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How can we restore marine ecosystems? Perspectives and tips from global experts

Marine ecosystem restoration – such as reconstructing saltmarshes that have been lost to human development, replanting coastal mangrove forests that have been degraded, and enhancing the structural complexity of damaged reefs – is an emerging field that seeks to move ecosystems to healthier states, often with the goal of increasing their ability to provide ecosystem services.

Marine restoration efforts can be expensive (median and average reported costs of US$80,000 and $160,000 for restoration of one hectare of marine coastal habitat with real costs likely much higher), but in most cases, the potential benefits of restoration projects are higher – often significantly higher – than the costs.

In addition, restoring marine ecosystems may sometimes be the only politically feasible means of increasing the flow of marine ecosystem services to stakeholders. A recent study of marine conservation and management of the Puget Sound estuary in the US found that estuarine restoration efforts (providing benefits such as improved flood control, recovery of salmon runs, and recreational opportunities) are able to garner broad stakeholder support while the designation of "no-take" MPAs has stalled.

For this issue of MEAM, we interviewed five global marine ecosystem restoration experts:

- Avigdor Abelson, a professor of marine biology at Tel Aviv University;
- Matthew Armstrong, a coastal engineer with Baird & Associates, a global water engineering firm;
- Stephen Crooks, a wetland scientist/geomorphologist with Silvestrum Climate Associates, LLC, a research consulting firm to address climate change challenges;
- Brian Silliman, a professor of marine conservation biology at Duke University; and
- Bregje van Wesenbeeck, a senior researcher/advisor on coastal systems and ecosystem-based adaptation with Deltares, a water and subsurface applied research institute based in the Netherlands.

We learned about a spectrum of marine ecosystem restoration projects, where the field of marine ecosystem restoration is currently, how we figure out if restoration is needed or not, how we deal with climate change when restoring marine ecosystems, and tips and best practices for thinking about and getting started with restoration projects.

MEAM: Can you briefly tell us about a few marine ecosystem restoration projects that you have worked on?

Abelson: Two restoration projects that I have been involved with recently have targeted degraded coral reefs ecosystems in the Philippines – one in Boayan Island (Palawan) and the other in Ticao Island (Bicol, Luzon)[1]. In both cases we tried to figure out the main causes for the massive degradation of the reefs, major ongoing stressors, and relevant stakeholders in the area. From this information, we selected affordable restoration tools matched to each site's larval supply, siltation/sedimentation level, reef structural complexity, and social circumstances.

Both Boayan and Ticao Islands suffered from very low fish biomass and species diversity, extremely low coral cover, and high live cover of algal turfs and macro-algae (seaweeds). In Ticao, the reef also had very low structural complexity (with vast areas of nearly flat surfaces) and high sedimentation rates. In both locations, over-fishing and destructive fishing (cyanide fishing in both areas and ongoing dynamite fishing in Ticao) and siltation and pollution due to deforestation in the watersheds were the main causes for reef degradation.

The differences between the sites were mainly related to spatial scales and governance. In Boayan, the watershed is very small, whereas in Ticao the watershed is two orders of magnitude larger than in Boayan with a large river that feeds sediment to the reef. The small reef area and local social-political circumstances enabled declaration and enforcement of a marine protected area (MPA) in Boayan, whereas in Ticao it was impossible to protect the reef.

In Boayan, it was possible to alleviate the siltation with construction of a retention pond and plantation of vetiver grass that could hold the ground. Other restoration tools were coral transplantations and construction of small artificial reefs of high structural complexity to enhance the recruitment of fish. In Ticao, due to the large watershed size, it was impossible to restore the watershed to reduce siltation, therefore we enhanced the structural complexity of the reef by building pyramid-shaped structures of local rocks over the sediment-covered flat reef.

Example of a degraded reef with low structural complexity. Photo credit: Avigdor Abelson, University of Tel Aviv.

Structural complexity enhancement of a reef. Photo credit: Avigdor Abelson, University of Tel Aviv.

Another difference between the sites is the size of the fishing community. In Ticao there are over 100 fishermen, whereas in Boayan the community is small – just a few dozen fishermen. Therefore, in Boayan some alternative livelihood could be provided via jobs as restoration assistants. In Ticao the alternative livelihood had to be much broader. It included seaweed farms, artificial reefs as alternative fishing grounds, and a manta diving project in which we developed ecotourism activities including data-based manta ray encounters.

Our results in both sites showed significant improvements of corals and fish recruitment. In Boayan we could also observe the return of large schools of herbivorous fish such as rabbitfish and parrotfish thanks to the protection. In terms of interaction with the local community and creation of alternative livelihood sources, our project in Ticao has yielded better results thanks to closer interactions with the fishermen and the community leaders. However, the long-term success of both projects largely depends on the local governments and social leaders. Both communities need the long-term education of children and increased public awareness – activities which require national and international investment and large-scale planning.

Armstrong: The Holetown Waterfront Improvement Project (HWIP) in Barbados sought to restore a degraded reef system to stabilize beaches and prevent beach erosion that threatened hotels, residences, and recreational beach areas. Baird & Associates' role extended from conceptual development to final construction and post-construction monitoring. The final construction consisted of two submerged reefs and three more traditional groins along with a section of concrete walkway to restore year-round beach access.

Folkestown Beach Restoration Project. Photo credit: Matthew Armstrong, Baird & Associates.

Building on the success of the HWIP project, Baird is currently working on a similar project in which reef restoration is a primary element of a beach stabilization and wave attenuation project. This new project has taken the reef restoration a step further by involving marine biologists and fish scientists in the design of structures to increase the colonization of the manmade structures by fish and corals. This is an encouraging step in the industry because coastal structures were historically designed with the goals of reducing waves and combating beach erosion and any benefits to marine life were secondary.

Crooks: I have worked on tidal marsh restoration projects for over 20 years as a scientist or restoration practitioner. Two completed projects that I have worked on include:

- The 450-acre Qwuloolt Estuary Restoration Project in Washington State (USA) that restored natural hydrologic processes and native vegetation to sustain salmon and other native fish, and to reconnect the Tulalip Tribes [indigenous peoples] and the public to the marsh.
- The 700-acre Hamilton Wetland Restoration Project that restored tidal wetlands on a former airfield using 7 million cubic yards of dredged material from the Port of Oakland. We developed concepts and designs for seasonal and tidal wetlands restoration, created a broad, living-levee wildlife corridor, and placed sediment to maximize ecological benefits.

Silliman: My lab is collaborating with the Elkhorn Slough National Estuarine Research Reserve (in the US) to test if harnessing mutualistic species interactions can increase success of restoring salt marshes. The effort involves renourishing multiple acres of marsh with a thick layer of sediment and then planting marsh plants. Instead of spacing the plants out – the typical process for marsh restoration – we will test if planting in clumps generates higher yields. This alternative design should allow for plants to work together in a mutualistic way to buffer against drought and wave stress, and should therefore increase their growth rates and speed the return of the marsh.

In the US state of North Carolina, we are planting seagrasses with clams to see if clams can act like fertilizer stakes to increase seagrass establishment and persistence. Clams may enhance seagrass growth because seagrasses are nutrient limited and clams increase nutrients in soils through feeding and fecal deposits. And in China and California, we are testing if predators can enhance growth of plantings by keeping grazers in check. In California, we are investigating if sea otters can control crabs that otherwise eat restored plants, while in China, we are testing to see if majestic red cranes can provide the same service. These experiments are supported by the Lenfest Ocean Program, and you can read more about them here.

van Wesenbeeck: I have mainly worked on mangrove restoration using methods to improve abiotic conditions for mangrove recruitment. These methods include restoring hydrology and construction of permeable brushwood structures to dampen waves and trap sediment to increase bed level and further reduce wave impact.

Retention pond. Photo credit: Avigdor Abelson, University of Tel Aviv.

MEAM: How would you characterize the field of marine ecosystem restoration right now?

Abelson: Marine ecosystem restoration (MER) is a developing field of applied science and is rapidly growing in importance as marine ecosystem degradation accelerates. The science of MER is lagging behind terrestrial and aquatic ecosystem restoration unfortunately. This is probably because marine ecology is a relatively new scientific field compared to terrestrial and aquatic ecology. Another likely explanation is the relatively low investment in MER by government agencies.

Some directions where MER science really needs to develop include:

- Publishing information about the success/failure cases of past projects
- Paying more attention to the social aspects of ecosystem restoration
- Increasing the development of long-term projects
- Bridging gaps between scientists and practitioners, and between restoration-focused scientists and ecologists.

A critical future role of MER is, in my opinion, to help promote adaptation of marine ecosystems to climate change related effects. At present, MER tools are not directed at counteracting or enhancing resistance to climate change related threats such as ocean warming, sea level rise, and acidification. Because climate change mitigation can take a long time to affect the Earth's climate, practices that promote adaptation should be included in MER development to improve long-term project success. At present, there are two potential directions for adaptation that are considered in the literature: the 'Predict-and-Prescribe' and the 'Portfolio' approaches. 'Predict-and-Prescribe' approaches are based on the idea that manipulating species (or genotypes) of ecosystem engineers can improve the resilience of an ecosystem to changing conditions and identifying and ensuring that there are spatial refuge sites. 'Portfolio' approaches are proposed to take into account our inability to fully understand or predict the impacts of large-scale stressors and therefore seeks to identify portfolios of genotypes and species (optimal sets of propagules) or sites (which form 'adaptation networks') that can survive various combinations of future conditions. Portfolio approaches are not widely applied yet, but in my opinion, they are applicable and can be operationalized with diverse reef sites that are in good shape despite the anthropogenic and natural stressors they have been exposed to in the past (e.g., extreme temperature and salinity fluctuations, high sedimentation rates, and eutrophication). Such reefs are expected to survive various combinations of future conditions.

Healthy reef. Photo credit: Avigdor Abelson, University of Tel Aviv.

Armstrong: Marine ecosystem restoration is in fashion. It has certainly gained traction in the past decade, which is extremely encouraging. Natural ecosystems evolved the way they did in part because it is the most efficient way to resist storms. The concept of working with nature instead of against it helps to draw on what has worked through history rather than trying to force our human ways onto a system where they are not natural. We are encouraged that both government and private sector clients are now asking for these types of designs and realizing that long-term benefits are sometimes well-worth higher upfront costs.

Crooks: Marine ecosystem restoration in the US is a massive industry involving the public and private sectors. The industry pumps hundreds of millions of dollars into the economy each year and keeps thousands of people employed. Restoration activities began in places like San Francisco Bay in the early 1970s. Back then restoration projects were small and had no or very limited success, resulting in relatively low ecological benefits. Improvements in science and restoration practice over the subsequent decades are now able to deliver landscape-scale projects, measured in thousands of acres, that incorporate a more refined understanding of ecological processes, landscape interactions, and resilience to climate change. Now the forefront of restoration planning focuses on wetland-upland transitions, preparing for sea level rise, reducing long-term flood risk through green infrastructure approaches, and accounting for carbon sequestration.

Silliman: Marine ecosystem restoration is in its infancy in many ways, especially for habitats like coral reefs, seagrasses, and kelp forests. For marshes and mangroves, the science and practice are more advanced, and we can bring back these ecosystems fairly regularly. This is often associated with huge costs, however, sometimes as much as hundreds of thousands of dollars per acre.

In terms of innovation, marine restoration is slow and has lagged behind restoration advancements in freshwater and terrestrial systems. If marine restoration is going to a viable conservation strategy, we must innovate and dramatically increase yields and lower costs. We need to look beyond restoration efforts in freshwater and terrestrial systems, however, and be inspired by a diverse suite of fields, including agriculture, genomics, and engineering.

van Wesenbeeck: There has been a lot of work done on marine ecosystem restoration, but the scientific knowledge on restoration does not always reach practitioners and grassroots organizations in the field/on the ground. As a consequence, many pointless restoration efforts that have no good ecosystem basis are happening, especially in the area of mangrove restoration, where most restoration efforts consist of single-species planting in areas that are not suitable for mangroves because they are too low in the intertidal zone or too exposed to wave impact. In additional, these areas are already home to other valuable species, such as seagrass and shellfish, and planting efforts often damage these other ecosystems.

What is (and what isn't) ecosystem restoration?

A 2015 paper by Suding et al. outlines four core principles for ecosystem restoration:

1. Restoration increases ecological integrity
2. Restoration is sustainable in the long term with as little human intervention as possible
3. Restoration is informed by the past and future (i.e., both historical states and potential future trajectories under climate change inform restoration goals)
4. Restoration benefits and engages society by increasing the provision of ecosystem services and engaging communities in restoration activities.

In most cases, mitigation, rebuilding of ecosystem services, greening, and endangered species recovery activities do not fully address all of these principles and are therefore not full ecosystem restoration activities.

MEAM: How do you suggest marine ecosystem restoration projects set baselines targets to aim for, especially in the face of climate change?

Silliman: Stakeholders need to set objectives for the project, and then we can build to maximize those goals. What I am finding now is that managers are greatly expanding their goals beyond the typical 'save native species and let's put something back that was there 200 years ago' to include objectives such as building land, protecting shorelines from sea level rise, enhancing local fisheries and tourism, and sequestering carbon. This change is very forward thinking, and means that baselines generated by looking at one point in history are just one objective being taken into consideration. The current process of setting goals for restoration is now both backward and forward thinking, and there will be both synergies and conflicts generated in that process.

Seaweed culture. Photo: Avigdor Abelson, University of Tel Aviv.

Crooks: It is important to place each project within a landscape context and understand how the landscape will evolve with climate change over coming decades and centuries. Planning for climate change is to recognize moving baselines and ongoing changes in the landscape, spatially and temporally. Not all projects will exist in their current form in the future. Some will transition from one habitat type to another over time. By planning for a target ecological and urban mosaic that will exist in the future we can factor in the evolution of the landscape and strategically plan the phasing of restoration actions.

Armstrong: Baselines are extremely important, and with climate change they are changing more rapidly than ever before. Our approach is to look at historical data to set a baseline based on the past 30+ years of real data and to account for climate change as an addition to that baseline. This explanation is very simplified as climate change affects multiple aspects of the climate. We look at historic water levels as well as water levels under diverse scenarios of rising sea level, increased storm intensity (leading to higher storm surges), and increased rainfall.

MEAM: If a degraded ecosystem has protected status, is there any way to figure out if the ecosystem will recover on its own or needs help?

Crooks: Before embarking on restoration actions to a degraded system, it is very important to understand what has caused the degradation. All over the world, millions of dollars are wasted in the drive to do something quickly rather than understand the cause of ecosystem decline. Reports of mangroves being planted six times and repeatedly failing and funders being asked for money to try again are depressingly common. Funders often want to see action and are reticent to spend money on science, or community engagement or follow-up monitoring. Nevertheless, these actions are critically important if these and future projects are going to be successful.

When assessing a project we look at the causes of a given condition and aim to develop a forward looking projection of ecosystem condition. We then assess different restoration approaches to explore whether they will lead to a different ecological outcome. Sometimes this is relatively straightforward. Sometimes there are ecological or geomorphic nonlinear feedbacks that can make projections uncertain. An example would be projecting the evolution of a large tidal wetland restoration project with high wave energy conditions and declining sediment availability. In such cases, planning should include risk-based and adaptive management approaches to planning for individual sites and for sites to be elements in the evolving landscape mosaic.

Abelson: Continuous trend monitoring is fundamental to understanding target ecosystems and sound marine ecosystem restoration. Trend monitoring can inform ecosystem managers if the protected site is recovering, degrading, or stagnating. Some monitored parameters that can serve as indicators of the ecosystem state include:

1. Natural recruitment rates of autogenic ecosystem engineer species (e.g., mangroves, reef-building corals that change the environment via their own physical structures)
2. Population size of key species (e.g., allogenic engineer species like grazing fish that change the environment by transforming living and nonliving materials from one physical state to another via mechanical or other means)
3. Species diversity.

An artificial reef for fish recruitment. Photo credit: Avigdor Abelson, University of Tel Aviv.

Generally speaking, if any of the above parameters is consistently declining (or there is no recruitment), that factor may impede the natural recovery of the ecosystem and it has to be addressed before the restoration implementation. In contrast, if the parameters are improving, restoration intervention is not required unless the recovery process is very slow. If this is the case, restoration tools can accelerate the recovery process. Finally, if the indicative parameters reveal stagnation (no improvement, low recruitment) despite the protection and no stressors have been identified (or removed), then an appropriate restoration intervention is essential.

Armstrong: Recovery of different aspects requires different approaches and timelines, so a lot depends on the needs of the client initiating the review. For example, the natural recovery of coral on a degraded reef would take decades, if it would happen at all. So it is impractical to leave nature to heal itself on that timescale. On the other hand, revegetation of sand grasses on an eroded dune may be possible within a couple years and, if the conditions are right, may need relatively little continued human intervention. I am generalizing quite a bit here, but these scenarios illustrate the importance of developing a thorough understanding of the system you are trying to affect and not just looking at single aspects in insolation.

van Wesenbeeck: You can do this through monitoring as well as assessing the pressures that caused ecosystem deterioration. Often anthropogenic pressures, such as pollution, should be tackled with longer-term management plans.

Silliman: Conducting smaller scale experiments that look at disturbance and the presence of key positive species interactions and recruitment is the way to figure that out. What I typically see is that degraded systems have a hard time recovering because the mutualistic species interactions that allow systems to recover from stress are missing.

MEAM: What advice do you have for conservation/management groups considering putting resources into marine ecosystem restoration? In particular, do you have any rules of thumb for deciding if restoration of an ecosystem is feasible and practical?

van Wesenbeeck: Make use of the science that is out there! Do an assessment of why an ecosystem is degraded or disappeared, and take into account the full sequence of ecosystems present and their interactions. Ecosystems often occur in sequences along gradients. So to have a healthy seagrass bed, you may need a healthy reef to mitigate wave impacts and a healthy beach forest to limit runoff of nutrients and sediments from land. Then assess what efforts you can do along this wider range of ecosystems and implement sustainable management plans with local communities, so that your effort is of longer-term use.

If you are thinking of just a single, one-time intervention and then running away, maybe consider just not doing it and saving up until you can bring some more consistency.

Abelson: I have witnessed many marine ecosystem restoration projects (of coral reefs, seagrass meadows, and mangrove forests) that had no scientists involved or scientific guidance, and all have failed. So my first piece of advice would be to have scientists involved, and if possible, at least two experts – one who is a restoration ecologist of the specific ecosystem and the other an ecologist who is well familiar with the specific area.

Make sure the stressors responsible for the ecosystem's current degraded state have been removed or no longer exist. If they still exist and it is impossible to alleviate them, the chances for successful ecosystem restoration are very low (or have questionable cost effectiveness).

Try to follow a rule of "less human dictation, more natural recovery" (see Figure 1).

Figure credit: Avigdor Abelson, University of Tel Aviv.

We have to keep in mind that being technically able to apply an intervention doesn't mean we have to do it.

And a few more rules:

- Inspect the local recruitment rates before restocking/reintroducing any species.
- If restocking, don't restore using the wrong species in the wrong location.
- If restocking, pay attention to species and genotype diversity.

Crooks: Do proper due diligence. Why is the site degraded? Is degradation due to an acute effect onsite or a pervasive problem, such as nutrient loading leading to water quality decline and dieback of seagrass? Costs of thorough planning and evaluation at the start of a project will add some early costs but will save more in expenses during the life of the project and substantially reduce risk of failure.

Having a rigorous planning process that links science to the entire process (from setting goals and objectives to the design and construction of the project to post project monitoring) will greatly improve restoration outcomes and reduce wasteful spending.

On a more basic level, involve an ecologist and geomorphologist on the team. Together they will have a sense of restoration feasibility from both ecological and physical perspectives.

Silliman: Bring a diverse group of thinkers together to design the project, including but not limited to theoretical ecologists, general field ecologists, fishery scientists, modelers, habitat specialists, economists, accountants, hydrologists, restoration experts from other fields, elected representatives, and farmers. Also, before investing tons of money, test if the ecosystem can recover on small scales if new plantings are configured in ways that allow for positive species interactions to occur.

Armstrong: Take the time to understand seasonal and baseline variability so that you can reliably attribute events to the success (or failure) of a project. The causes of degradation can often be quite removed from the degraded coastline, and planning an effective and successful restoration project may involve decision making in areas that much of the public may consider unrelated. For example, a degraded coral reef may be suffering due to poor water quality from groundwater discharge, and 'fixing' the reef may have to start with 'fixing' land use practices well inland of the coast.

Making it social-ecological marine restoration

A 2016 paper by Robert France highlights lessons and best practices learned from terrestrial restoration projects. In particular, it emphasizes how making ecosystem restoration effective means delivering ecosystem services to stakeholders:

- Avoid science/engineering only. Identify stakeholders and put them front and center. Assess the cultural modification of the restoration location. Include a social scientist on the restoration team. Integrate technical knowledge of experts and local wisdom of residents.
- Instill adaptive management. Implement flexibility in governance to facilitate project resilience.

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[1] These projects were led by environmental activitsts Ditchay Roxas and her late husband Philippe Girardeau.

Healthy reef. Photo credit: Avigdor Abelson, University of Tel Aviv.