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Saving shores and establishing estuary systems: How restoration can save marine ecosystems.

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0. Abstract

Our oceans have always been full of life, providing a seemingly endless source of wealth for mankind. But as the world's population keeps growing, and as countries become more developed and wealthy the demand for fish and other seafood's keep growing with it. However this growing demand for seafood has caused fisheries to increase dramatically over the past several decades. Fishing methods as trawling and overfishing in general can come at great costs for the ecosystems that the targeted fish species live in. And thus with increase in seafood catch has come a startling increase in destruction of fish habitats. The growing human population has caused a rise of the oceans temperature as well, due to rising global warming. Overfishing in combination with global warming has caused a lot of damage to our marine ecosystems, leaving a lot of coastal and estuarine ecosystems in a state of deterioration. In order to ensure the survival of these ecosystems we need to make an effort of actively, as well as passively restoring them. Three of the most endangered and overfished ecosystems are seagrass meadows, coral reefs and bivalve reefs. This bachelor thesis aims at providing an overview of the restoration efforts that are being made to these three ecosystems, as well as the efforts that have been made in the past. I have found that in seagrass restoration the number of transplanted plants plays a big part in the success of the restoration. Large scale transplantation combined with the use of newly devised biodegradable grids used in the restoration yield the most promising results. For the restoration of coral reefs it seems to be more important to look at genetic diversity of the transplanted corals. More recently a very promising method of coral restoration, using the restocking of grazing fish species on the reef, has been developed, this holds a lot of promise for the future of degrading coral reefs. In the restoration Chesapeake Bay large quantities of oyster have been transplanted, but it appears that this is not adequate for the restoration of the reefs. It is needed to take a better look into disease tolerance and the new reefs need to be monitored more closely. But more than just restoration is needed to save these ecosystems, we need to take a look at the factors that have caused the decline as well.

1. Introduction

Our oceans have always been full of life, providing a seemingly endless source of wealth for mankind. Traditionally, life in the ocean has always been an important producer of fish and mammals for consumption (Tacon & Metian, 2008), but also services such as transport, coastal protection and more recently, eco-tourism, are highly valuable (Burke & Maidens, 2004). However, striking accounts of overfishing (Jackson et al., 2001; Myers & Worm, 2003), ocean eutrophication (Diaz & Rosenberg, 2008) and other forms of habitat destruction (Baker et al., 2008; Waycott et al., 2009) have changed the world's oceans dramatically over the past 50 years. Today, the large-scale changes to ocean life is accompanied by the disappearance of many valuable resources and services.

Some threatened species do not only hold great value for mankind, but are also fundamentally important for the ecosystems in which they are found. One important species group are foundation species. Foundation species are habitat-forming species; they construct biological habitats that promote the establishment of other species. Typical examples include large algae that host a number of epiphytes that live on their thalli, or trees that host organisms in their bark. Another way species can be fundamentally important is to positively affect the fitness of other species through their modification of the environment (van Katwijk et al., 2015). These species are called ecosystem engineers; species that directly modulate the availability of resources to other species (Jones et al., 1994). With the disappearance of these species entire ecosystems can collapse, thus the disappearance of these species can pose a big threat to marine biodiversity. These species include, but are not limited to; seagrasses, corals and reef-forming bivalves. In this thesis I focus on threats to these ecosystems and evaluate the success of different restoration efforts.

Corals are reef-forming invertebrates that live in colonies, their reefs provide important ecological functions for an associated and highly divers ecosystem (Muscatine and Porter, 1977). Corals form a hard exoskeleton to protect the otherwise soft bodied organisms. Living in colonies of numerous organisms, these exoskeletons build up to the reefs that characterize many of our tropical coasts. The reefs don't only provide shelter and protection to the corals themselves, but they also provide a sanctuary to numerous other organisms (Hixon & Beets, 1993). The reefs often contain lots of nooks and crannies, providing shelter for small fish and crustaceans.

The sheer size these reefs can grow to can even influence the tide and nutrient availability of the surrounding area. The reefs are often so big that they break the incoming tide, creating a zone where hydrodynamic stress is reduced (Monismith, 2007). These areas of low hydrodynamic stress are often utilized by numerous organisms that are vulnerable to high stress. Not only do the corals provide this much needed sanctuary, they also do a great job of trapping nutrients, zooplankton and possibly phytoplankton (Odum & Odum, 1955; Yahel, 1998; Monismith, 2007), thus providing a high concentration of food sources for a multitude of animals. This results in corals being both foundation species as well as ecosystem engineers.

Another group of species that fulfils the role of ecosystem engineer in a way that is very similar to that of the corals, is the group of reef building bivalves. Examples are the Blue Mussel (*Mytilus edilus*) and most of the oyster species. These animals live in vast stretching colonies, just like corals, they live in hard shells which can build up to big reefs as well. Much as the coral reefs, bivalve reefs facilitate the environment for numerous other species in the way of providing shelter for smaller and more vulnerable organisms. Breaking the tide and thus reducing hydrodynamic stress and creating sediment stability for organisms that are established behind the bivalve reef (Donadi et al., 2013; Borsje et al., 2011). And since most bivalves are filter feeders as well (Ward &

Shumway, 2004), they also have the potential to trap nutrients, and thus enrich the water with nutrients for other organisms to benefit from.

Seagrasses are a third species group that fit in the role of foundation species and ecosystem engineer by providing shelter and relieving hydrodynamic stress. Seagrasses are marine flowering plants that grow from rhizomes and roots anchoring in soft or sandy bottoms, and are often found in large meadows. Seagrasses typically relief stress for example by providing shelter and sediment stability, resulting in lower water turbidity and reduction of hydrodynamic stress (van Katwijk et al., 2016). Seagrasses also play a fundamental role in maintaining populations of commercially exploited fish and invertebrates. They do this by providing a permanent habitat, nursery areas, feeding areas, and/or refuge from predation (Jackson et al., 2001). Seagrass meadows are often home to high biodiversity, including iconic and highly endangered species. Additionally, strong linkage exists between seagrasses and coral reefs, and seagrasses and mangroves. Making loss of seagrass habitat a contributing factor in the degradation of the world's oceans (Ogden, 1980).

Even though coral reefs, bivalve reefs and seagrasses provide mankind with numerous resources, and are important to marine life, these ecosystem are mostly found in a state of decline. These three ecosystems are some of the most endangered ecosystems on earth (Diaz & Rosenberg, 2008; Waycott, 2009). Often ecosystems are not capable of recovering on their own, thus conservation measurements alone will not be enough to save them (Young, 2000). This is why active restoration is needed in order to save marine ecosystems.

In this thesis I will review the conservation status of seagrass, bivalve reef and coral dominated ecosystems: I will summarize both past and present threats and restoration efforts. Finally, I will evaluate future trends and propose necessary conservation actions for these ecosystems.

2. Results

2.1 Seagrass Beds

Seagrasses are among the most productive and valuable ecosystems in the oceans (Costanza, 1997). They cycle around 1.9 trillion dollars' worth of nutrients every year (Waycott, 2009). They provide a food source for endangered grazers such as Dugongs, Manatees and Turtles. While seagrass meadows are an important nursery location for numerous fish species, there are also species that spent their entire lives in the meadows (Nagelkerken et al., 2000). Seagrass meadows even support fisheries for as much as \$3500 ha^{-1} y^{-1} (Watson, 1993). These ecosystems are thus not only very valuable because of their ecosystem services, but also because of the value that mankind can get out of them (Barbier et al., 2011).

Despite their value, the seagrass systems are facing a major problem. As of 1980 seagrasses have been disappearing at a rate of 110 km^2 y^{-1}, this comes down to the disappearance of 29% of all seagrasses since these ecosystems were initially recorded (Waycott, 2009). One of the major threats to seagrass meadows is the impact of human handling. Mankind's actions pose both a direct and an indirect threat to the survival of the seagrass ecosystem (Table 1) (Duarte, 2002). The meadows are directly harmed by mechanical damage from eg. trawling and fisheries, the creation and maintenance of coastal infrastructures like piers and harbours, eutrophication as a consequence of water pollution, coastal engineering and aquaculture (Duarte, 2002). Indirect impacts can mostly be traced back to the effects of global warming, like the rise of seawater temperature, increased CO_2 concentrations, sea-level rise, and the increasing occurrence of storms.

Table 1 Impacts of direct and indirect human forcing on seagrass ecosystems.

Type	*Forcing*	*Possible consequences*	*Mechanisms*
Direct impacts	Mechanical damage (e.g. trawling, dredging, push nets, anchoring, dynamite fishing)	Seagrass loss	Mechanical removal and sediment erosion
	Eutrophication	Seagrass loss	Deterioration of light and sediment conditions
	Salinity changes	Seagrass loss, changes in community structure	Osmotic shock
	Shoreline development	Seagrass loss due to burial or erosion	Seagrass uprooting
	Land reclamation	Seagrass loss	Seagrass burial and shading
	Aquaculture	Seagrass loss	Deterioration of light and sediment conditions
	Siltation	Seagrass loss and changes in community structure	Deterioration of light and sediment conditions
Indirect impacts	Seawater temperature rise	Altered functions and distributions	Increased respiration, growth and flowering, increased microbial metabolism
	Increased CO_2 concentration	Increased depth limits and production	Increased photosynthesis, eventual decline of calcifying organisms
	Sea level rise and shoreline erosion	Seagrass loss	Seagrass uprooting
	Increased wave action and storms	Seagrass loss	Seagrass uprooting
	Food web alterations	Changes in community structure	Changes in sediment conditions and disturbance regimes

(Duarte, 2002).

All the different factors contributing to the loss of seagrasses have stimulated the research of protecting and restoring seagrass ecosystems (Orth et al., 2006; Katwijk et al., 2015). Katwijk et al. (2015) studied a total of 1786 restoration trials, with the oldest dating back to 1935. This allowed them to construct the following map of seagrass restoration trials (figure 1).

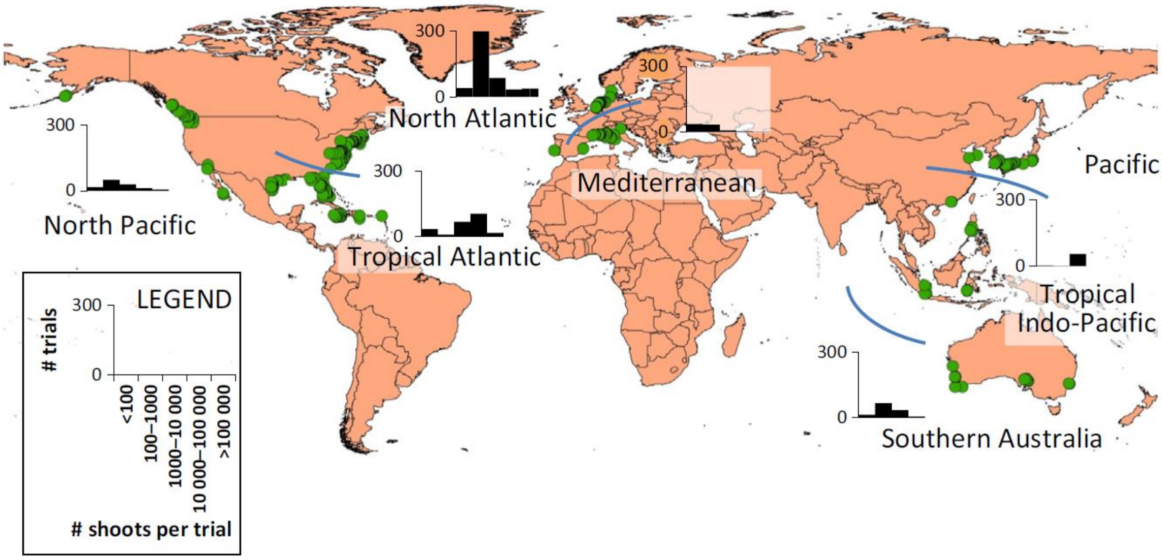

Fig. 1. Map of 1786 trials analysed (green dots represent trials). Frequency diagrams of the initial scale of the restoration trials per bioregion show that most trials start with <1000 shoots. Blue lines separate the bioregions.

(Katwijk et al., 2015).

Most of the restoration trials are located around the American continent, with a peak in the Atlantic Ocean, and a small number of shoots transplanted. This seems to correlate with human activities, which are a big factor in the disturbance of seagrass ecosystems (Short & Wyllie-Echeverria, 1995). Most of the trials have a sample size of 100-1000 shoots per trial (figure 1) where as some of the bigger trials exceed a sample size of 100.000 shoots per trials. This raises the question of whether or not such an amount of planted shoots has any influence on the success rate of the trial.

According to the statistics of Katwijk et al. (2015) it does indeed matter how much shoots per trial are planted. Estimated survival of trials with less than 100 shoots was 21%, whereas the estimated survival of the larger trials was 42%. That means a 20% increase of survival chance with the increase of sample size. Not only did the survival chance increase, but also the growth rate saw an increase with the increase of shoots per trial (figure 2).

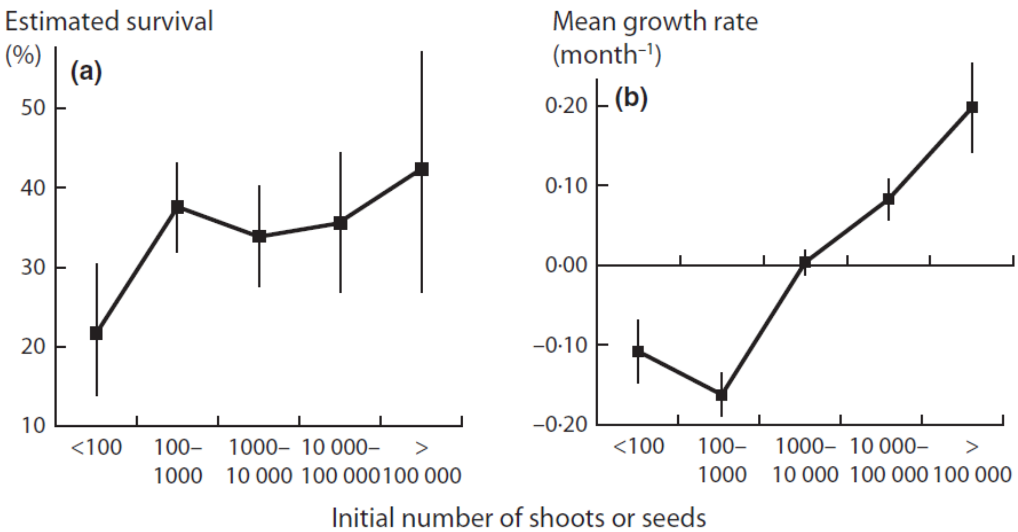

Figure 2: Estimated survival of transplanted shoots in relation to the amount of shoots planted in the trial, ±confidence interval (proportional hazard model over entire period *P* = 0.0070) (a). Log mean population growth rate (log of increase in number of shoots mo^{-1}) ±standard error of the mean, ANOVA *P* < 0.0001, d.f. = 4 (b).

The conclusion that the amount of plants transplanted in a trial was already found in an earlier study by Bos & Katwijk (2007), where they concluded that the planting density plays a big role in the survival of the transplanted shoots. Locations with a planting density of 5 plants m^{-2} (low density) had a significantly lower survival rate than locations with a planting density of 14 plants m^{-2} (high density). However, during this study it was also found that another big factor in the survival of transplanted plants was the amount of hydrodynamic stress the plants were exposed to. Three weeks after the transplantation of the plants 76, 68 and 28% of the plants in areas with low, intermediate and high exposure, respectively, to currents and waves survived (Bos & Katwijk, 2007). Thus it is not only the planting density, but also the planting site that plays a crucial role in the success of a restoration trial for seagrasses.

This was later confirmed in another article written by Katwijk et al. (2009), in which they set up a guide for the successful restoration of seagrass beds. Katwijk et al., stated that selecting the right habitat can be crucial and dependent on a few criteria, namely: (1) the area should have a history of seagrass growth; (2) the depth of the area should be similar to that of other, natural, seagrass beds; (3) the habitat requirements as set up by Calumpong and Fonseca (2001) should be met as much as possible.

One of the most recently devised innovations in seagrass restoration has been set up by Kidder et al., (2015). They have modified the “TERFS” (Transplanting Eelgrass Remotely with Frame Systems) of Short et al. (2002). Kidder et al. have been using this modified TERFS method with success for several years (Disney and Kidder, 2010).

The standard method of TERFS involves tying eelgrass onto wire grids weighed down with bricks, but this method presents some problems in the later stages of restoration. Once the eelgrass plants have settled in their new habitat, these grids need to be removed. There are 2 clear problems with this, the first is that the removal of the grids is very intensive work that requires a lot of labor, expenses, and cleaning of the grids so that they can be reused. The second problem is that the eelgrass roots often attach to the grids, overgrowing them. This means that if the grids are removed it is very harmful to the transplanted plants, decreasing the success rate of the restoration with up to 60% at some projects (Kidder et al., 2015).

The modification that they designed is a novel BioDegradable Grid (BDG) that is constructed of spruce side rails laced with sisal twine and weighed with small sandbags. The idea is that the twine and sandbags disintegrate in the course of one winter, leaving only the waterlogged wood frame to disintegrate more slowly. Unlike with the commonly used PVC grids nothing has to be removed after the transplantation, so the transplants do not have to be disturbed after rooting in the environment. Since nothing has to be removed, the labor that comes with the removal and preparing of the grids for reuse is eliminated from the process. Thus this method of using BDG’s is not only more successful, it is also a lot cheaper.

The usage of BDG’s has been tested by Kidder et al. (2015) against the use of regular wire grids. At multiple locations they have performed transplants with both BDG’s and the regular wire grids. Then after 11 months they returned to the sites and counted the living plants that had remained at the transplantation site. This test did take into account the removal of the standard wire grids. From the results of the experiment it can be concluded that the restorations preformed with BDG’s have been more successful that those preformed with regular wire grids (Figure 3). This means that the BDG’s are not only a cheaper alternative to regular wire grids, they are also better suited for restoration purposes.

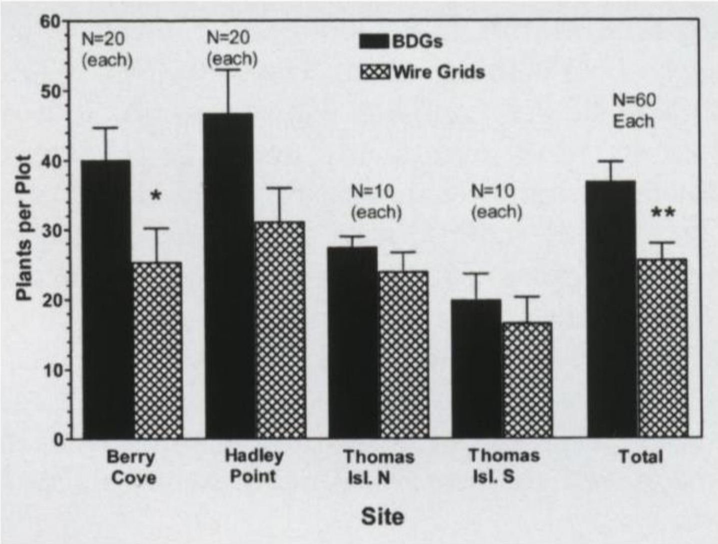

Figure 3: Transplants on BDGs did as well or better than those on wire grids before grid removal. Twenty plants were initially tied onto all grids. At Berry Cove, there were significantly more transplants on BDGs than on wire grids 11 months after transplant (p = 0.018). When grids from all locations were combined (N = 60 of each type), the difference between BDGs and wire grids was also significant p = 0.0016). Error bars are standard error for N = 20 grids of each type in each location with the exception of Thomas Island, where N = 10 grids of each type in each area.

2.2 Reef Building Bivalves

Gottlieb and Schweighofer (1996) stated that native oyster restoration or the introduction of an exotic oyster species (*Crassostrea gigas*) have been widely advocated in the scientific literature as the solution to eutrophication in Chesapeake Bay (Pomeroy et al., 2006; Coen et al., 2007). Chesapeake Bay is an estuary from the Atlantic Ocean, and can be found in the west of the North American continent. It has been the location of a multitude of Oyster restoration trials.

Oyster populations used to thrive in Chesapeake Bay, with a reported peak catch of 615 thousand tons in 1884. But over the time the populations have become damaged due to the high amount of fishing practices, bringing the yearly catch down to 12.000 tons in 1992 (Rothschild et al., 1994). Rothschild contributes this decline solely to the damage caused by overfishing the resource, whereas other researchers have claimed the decline to be caused by reduced water quality and disease as well (Haven et al., 1981, Kennedy & Breisch 1981, 1983, Héral et al., 1990). After this decline has been observed and the oysters nearly disappeared from the bay numerous attempts have been made to restore the oysters to their former abundances.

One of the biggest organisations concerning themselves over oyster restorations, especially in the Chesapeake Bay, is the Oyster Recovery Partnership (or ORP). From 2000 until 2015 they have restored and transplanted billions of oysters in Chesapeake Bay (Figure 4)

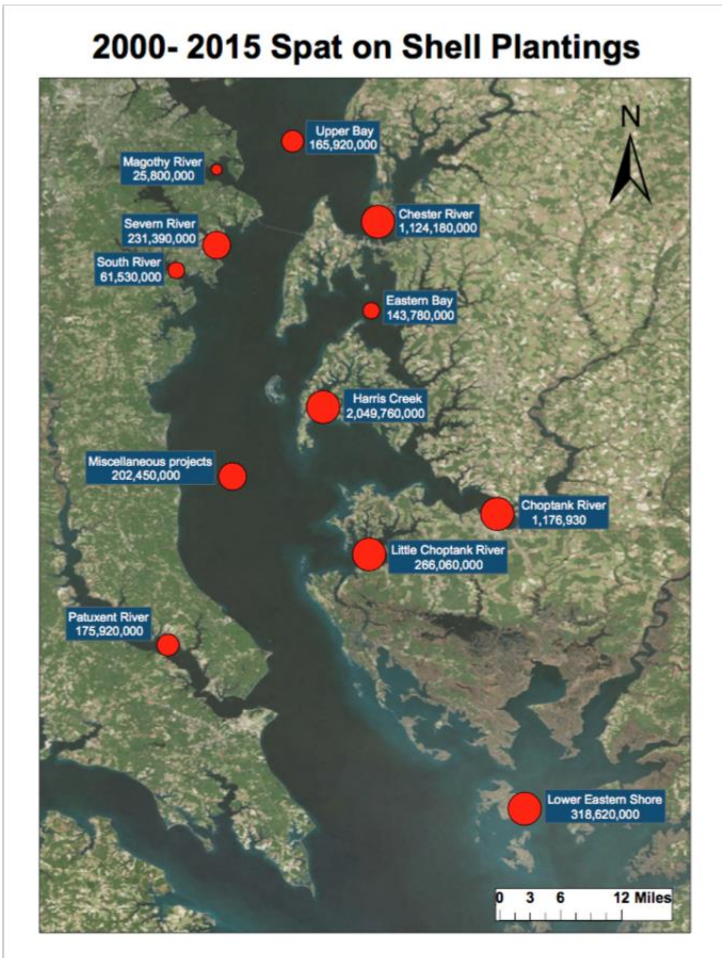

Figure 4: Map of transplanted "spat on shell" as performed by the ORP. Spat on Shell means that a young oyster spat has been put on an empty recycled shell of an adult oyster (Oyster Recovery Partnership).

The Oyster Recovery Partnership has made a huge effort to restore the original ecosystem in the last 15 years, with some places over 2 billion oysters restored. However the ORP is reintroducing the eastern oyster (*Crassostrea virginica*) in these projects, which is the native oyster that was originally found in the area.

The ORP does a lot of work in the restoration of the Chesapeake Bay oysters, but it is speculated that their restorations might not be as successful as they would like. Even though they carefully place the spat on shell to construct new reefs, and they take care of the juvenile oysters to ensure a stable population (Oysterrecover.org), the ORP's efforts have been doubted. Mann and Powell (2007) describe that a few very important factors are being overlooked in the restoration of Chesapeake Bay, causing the restoration efforts to be in vain. Mann and Powell describe that restoration efforts on other estuarine and marine species have not been looked upon well enough. This limits the reintroduction of the oyster, which is expressed in a lack of predicting recruitment and a lack of limiting disease impacts.

Mann and Powell theorise that the problem is caused by the calculations of Newell (1988), which estimate that an the native oyster populations of approximately a hundred years ago could filter all the water in the Chesapeake Bay in roughly three days. These calculations have captured the imagination of ecological researchers as well as politicians that are searching for a "quick fix" for the water quality of the Bay, resulting in an "its okay, more oysters will fix it" mentality in the oyster restoration. But the conditions have long been far from the same as a hundred years ago: the oyster populations are severely depleted; oyster regeneration times have been restricted; recruitment levels and options for rebuilding have been limited; and the Bay environment has been irreversibly changed over the years. This all causes that the filtration ability of the oyster populations that were found a hundred years ago will never be met again.

As Mann and Powell have stated, releasing more oysters in Chesapeake Bay is not going to work as a restoration measurement, but there are ways to control the population. This is mostly done by means of aquaculture. The basics of this approach is a strategy which depends upon selective breeding, management around disease and rapid growth to market (Breitburg et al., 1999). This means that the environment in which the oyster are grown are strictly monitored and even controlled in a way to ensure the growth and survival of the oyster. This method is mostly used to create populations that will be harvested by fisheries. But selective breeding programs have also been carried out with a focus on creating more resilient and disease tolerant oysters with higher growth rates (Luckenback et al., 2000). These oysters will be "produced" at oyster farms, by means of aquaculture, and then used in restoration projects to create more resilient populations that have a higher chance of survival.

Oyster farms can also provide relieve to the natural oyster populations. If fisheries are restricted to the oyster populations that are grown by means of aquaculture this has positive effects on the natural populations. If oyster farms are used for commercial gain that would mean that fishing on natural reefs is no longer needed. And thus is natural reefs are relieved of fisheries this means that the biggest endangerment to the oysters would be taken out of the equation, allowing the natural reefs a big relief.

2.3 Coral reefs

Corals are among the most threatened marine ecosystems globally, facing destruction from many different factors, from human impacts to global warming (Bellwood et al., 2004). This has led to a steady decline of the systems over several years (figure 5)

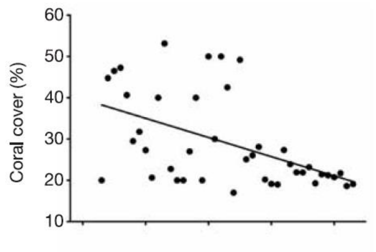

Figure 5: degradation of coral reefs, Results of a meta-analysis of the literature, showing a decline in coral cover on the Great Barrier Reef. Each point represents the mean cover of up to 241 reefs sampled in each year (Bellwood et al., 2004).

One of the major problems for coral reefs is "coral bleaching". Corals are invested in a symbiotic relationship with dinoflagellates in the genus *Symbiodinium*, or more commonly known as zooxanthellae. These zooxanthellae contribute to the hosts energy production by the means of photosynthesis, they also accelerate the calcification in many skeleton forming species (Muscatine and Porter, 1977). In return for these benefits the host corals provide ample shelter and accessibility to sunlight for the zooxanthellae. But this is not without risks, when exposed to environmental extremes such as increased water temperatures and high irradiation the zooxanthellae's photosystems could be damaged. This leads to an overproduction of oxygen radicals, which can lead to cellular damage of the hosts. Thus when exposed to these radicals the hosts will often eject the zooxanthellae from their bodies, leading the corals without the benefits of the symbiosis. This means that the corals can get a shortage of energy and they can eventually die off. When this event shows up the corals lose the pigments that come with the zooxanthellae, leaving them bleak or even white. Hence the name coral bleaching (Baker et al., 2008).

Coral bleaching usually results in partial mortality of the corals living on the reef, and even though it can be survived (Harriot, 1985; Gates, 1990) it usually leaves the corals damaged and unable to reproduce. That being said, the survival is mostly found after mild bleaching events wherein the temperature rise is only slight and of short duration. During more severe bleaching events mortality rates approaching 100% common. In these scenarios the temperature rise holds for extended periods of time and recovery is slow and little. So has Riegl (1999) described the near-total extirpation of six species of *Acropora* in the south-eastern Arabian Gulf, with mortality rates of more than 90% (in 1996), where after more than a decade recovery has only been observed in a small area (Burt et al., 2008). This demonstrates that even though coral bleaching can be overcome by the resilience of the corals, it is a big problem and can be very detrimental for the ecosystem. Although bleaching is not always lethal, there are long lasting non-lethal, detrimental effects of the bleaching. So it is often described that years after a bleaching event corals have trouble spawning gametes, or making sure these gametes are pollinated (Szmant and Gassman, 1990; Ward et al., 2000). This is most likely due to the extreme stress and energy depletion of the corals. Condemning them to a state where they are still recovering and cannot spent an optimal amount of energy on gamete production, resulting in gametes that might not be suitable for reproduction (Baker et al., 2008). The long-term effects do vary between species, some are more resilient than others.

When coral reefs become too damaged, for example due too coral bleaching, they may undergo a regime shift (Bellwood et al., 2004). This means that due to the weakened state of the reef the competition with other organism's shifts to favor the competitors of the corals. Often times these are fleshy seaweeds and algae species, these species take over the niche that is left or occupied by the weakened corals. This results in the reef being dominated by these seaweeds and algae, leaving the reefs in a less desirable state. The problem with these regime shifts is that most times the alternate state of seaweeds and algae is a state that appears to be stable, and thus the regime will not shift back on its own. This is where restoration will be needed to bring back the corals and restore the reef systems.

But the restoration of coral reefs has proven to be a very difficult and a complex process. Therefore to save the reefs the focus has been laid more on protecting the still healthy systems rather than restoring the degraded systems (Hughes et al., 2010). Coral reef restoration has not been applied on a large scale basis due to its ineffectiveness in the face of natural threats such as climate change and ocean acidification (Pandolfi et al., 2003; Mumby & Steneck, 2008; De'ath et al., 2009).

However, in their recently published article Obolski et al., (2016) present and describe a model for restoration that could prove to be more effective than the current methods. Obolski et al., talk about the option of restocking the populations of grazing fish species that live on the reefs. The degradation of coral reefs often goes hand in hand with the migration of the reefs inhabitants. Once the reef is damaged too much these reef dwelling species lose the benefits of living on a vibrant reef and they would go in search of another reef to inhabit. Thus the degraded reefs are likely to remain in their unfavorable state, and uninhabited by grazers. The recovery of these grazing fish species will take years, if not decades, when left to nature itself (Blackwood et al., 2012), but the enhancement of these grazing species is expected to significantly accelerate this process. The idea behind this model is that the enhancement of the grazers will result in the accelerated grazing of the seaweeds and algae, thus opening the niche up for coral species to reestablish. This will eventually result in the disappearance of the seaweeds and algae and the return of the corals, restoring the system to its former health (Obolski et al., 2016).

Obolski et al. (2016) state that the restocking of grazing fish could not only keep the coral coverage up significantly, but also speed up the time in which seaweeds and algae are eliminated from the reef system (Figure 6). They also theorized that restocking of grazers would even be a successful restoration measurement in coral systems where the corals are sure to disappear completely without intervention (Figure 6A).

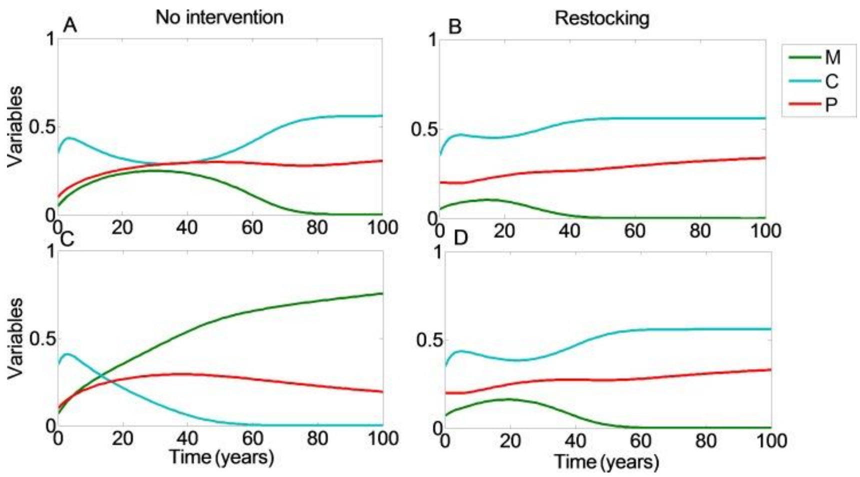

Figure 6: Plotted values of the coral coverage (*C,* light blue), macroalgae coverage (*M,* green), and grazing fish (*P,* red) with respect to time, no intervention (A and C), and restocking (B and D), for different initial conditions. (A and B) present the model variables simulated from initial values in which the reef will be restored without intervention (C_0 = 0.35, M_0 = 0.05). (C and D) present initial conditions in which the coral reef will deteriorate without intervention, but will return to high coral coverage when restocking is implemented (C_0 = 0.35, M_0 = 0.07). (Obolski et al., 2016.

For as much success this new method of restoration promises, it is only newly described, so current restoration projects still use to the "classic" restoration method of transplanting nursery raised corals. One big player in the field of coral restoration is the Coral Restoration Foundation (CRF), they performed numerous restoration projects throughout the Florida Keys and the Caribbean. The CRF strives to counteract the dramatic decline of coral reefs and near extinction of coral species in these areas, following a stressor event in the late 1970's and early 1980's (http://www.coralrestoration.org/about/, 2016).

The CRF has created innovative offshore nursery sites where they grow their corals until they are ready to be transplanted on a naturally formed reef. The CRF has innovated the way their corals are grown in the nurseries. They grow Staghorn and Elkhorn corals, which have the natural ability to grow and reproduce through fragmentation. This means that if a branch of the coral falls off, and the conditions are favourable, this branch can reattach to the rock and form an entire new colony. They use this natural ability of the corals to grow them until they are large enough to be transplanted onto a reef (http://www.coralrestoration.org/coral-tree-nursery/, 2016).

After transplantation the corals are monitored closely. The CRF strives to restore and create self-sustaining reefs that are resistant and genetically diverse. For this purpose the corals are tagged at two separate times, when they come into the nursery and when they are transplanted onto the reef, then the site where corals are planted are tagged as well to collect data on environmental influences (http://www.coralrestoration.org/outplanting-methods/, 2016). This allows them to create a reef with genetic variation, which is essential for the forming of an eventually self-sustaining system. It also allows them to select the right corals which they then use in their nurseries for further growing and transplantation, thus they can select on corals which are more resilient than their natural counter-parts and which are more resistant to stressors like coral bleaching (http://www.coralrestoration.org/research/, 2016).

In 2015 the CRF has managed to transplant around 21,500 Staghorn and 1,500 Elkhorn corals, with almost 300 different genotypes, from their nurseries to natural reefs. This puts them on the forefront of non-profit organisations that seek to maintain genetic diversity of these species and restore these populations, promoting a natural path to recovery (Anonymous, 2015).

Discussion

It has been shown that many marine ecosystems exist in a state of decline (Jackson et al., 2001; Myers and Worm, 2003; Baker et al., 2008; Diaz and Rosenberg, 2008; Waycott et al., 2009), a decline that is caused by an number of different factors. However, the most damaging factor seems to be either directly or indirectly caused by the actions of mankind: direct results of fisheries are extremely harmful for oyster beds and seagrass meadows (Rothschild et al., 1994; Duarte, 2002); indirect consequences of construction of ports, harbours, and piers damage and destroy seagrass meadows even miles away from the actual construction site (Duarte, 2002); or the effects of human induced global warming that cause massive coral bleaching effects spread out of the entire globe (Baker et al., 2008).

But we as humans are not only factored into the equation of marine decline as a major threat for marine life. We are doing a lot of work to save and protect these systems as well. There are numerous foundations, research institutes and programs dedicated to preserving and restoring marine ecosystems. Some of which have been very successful in the past and present. For example there is the Coral Restoration Foundation that has done a lot of work in the restoration of coral reefs throughout Florida and the Caribbean. Not only has this foundation been laying the groundwork for natural reefs to recover from destruction. They have also put a lot of effort in the innovation of the ways we consider restoration to be successful.

What makes the CRF innovative lies not only in the way they grow their corals for transplantation, but also in the efforts they make to keep genetic diversity in the reefs the work on (https://coralrestoration.org/research/, 2016). This genetic diversity is immensely important for the building of a self-sustaining coral reef system. It allows for the ecosystem to be more resilient to setbacks and stressors like seawater warming. This genetic diversity also promotes natural selection, due to a high number of different genotypes the chances that there are stronger and more resilient corals being transplanted is higher, and these corals will probably survive better after the transplantation thus creating a stronger and more resilient reef.

Another organisation that does a lot of work in marine restoration is the Oyster Recovery Partnership. The ORP has laid their focus on the restoration of natural oyster beds in Chesapeake Bay, Amerika. The ORP has performed a huge quantity of oyster restoration projects that have transplanted massive amounts of juvenile oyster, or as they call it “spat on shell”, with some transplantations ranging in the billions of transplanted oysters. The ORP farms young oysters in huge aquaculture facilities. After which they let the juvenile oysters attach to recycled shells from adult oyster, they then proceed to plant the spat on shell in the Bay. After this they return multiple times to check on the newly constructed reefs, to make sure that everything is going according to plan (http://oysterrecovery.org/).

But as described by Mann and Powell (2007) more than just the replanting of spat on shell is needed in the restoration of Chesapeake Bay. In order to ensure the successful restoration of oyster beds it will be needed to monitor environmental factors better. By means of aquaculture this can be achieved, we can select upon more resistant oysters that will survive better in the bay and are more resilient to disease (Luckenbach et al., 2000). If aquaculture would be combined with the huge effort of the ORP I do believe that the restoration of Chesapeake Bay will go in the right direction.

In the field of seagrass restoration it is most likely scientist and researchers maintaining to preserve and conserve the meadows that are leading in seagrass restoration. Seagrass restoration has been done for decades already, but the success rates are not always very high (Katwijk et al., 2015). This can be contributed to the fact that most seagrass restorations are performed by attaching the rhizomes of seagrasses to a grid that is then buried and left for a couple of months. After this time the grid has to be removed from the soil in order to prevent soil poisonin. This removal of the grid often results in a drop in success rate of the restoration since the plants attach themselves to the grid. These plants have to be removed from it which often means that the plants don't survive (Kidder et al., 2015). A brilliant solution to this problem was found by Kidder et al. (2015). They have described a way to construct the grids that are used in the seagrass restoration from pine wood, twine and bio-degradable sandbags, resulting in a grid that is completely bio-degradable. Not only do these grids dissolve in a short time span after the transplantation, but it is also theorised that the wood and twine that is used provide the transplanted plants with much needed resources for growth and survival (Kidder et al., 2015).

But seagrass restoration is not the only field of restoration in which new and innovative ways to help out the ecosystem are being found and applied. In a theoretical study performed by Obolski et al. they describe a way to restore coral reefs in a very natural and eco-friendly way. The idea behind the model that is described in their paper is to bring back the populations of grazing fish that live on the reef, to reefs that exist in an alternative state dominated by seaweeds and algae. By doing so these algae will be grazed and reduced, opening the ecological niche for the corals to return to their reefs (Obolski et al., 2016). At this point this is only a theoretical model, but it holds a lot of promise for the restoration of coral reefs.

It is very important to keep finding new and improved ways to restore marine ecosystems that are being endangered. Because often times the classical ways of restoration might not be effective enough to create self-sustaining ecosystems and save the future of these ecosystems (Hoegh-Guldberg, 1999; Duarte, 2002; Mann & Powell, 2007). Kidder et al. (2015) and Obolski et al. (2016) have done some great work in finding these new and improved restoration methods. These are very exciting methods that hold a lot of promise for the future of both seagrass and coral reef systems, and if they can be implemented on a large scale basis I do believe that they can do a lot of good work in building self-sustaining, natural ecosystems.

To answer the question whether or not active restoration can be the answer to dwindling marine ecosystems, and save these systems from extinction in the future, I do believe that a good possibility exists that this is the case. With all the research that is being performed on this subject, and the innovations that are being found, mankind really is putting a step in the right direction. But as with most problems, there is not any one answer that can solve the problem on its own. I do believe that more than just active restoration is required to save these ecosystems. Because if we allow the factors that endanger these systems in the first place to continue, then what use is restoration if the restored systems will just be destroyed once again?

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