005). Concerning coral reef management, it is regrettable that the large number of MPA set-aside was not effective even though, in many cases, tough management practices were implemented (De-Silva, 1997; McClanahan, 1999; Risk, 1999; Jameson et al., 2002; Epstein et al., 2005; Rinkevich, 2005b; Coelho and Manfrino, 2007). In other situations, MPAs failed to proceed from the declaration status to a valuable implementation stage (Sale, 2008), they did not reflect understanding of the risks and uncertainties involved, and suffered from confusion over their goals and purposes (Rinkevich, 2005b).

Scientists, in various instances, use concepts and theories developed for design and application of terrestrial protected areas (TPA) without paying heed to the major differences between MPAs and TPAs in nature, the reserve objectives, or the state of knowledge, reserve criteria, size, and location (Agardy, 2000; Carr et al., 2003). At present, management of many MPAs is carried out without adequate consideration for ecology, socioeconomic realities, or long-term management sustainability. Unlike their terrestrial counterparts, the relatively large 'openness' of marine ecosystems, populations, and communities, should influence the practices used, a factor not always considered in practice. However, even unique designs, criteria and applications specifically tailored for MPAs do not guarantee long-term effective outcomes (Parnell et al., 2005; Rinkevich, 2005b; Coelho and Manfrino, 2007).

Regardless of the answers to the debate about the effectiveness of MPAs, and the lack of guarantees for implementing and enforcing existing regulations (all discussed in Sale, 2008), I would like to focus on the way management of existing protected areas is performed; i.e., the lack of 'active' management tools (Rinkevich, 2005a). Managers, in the vast majority of MPA sites, have focused on new legislation and on protected areas, or on enforcement of existing legislation rather than on active management (implementing active rehabilitation instruments). I do not contend that rehabilitation and restoration instruments are necessarily superior to traditional 'passive' management tools. However, not employing a variety of restoration measures limits the success of MPA. Reef restoration activities are imperative where habitats are degraded and fragmented, the current situation in so many coral reefs. In other words, efforts should be concentrated both on how to conserve what is left (Young, 2000) as well as on active efforts in how to restore reef resources. In particular, restoration acts should partially replace the suite of 'passive' measures used to protect MPA.

3. Reef restoration - the 'active' approach

While restoration ecology promotes the concept of active measures, conservation biology usually highlights 'passive' measures, based on the rationale that natural processes should allow to mitigate impacts without or with minimal human surrogate (Epstein et al., 2003). The terms 'conservation' and 'restoration' used here (as in many other scientific communications) describe efforts to 'preserve' the original habitats or to 'replace equivalent' lost habitats or destroyed populations, respectively. Thus, restoration ecology is an active instrument, implying that at least some proportion of habitat goods and services are recoverable through anthropogenic manipulations.

Heeding the invaluable lessons gathered from the failures of traditional conservation, Hobbs and Harris (2001) predicted that restoration ecology would eventually become the dominant discipline in environmental science in the 21st century. This is not a simple task since technical approaches have already progressed faster than the conceptual science behind it (van Diggelen et al., 2001; see also Rinkevich, 2005a).

Restoration ecology is rooted in forestation. While conservation biology is considerably biased towards zoological features (by nearly 3 to 1 in manuscripts published), restoration ecology, is biased towards botanical issues (by more than 4 to 1; Young, 2000). It is therefore not surprising that silviculture principles, concepts and theories, are increasingly considered and applied to coral reef restoration (Epstein et al., 2003; Rinkevich, 1995, 2005a, 2006; Edwards and Gomez, 2007). I claim that 'silviculture' of denuded and declining coral reefs sites, when developed to a well established discipline, will serve as the most efficient way to perform long-lasting reef restoration, either on small or large-scales. It can be executed as a large-scale operation, financed by international bodies (i.e., the World Bank), or carried out as a small-scale operation by local communities. Achieving optimality would require more scientific work, but recent results on reef restoration (Shafir et al., 2006a,b; Shafir and Rinkevich, 2008; still at the experimental stage) have been more than promising.

Most forests (>90%) in the temperate zones, particularly in the northern hemisphere, are artificial. Can we, or should we, achieve the same state-of-the-art in reef management? Can reef restoration acts mirror those of silviculture?

4. Reef 'silviculture'

More than a decade ago, the well-established scientific field of terrestrial forestation (silviculture) led Rinkevich (1995) to propose a new coral reef restoration concept, deriving its rationale from silviculture. This notion, termed as "gardening the coral reef concept", is based on a two-steps protocol. The first step entails rearing coral "seedlings", in specially designed nurseries, to plantable size before applying the second step, rehabilitation (by active transplantation) of damaged area with the nursery-farmed coral colonies. Results (Shafir et al., 2006a,b; Amar and Rinkevich, 2007; Forsman et al., 2006; Shafir and Rinkevich, 2008; Shaish et al., 2008; unpublished; Fig. 1) revealed that this approach is highly promising. The nursery step of the "gardening concept" (Fig. 1) has been drawing the most scientific investigation, and its conceptual and technical issues have already been addressed in details, in several localities worldwide (Eilat- Red Sea, Phuket Island–Thailand, Singapore, Bolinao- the Philippines, Tanzania–Zan-

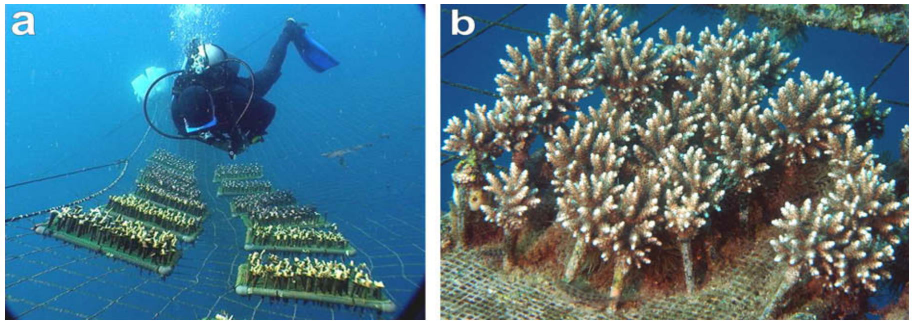

Fig. 1. A prototype coral nursery in Eilat (Red Sea). (a) A mid-water floating coral nursery (14 m above substrate , 6 m depth) one week after establishment and coral fragments insertion within culturing trays. Each coral fragment (about 2-3 cm length) is glued onto a small plastic pin. (b) A tray with *Acropora valida* fragments one year thereafter. Large and healthy coral colonies (survivorship about 90%) amenable for outplanting. (Shafir et al., 2006a, b; Photographs: (a)- *D. Gada*, (b)- *S. Shafir*).

zibar and Mafia Island, Jamaica; most results are yet unpublished). Issues like nursery structure, its initial set-up, shape and construction, nursery location, maintenance subjects, coral species cultured (types, numbers) and genotypic considerations, spacing of farmed coral colonies, realistic number of generated and farmed colonies, duration of nursery phase, growth rates, longevity of farmed colonies, pest control and economic considerations, are only some of the issues studied recently. The second phase of transplantation, which is still in its infancy, is discussed below. Cumulatively, results from different reefs worldwide revealed that the gardening tenet, with further modifications and adjustments to local site conditions, could be used as a ubiquitous supplementary management instrument to rescue reefs from the on-going impacts of human activities.

The two dominant critical arguments against implementing active restoration with nursery-reared corals in coral reef management are the 'scale' and 'cost' issues (i.e., Edwards and Gomez, 2007). Truly, there is yet no major coral restoration act that comes close to terrestrial restoration figures, as all rehabilitation projects are less than a decade old and still at experimental stages, not exceeding ten thousands corals per project, whereas silviculture has been undergoing worldwide rigorous scientific evaluations for about two centuries (literature cited in Brockerhoff et al., 2008). Several 'cost' evaluations have been discussed recently (Shafir and Rinkevich, 2008) and while they will not be reiterated here, results clearly support the assessment (see also Rinkevich 2005a, 2006) that active reef restoration is economically feasible and the cost of a nursery-farmed coral colony is competitive and compatible with a nursery grown tree. We also found that mid-water nursery fixed costs are relatively small compared to the costs of terrestrial nurseries (Shafir and Rinkevich, 2008).

The terrestrial silviculture figures are alarming. Some are listed below in order to grasp the magnitude of silviculture in comparison to reef restoration. Globally, the total area of natural and semi-natural forests that has been decreasing by almost 13-14 million ha annually, which is partly compensated by new silviculture areas of about 2–3 million ha/year (FAO, 2006; WWW, 2007). Just for comparison, coral reefs are declining much faster than forests, about 2%/year (Bruno and Selig, 2007); yet without any significant 'transplantation' act that could partly balance the increasing losses of habitats. On the other hand, there is a dramatic increase in MPA total area and numbers (World Resources Institute, 2005), accompanied by all types of legislative initiatives. On the global scale, total area of plantation forests exceeds 140 million ha, and in countries like UK, New Zealand, China and France, about 67.6%, 22.3%, 15.9% and 12.7% of the forests, respectively, are man-made (reviewed in Brockerhoff et al., 2008). A similar figure can be extrapolated to the loss and restoration of mangrove forests. About 4 million ha of mangrove forests had declined during 1980 to 1990, representing an annual loss of about 2%. It was reduced to 1% year^{-1} between 1990 and 2000 with improved legislation and management acts. Balancing this loss of mangroves worldwide would require the net restoration of approximately 150,000 ha year^{-1} (Bosire et al., 2008). In contrast to the coral reef situation, much has been done in mangrove silviculture and restoration (reviewed in Bosire et al., 2008).

5. Conclusion

I agree completely with Sale (2008) viewpoint that reef management, as is executed, is failing. I also acknowledge the importance of the recommendations raised (Sale, 2008). However, even without considering the further global change, all enforced legislation, education, stakeholders' intimate involvement in traditional management acts, and all other good recommendations, will not prevent coral reefs from deteriorating at the same or similar path as at present. It is imperative to revise substantially current management protocols and rationales and to include active reef restoration as an integral part of routine management.

It is beyond dispute that socio-economic drivers are behind successful terrestrial silviculture, and attempts are made to mimic this in mangrove silviculture. Widespread forest degradation, economic needs and evaluations, coupled with the increasing awareness of the importance of forests have spurred attempts to restore forests with high success and return. Natural forests are usually more diverse than plantation forests (Brockerhoff et al., 2008) but there is abundant evidence that plantation forests contribute to biodiversity conservation by various mechanisms, providing valuable habitats, even for threatened and endangered species. As the coral reef arena is free of the ecological burden imposed on forests (where main objective is often the production of timber or fuel wood), more ecological considerations should assist in improving 'planted reefs' compared to 'planted forests'.

When further developed, reef restoration measures will certainly incorporate economic considerations. There are also plans (but no funds) to build large-scale coral nurseries, because so far, restoration has been carried out only on scales of tens of square meters to several hectares (Edwards and Gomez, 2007). Only large-scale nurseries and transplantation will be able to help counter extensive reef degradation at the scale of several square kilometers and more, similar to the successful way it is done in terrestrial habitats.

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