Determining the efficiency of artificial reefs in different settings and the best parameters for their success

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Abstract

Anthropogenic climate change has had severe impacts on environments around the world, none more so than coral reefs. Despite occurring in less than 1% of global marine environments, these reefs are responsible for over 25% of all marine biodiversity and play a crucial role in maintaining the health of our oceans. Degradation of reefs as a result of continued bleaching events, high temperatures, severe storm events and continued disturbance by human development have led to a reduction in coral reef health and subsequently a drop in marine biodiversity. In response to continued global deterioration of reef health, coral rehabilitation programmes have been launched around the world in order to help reduce the rate of reef loss and to try protecting the valuable ecosystems they support. Coral rehabilitation and conservation efforts have been undertaken on a global scale from the Asia-Pacific to the Caribbean and the Indian Ocean. There is a need to better understand what the best practice for rehabilitation within these areas, how artificial reefs are being used, and to what extent they are contributing to the conservation of biodiversity and marine environments. This research paper will analyse recent artificial reef literature from different global regions, specifically looking at several parameters related to their implementation and effect on local environments. These include: types of artificial reefs, their physical and biological configuration, how they contribute to biomass growth, and whether certain substrates affect their success rates. By recording these variables and comparing artificial reef efforts in different regions, it will create a comprehensive understanding of current marine conservation efforts. This analysis will determine the most effective ways to conserve and protect biodiverse coral sites using artificial reefs.

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1.0 Introduction

On top of being one of the most biodiverse ecosystems on Earth, coral reefs provide a range of ecosystem services that are important on both a local and global scale. A healthy coral reef not only helps support local tourism and fisheries industries but is an important carbon sink and oxygen producer. As such, coral reefs are of vital importance to the health of the oceans and the planet (França et al., 2020). Climate change as well as human development have been exerting extensive pressure on coral reefs, evident in more frequent severe storms, bleaching events, eutrophication and pollution. In response to this, coral conservation and rehabilitation efforts have taken hold across the world (Boström-Einarsson et al., 2020).

The methods used to rehabilitate coral reefs have differed across the world, depending on both the local impacts within regions as well as the entities taking part in conservation efforts. There is a growing debate as to the efficiency of the various methods used by projects in different parts of the world and whether a particular method is showing more prowess (Boström-Einarsson et al., 2020). In order to create solutions that will work effectively throughout rehabilitation projects in different regions, there is a need to understand the impacts and management methods espoused across the world (Rinkevich, 2005). However, research into reef rehabilitation efforts, their methodologies, and efficiencies have often focused on coral reefs in major regions such as the Caribbean and Asia-Pacific.

There are gaps in our knowledge surrounding the status of reef environments outside of the Caribbean and the Asia-Pacific as well as the issues they face and how local conservation efforts are working towards protecting them (França et al., 2019). In order to better grasp the global impacts of climate change and other such environmental stressors on reefs and find workable solutions, further research is needed to monitor and assess reef health and rehabilitation efforts globally as a whole. There is a need to investigate the developments or rehabilitation efforts throughout the world using a similar baseline. In this case, the use of artificial reefs, submerged structures that can take several forms, sizes and management styles will be the shared common factor.

Worldwide, artificial reefs have been used to help with marine conservation and biodiversity efforts. Their relatively easy concept and low realization costs have made them a staple of reef rehabilitation programmes, some global regions have experimented with new, more complex styles, while others have sought to maintain the simplest structures and management methods (Rinkevich, 2005; Ceccareli et al., 2020). Despite large amounts of papers and data available regarding artificial reefs, there has been little large-scale analysis of their efficiency, success and the parameters driving those variables (Paxton et al., 2020).

In order to better manage marine conservation efforts and build stronger programmes, there needs to be better understanding of how artificial reefs can contribute to reef rehabilitation. Additionally, it must be investigated whether their implementation is conducive to the creation of new biodiversity, to which extent, and the best ways to ensure their success. This makes this both an exploratory study into the artificial reef methodology being used by local rehabilitation teams worldwide, but also a complementary investigation into how the coral reefs are faring and how effective artificial reefs have been. By understanding the status of coral rehabilitation efforts and the issues faced in different regions will help complement global research on the topic and provide more accurate management methods on both local and international levels (França et al., 2019; Paxton et al., 2020; Boström-Einarsson et al., 2020).

2.0 Materials & Methods

During the planning phase of this research, it was decided that to best represent each region's efforts with artificial reefs and associated coral rehabilitation, a minimum amount of sources (peer reviewed papers, grey literature, reports… etc) from each will be collected and analysed. The regions were split as follows: Caribbean; Africa; Indian Ocean; Asia; Australia; Pacific Ocean; South America; Europe; and Others. Papers collected would have been published in the last three years to keep the sample size small and results recent. Artificial reef type would not include shipwrecks, oil platforms, offshore wind turbines or other industrial focus.

It was originally expected to be a minimum of 90 and maximum of 180 papers analysed as part of the larger study. Once collected, each paper will be analysed to find: the type of artificial reef; the management style used; biotic parameters; observations; results identified by the study; and the limitations identified by the study. After all these papers are analysed, the findings and discussions per region, then globally, will be shared to then determine what are the most efficient types of artificial reefs, the parameters needed for their success, and what changes they have led to. These would all be recorded through a codebook created for this purpose.

In practice, it was found that there were wide inequalities between regions and recent publications, as well as less papers than expected that fell within the parameters above. A discrepancy in global publication location was expected, but not to this point. As a result of these issues, the target of 90 – 180 papers was halved to 45-90. Over a hundred papers were found within the initial research time frame, this was further whittled down to 57 for codebook analysis. During this phase, 7 papers were further excluded.

Overall 50 papers were collected from 10 regions. Three of these were grey literature, and the remaining 47 were primary research split as the following: 38 published articles, 4 historical context papers, and 5 meta-analysis papers. They were found using Google Scholar, Mendeley, the National Oceanographic and Atmospheric Administration 'Coral-List' email chain, and paper recommendations from my supervisors, Rolf Voorhuis (Coral Reef Care) and Nicole de Voogd (Naturalis Biodiversity Center).

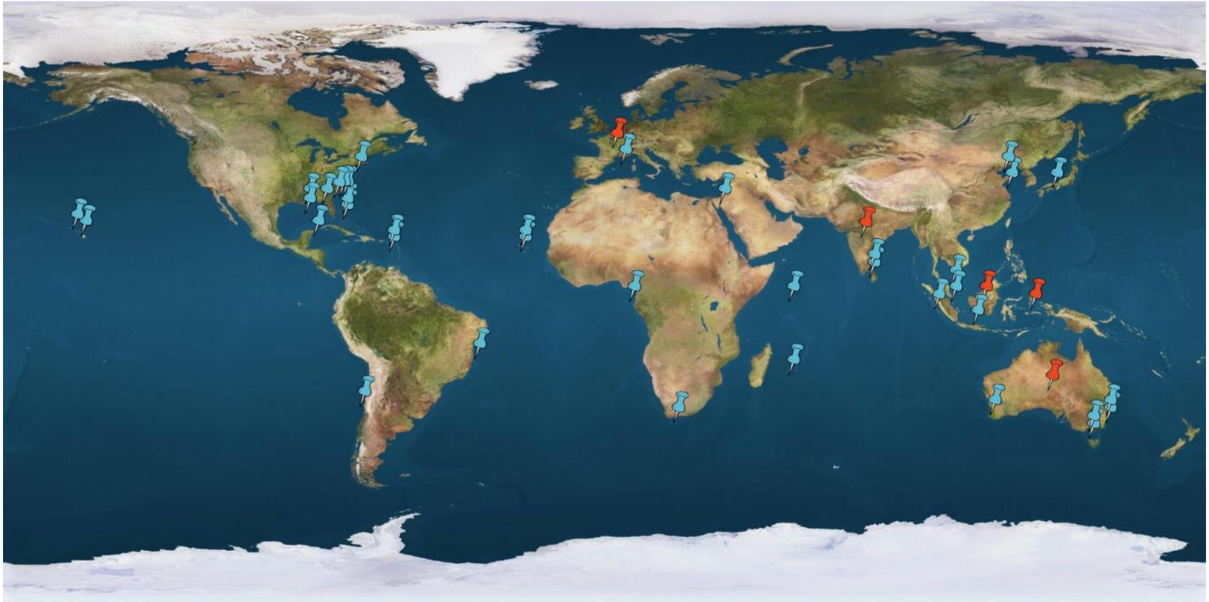

Figure 1.0: Location of each study used, blue pins representing individual field research and red representing meta-analysis papers for that region.

2.1 Schedule

Search and collection of papers was carried out between November-December 2020, with codebook analysis taking place throughout January 2021. Analysis of the codebook results and synthesis of the literature happened the following month, with the report written in March and April of the same year.

3.0 Results

While the parameters remained constrained, the wide array of artificial reefs, management styles and research topics created a large pool of observations. Despite the differences, there were certain key conclusions and trends that were noticed throughout. In general, the conclusions reached by global researchers fell in line with currently accepted field practices and scientific knowledge, these included:

- There is a positive relationship between the creation of artificial reefs, and the amount of biodiversity within the project area;
- Artificial reefs using local associated organisms are more successful in attracting biodiversity;
- Creating artificial structures that were homogenous with the local environment were more successful in attracting biodiversity;
- Artificial reef form and type determine which species populate it;
- Complexity of the structure plays an important role in determining its success;
- Proximity to a natural reef is crucial has a positive effect on artificial structure survival;
- More research is needed.

While these conclusions provided insights into different regional aspects and will be covered in more detail below, they suggest that earlier research in artificial reefs are still valid, with researchers continuing to debate the same questions posed then. However, there are some significant changes in terms of outlook regarding climate change and future conservation considerations. Additionally, these papers contained a range of trends that were described in similar fashion in other regions, but that researchers could not conclusively prove or disprove. Some of the more common trends were:

- Artificial reefs do create biodiversity;
- ReefBall-type artificial reefs are the least efficient at attracting or producing biodiversity; and
- Using several different artificial reef types during projects created a more natural biodiversity profile.

Section 4.0 will further break down and discuss how the collected literature adds to the debate on the use of artificial reefs, their role in marine conservation, and the considerations for future projects.

3.1 Biotic & Abiotic Factors

3.1.1 Complexity

Complexity is accepted as being a key factor in determining how successful ARs in both providing sufficient opportunities for benthic communities to assimilate the structure, and providing spaces for different faunal species to interact with (Carr & Hixon, 1997; Hixon & Beets, 1989). This tenet has continued to hold true throughout current research. Comparisons between different AR types with various levels of complexity have shown that more complex structures exhibit quicker benthic colonization and mimic local reef assemblages (Cresson et al., 2020; Good, 2020; Schweitzer & Stevens, 2019; Sreekanth et al., 2019; Tessier et al., 2015). However, complexity should be scaled based off the ARs' goals and the local environment.

Conservation-centric structures should imitate natural reefs and the traits sought by the species present. ARs that have been built to mimic the local environment tend to outperform generic structures such as ReefBalls in terms of species richness (Hylkema et al., 2020; Komyakova & Swearer, 2017; Komyakova et al., 2019). In certain cases, structures do not need to be physically complex to be successful but provide functional habitats in line with local environments. Hylkema et al. (2020) found that 'layer-cake' and loose basalt rock ARs had high and intermediate scores in terms of biomass and species richness in the Caribbean, while the use of coral rubble and low-cost local "materials of fortune" have had varied success in Asia (Alam et al., 2020; Diringer, *pers. obs.*, 2018). Voorhuis (*pers. comm.*, 2021) recommends stabilizing coral rubble adjacent to active natural reef sites and installing artificial structures directly into it. This ensures that the complexity of the local environment is fully used and promotes the chances of the area are successfully integrated.

Simple structures used for commercial fishing means, such as those reviewed by Folpp et al. (2020) or Tessier et al. (2015; see Section 3.3) feature very little protective spaces for demersal species and host higher numbers of predator/angling species. This is also true for the aforementioned man-made structures - oil rigs, shipwrecks, caissons, disaffected industrial equipment, and other forms of non-natural structures. Lack of functional complexity, accompanying high verticality and designs that do not imitate natural environments ensure that these structures attract species more so than create natural habitats capable of producing biodiversity. This makes them more suitable for commercial fishery operations rather than conservation-based programmes (Becker et al., 2016; Folpp et al., 2020; Friedlander et al., 2014).

3.1.2 Positioning

ARs set up near, or on, natural reefs were found to be more successful in promoting biodiversity and becoming a part of the local environment (Boström-Einarsson et al., 2020; Puspasari et al., 2020; Tessier et al., 2015). The proximity to other reefs and local assemblages ensures that the structures become assimilated as a part of the local environment faster. While this also makes the determination of the creation of "new" biodiversity harder to differentiate from normal reef activity, it does not detract from overall ecological conservation efforts (Boström-Einarsson et al., 2020; Paxton et al., 2019). Creating artificial reefs in an area that is already significantly damaged, or does not have a healthy reef nearby, is not likely to restore the local environment, but instead likely to change the composition of the ecosystem at both a physical and ecological level (Fukunaga & Bailey-Brock, 2008; Hammond et al., 2020; Kilfoyle, 2017).

In addition, proximity to shore also plays a hand, with Wu et al. (2019) concluding that shallow water (9-11m) provides a higher chance of AR success in the Yellow Sea as well as Raj et al. (2020) in the Gulf of Mannar (3-6m). This is further bolstered by Tessier et al. (2015), who affirm in their own meta-analysis of French AR programmes that there was an assumption that shallower reefs (<30m) had higher colonization rates – especially among complex structures. In both cases, shallower reef programmes also ensured easier monitoring and protection of these areas, potentially providing further pathways for AR success. A study on deep-sea (93–245m) artificial structures in Hawaii provides further insight, with Jones et al. (2020) noting that these ARs did not mimic natural reef assemblages.

The benefits of shallow deployment may also include helping reduce the impact ARs have on predation rates. ARs have a documented attraction factor that especially in their early stages when there is little natural shelter or growth on them makes them ecological traps that can have a negative impact on reef biodiversity and replenishment rates (Komyakova & Swearer, 2017; Mablouké et al., 2013). In addition to this, Paxton et al. (2020a) noted a correlation between AR depth/verticality and predator population size, with ARs deployed deep offshore as well as those with large verticality shown to attract predators at a higher rate. Similar observations relating to high verticality and predator presence have been made by Voorhuis in South East Asia (2021). This is especially noticeable in man-made structures such as shipwrecks and oil rigs (Friedlander et al., 2014; Jones et al., 2020; Le et al., 2019; Plumlee et al., 2020), but has also in AR types that lack complexity, rugosity, or that do not fit within the local environment (Komyakova et al., 2019; Lemoine et al., 2019).

3.1.3 Orientation

In addition to location and complexity, considerations must be made as to the orientation of artificial structures within reefs. Current can have important implications for programmes, especially when taking into account substrate and AR type. In the Gulf of Mexico, Myron (2020) noted a change in macrobenthic and epifauna colonization rates on ARs linked to substrate type and the physical characteristics of the structure itself. While unable to pinpoint the exact relation between these variables, Myron (2020) believes they are crucial to the success of AR programmes and their success in mimicking local assemblages. Structures with horizontal edges were found to host more ascidians and turf, while being more susceptible to sedimentation. This manifested in "significantly lower" macrobenthic alpha biodiversity on ARs exhibiting more horizontality.

Sedimentation on structures can be reduced by lowering structure verticality and orientating ARs in the path of currents. This has the added benefits of providing continuous steam of nutrients for settling organisms and provides more opportunities for successful (both assisted and natural) local benthic colonization (Higgins et al., 2019; Raj et al., 2020; Zakaria et al., 2020). Additionally, this favours the development of benthic communities on new structures, helping to ensure a greater chance of success. However, Myron (2020) linked his findings to other researchers in the Gulf of Mexico who noted that structures not resembling natural environments acquiring higher rates of invasive benthic species. This also demonstrates how AR structures can alter local environments if considerations are not put towards the effect of current, orientation, depth, and overall location.

Orientation of AR compared to surrounding substrate should also fall under consideration. Sandy substrate in areas of high turbidity or strong currents can add to the issues faced by horizontal structures (Jayanthi et al., 2020; Myron, 2020; Raj et al., 2020). In the Gulf of Mannar, ARs were purposefully placed on sandy substrate and orientated in ways that led to the success of their respective programmes. In the case of Jayanthi et al. (2020), this involved blocking the natural process that was eroding local sand banks and reducing marine habitats, while Raj et al. (2020) noted rapid natural coral attachment on AR structures that were placed near healthy natural reefs. In the Red Sea, Higgins et al. (2019) created floating portions anchored to the bottom in order to negate the effects of sedimentation and maximise areas for benthic communities and local fish assemblages to make use of limited AR space.

3.1.4 Substrate

As aforementioned briefly in the above sections, substrate is known to both be affected by and affect artificial reefs implementation. The literature widely acknowledges that hard substrate – let that be coral rubble, rocky outcrops, or loose consolidated conglomerates – are more likely to help with a structure eventually becoming a part of the local environment (Boström-Einarsson et al., 2020; Komyakova et al., 2019). Two wide-ranging meta-analysis of coral reef rehabilitation, one on substrate stabilisation (Ceccarelli et al., 2020) and another on best practice (Boström-Einarsson et al., 2020) identified how ARs present on low-stability substrate had lower coral transplant survival rates than ARs built into or submerged on harder, more consolidated substrate.

The use of seagrass beds as a substrate for ARs has seen some positive results among conservationists (Kilfoyle, 2017; Layman et al., 2016), as a result of substrate stability and high opportunities for colonization by species commonly found within seagrass environments. Sandy substrates have a higher chance at producing biodiversity (Campos et al., 2020; Folpp et al. 2020; Hylkema et al., 2020) but at the expense of altering the local environment at a level that can be deemed damaging (Fukunga & Bailey-Brock, 2008; Hammond et al., 2020; Kilfoyle, 2017). By adding a new physical layer where there had previously been none, it can alter currents and biological processes associated to them. Jayanthi et al.'s (2020) project to create more physical surface area to create new reef environments by using ARs to accumulate sand is a good example of what effect these structures can have on local areas.

Further studies have shown that the use of sandy substrates far from natural reefs can lead to rapid algal growth on the structures themselves due mostly to a lack or limited amount of grazers. In some cases, the added natural algal growth on ARs led to a shift in community composition (Hammond et al., 2020; Kilfoyle, 2017). This highlights the need to ensure location where ARs are being deployed has species capable of handling added algal growth, or alternatively, creating a slow progressive AR deployment plan that does not overload the local environment or risk a failure to create a viable marine conservation environment (Lechanteur & Griffiths, 2001; Hammond et al., 2020). In the context of climate change and the increasing amount of strong storm events, the need for a strong substrate base and equally strong AR is especially important (Ceccarelli et al., 2020; Hylkema et al., 2020; Kilfoyle, 2017; Ng et al., 2017). As such, recommendations for conservation or rehabilitation projects should rest on using hard substrate, or through the stabilization of coral rubble adjacent to natural reefs.

3.1.5 Associated Organisms

When combined with local organisms – such as macro-algae or coral reef – ARs were more likely to quickly attract new inhabitants and mimic local reef assemblages (Boström-Einarsson et al., 2020; Campos et al., 2020; Kilfoyle, 2017; Komyakova et al., 2019). Combined with positioning close to natural reefs and within prevailing currents, associated organisms can thrive and quickly become a part of the local reef ecosystem (Campos et al., 2020; Raj et al., 2020). While the use of coral nurseries and macroalgal transplants as a means to populate otherwise bare ARs has been used for several decades (Jaap, 2000; Edwards & Gomez, 2007), there remain some insights regarding to best practice:

- Coral transplantation has continued to show positive signs as far as helping AR structures become viable habitats for fish assemblages (Zakaria et al., 2020);
- *Acropora spp.* are one of the best coral species to transplant, exhibiting fast growth rates, higher survivability rates than most other coral species while providing another level of complexity to ARs (Montoya-Maya et al., 2020; Munasik et al., 2020);
- Verticality/horizontality as it pertains to sedimentation is an important consideration to make to ensure associated organisms are able to survive (Munasik et al., 2020; Myron, 2020);
- Transplanting associated organisms may be more favourable after the AR has settled for several weeks as to not create competition between transplants, fouling organisms and benthic colonizers (Kilfoyle, 2017; Myron, 2020);
- Proximity to reefs and shallow deployment of ARs can have a positive effect of coral transplant success rate, however, if these same areas see high levels of wave action, it could lead to higher mortality (Munasik et al., 2020);
- Large transplantation of entire coral colonies onto hard substrate has shown success as an effective way of rehabilitating natural coral reefs without ARs (Montoya-Maya et al., 2020);

- Larger, mature coral transplants (>15cm) have more chance to recruit and speed up the reef rehabilitation progress (Montoya-Maya et al., 2020); and
- ReefBalls are more efficient when used with associated organisms (Hylkema et al., 2020; Komyakova et al, 2019; ReefBall, 2008).

3.2 Artificial Reef Types

Over 60 different artificial reef types were described in the collected papers. In general, ARs that were custom-built to fit the local environment were more successful, and projects which combined multiple different styles in villages were found to mimic natural reef assemblages the best. Below are the designs that researchers identified as having positive impacts on biodiversity:

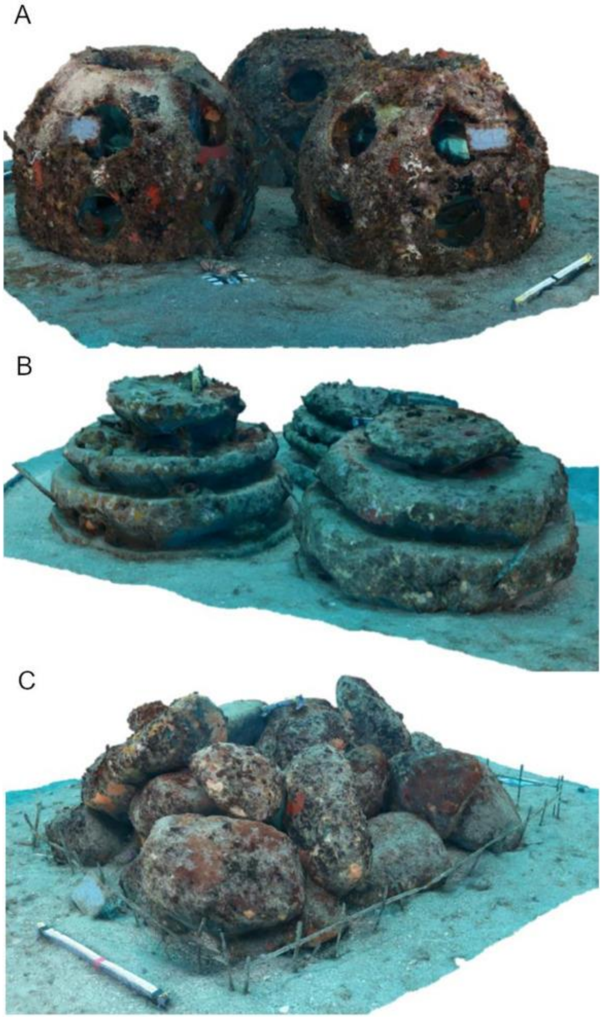

Image 1.0: *Three types of ARs used in Hylkema et al. (2020) study, taken from paper.*

Hylkema et al., 2020 (figure inset) compared ReefBalls (A), layered cake (B), and locally sourced basalt rock (C) plots in the Caribbean. Their conclusions were that all structures led to higher fish abundance, biomass and species richness when compared to the control plot. Layered cake performed better than ReefBalls after one year of colonization and suggested that the local volcanic rock plot (which cost 4-10x cheaper) which had intermediate values throughout the study would be a better option than ReefBalls should results continue on the current, monitored trend.

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Raj et al., 2020 and Jayanthi et al., 2020 both used similar ferro-cement structures (figure 1.1) that proved to be successful in the Gulf of Mannar. These ARs saw rapid coral growth and colonization from other benthic species.

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Tessier et al., 2015 alone used 32 different artificial reef structures to cater for the variety of fish assemblages across France and overseas territories. However, their management approach called for combining a multiple ARs into a “village” as can be seen in figure 1.2.

The floating design used by Higgins et al. (2019, figure 1.3) in the Red Sea created more opportunities for benthic growth and reduced issues caused by sedimentation. Use of ceramic tiles is fairly prevalent throughout coral restoration efforts but having them ‘float’ led to a biodiverse assemblage on different ceramic tile orientations.

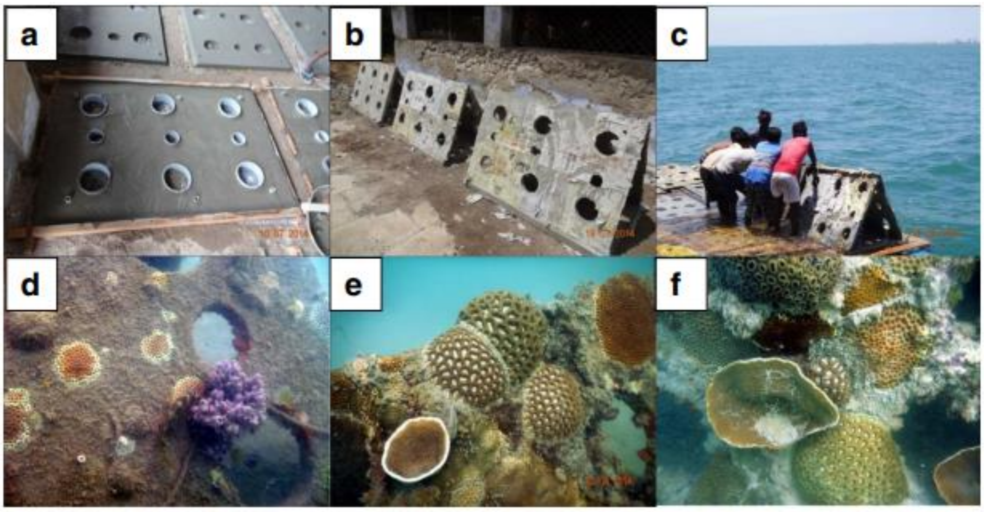


Image 1.1 (inset): *Ferro-Cement structures used by Raj et al. (2020), labelled as: "a. Construction of AR modules; b. Constructed AR modules; c. Deployment; d. Coral attachment in 2008; e. Coral attachment in 2014; f. Coral attachment in 2017", taken from paper.*

Image 1.2 (below): *Village-style AR deployment used by Tessier et al., 2015, taken from paper.*

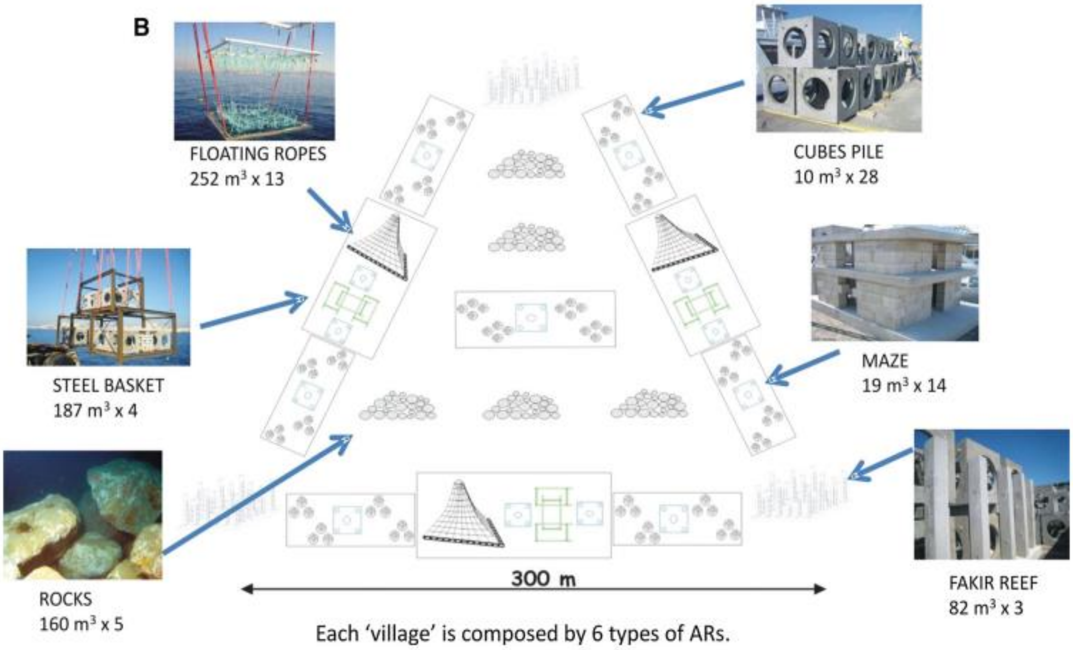
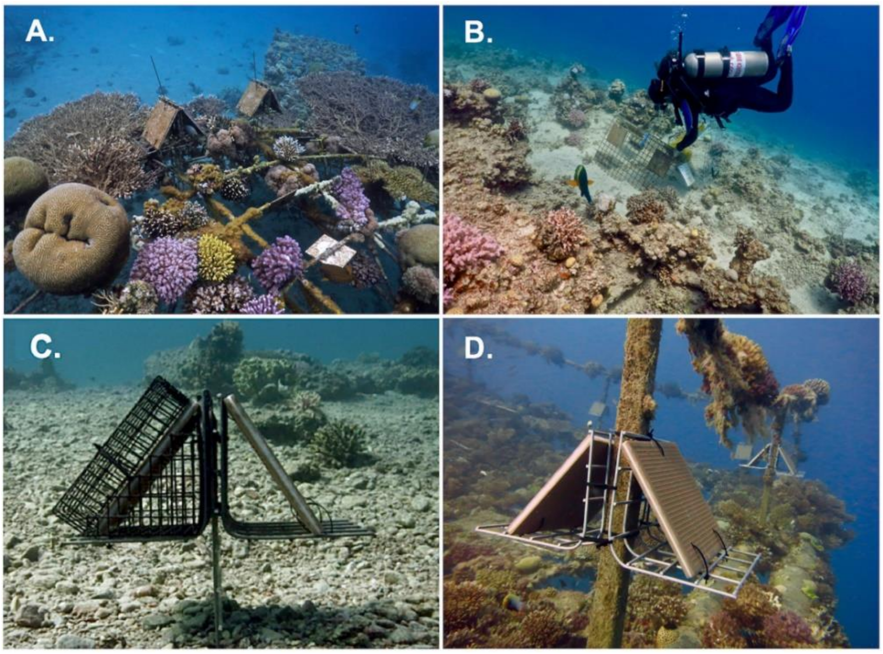


Image 1.3 (inset): *Floating AR structures used by Higgins et al., 2019, taken from paper.*



4.0 Discussion

4.0.1 Factors

Artificial reefs as a tool for ecological conservation have been used for decades. However in that time span there remain many unknowns and intangibles within the discipline regarding best practice in project management, monitoring, or the scientific reasoning behind certain programmes. A majority of researchers called for more time to be spent going over guidelines and the decision-making process behind AR programmes (Boström-Einarsson et al., 2020; Ceccareli et al., 2020; van Oppen et al., 2017).

While there is a wide gap in knowledge in different regions, the data collected suggests that there are overlaps in how ARs can help conservation and rehabilitation efforts - the biotic and abiotic factors laid out in section 3.1 represent an up-to date gathering of current knowledge. However, on top of these general trends identified in the papers analysed there were several points of contention regarding the roles of artificial structures, how they should be used, and the management of them.

4.0.2 Roles of Artificial Reefs

Structures that are built to match the local ecosystem from a physical and ecological standpoint have a good chance of showing signs of success as a tool for biodiversity conservation – but the opposite is also true. Several researchers were dubious of the use of ARs in situations where local reefs were either too degraded for structures to be of use, but also in cases where structures were not deemed to be adequate from a scientific level.

This can be seen in papers such as Friedlander et al. (2014) or Streich et al (2017), which primarily sought to investigate the effects of non-conventional ARs (old industrial equipment, oil rigs, etc) for commercial fishing practices and to form bridges between different biological communities. Their recommendations suggest that these ARs are successful in a commercial sense, but do not weigh in on the impact on the environment and how it impacts local biodiversity. On a smaller scale, ARs for their value as recreational or artificial fishing practices such as those reviewed by Folpp et al. (2020) or Mablouké et al. (2013) demonstrated:

- The attraction created by ARs;
- How fisheries ARs can affect local populations; and
- ARs can be used without consideration for conservation/environmental management.

The latter being at the crux of the debate between conservation-minded researchers and those investigating how these structures can be used to benefit fisheries or tourism. This somewhat reflects current tensions globally between environmental concerns and economic bottom-lines, but creates an interesting paradigm for environmental managers. The exact specifications that make an artificial reef successful from a conservation perspective are the opposite of those for commercial reasons (Lemoine et al., 2019). Structures sunk farther offshore with high verticality (both designed ARs and shipwrecks/oil rigs) do not mimic the local expected assemblages within those areas (Jones et al., 2020; Paxton et al., 2020a). They attract predators and larger visiting species and are not suitable habitats, creating the ecological trap that researchers have warned about conservation based ARs that do not meet the above biotic/abiotic factors (Komyakova & Swearer, 2017; Mablouké et al., 2013).

How do these non-conventional ARs fit in the mold of marine biology, conservation and environmental management in an atmosphere where research funding is limited, climate change is having severe impacts on marine ecosystems, and we still lack a complete understanding of global coral ecosystems?

The line of demarcation between success and failure of an AR seems based more so on the role it is set out to accomplish – but the potential negative impacts have led to certain researchers to echo the sentiment set out by the Precautionary Principle (Komyakova et al., 2019; Montoya-Maya et al., 2020). Where certain papers vocally advocate for continued support and research in AR programmes aimed at conservation and rehabilitation of damaged areas (Boström-Einarsson et al., 2020; Puspasari et al., 2020), others are less supportive – whether it be because of the perceived environmental impacts of adding to the environment (Fukunaga & Bailey-Brock, 2008; Hammond et al., 2020), or uncertainty as to how these programmes can succeed without greater support (Boström-Einarsson et al., 2020; França et al., 2020).

4.0.3 Management & Monitoring

Where the debate forms a consensus is on management and monitoring. Overall researchers were quasi-unanimous in calling for more of it, with case studies on opposite sides of the spectrum showing what it could achieve (Ng et al., 2017; Tessier et al., 2015). The addition of more protected areas as well as better understanding of the environment that managers and researchers would be working on was also identified as key components linked to the success of any programme. However, funding and manpower remain the underpinning factors critical to success.

Below is the decision tree set out by van Oppen et al. (2017) that represents the best ways to form strategy and management of reef programmes using cryrepositories. While this figure – much like a lot of the information conveyed throughout this paper – may seem like a common frame of thought, the experiences relayed through the analysed papers indicate that it isn't. The main framework proposed by this decision tree can be adapted to any rehabilitation programme.

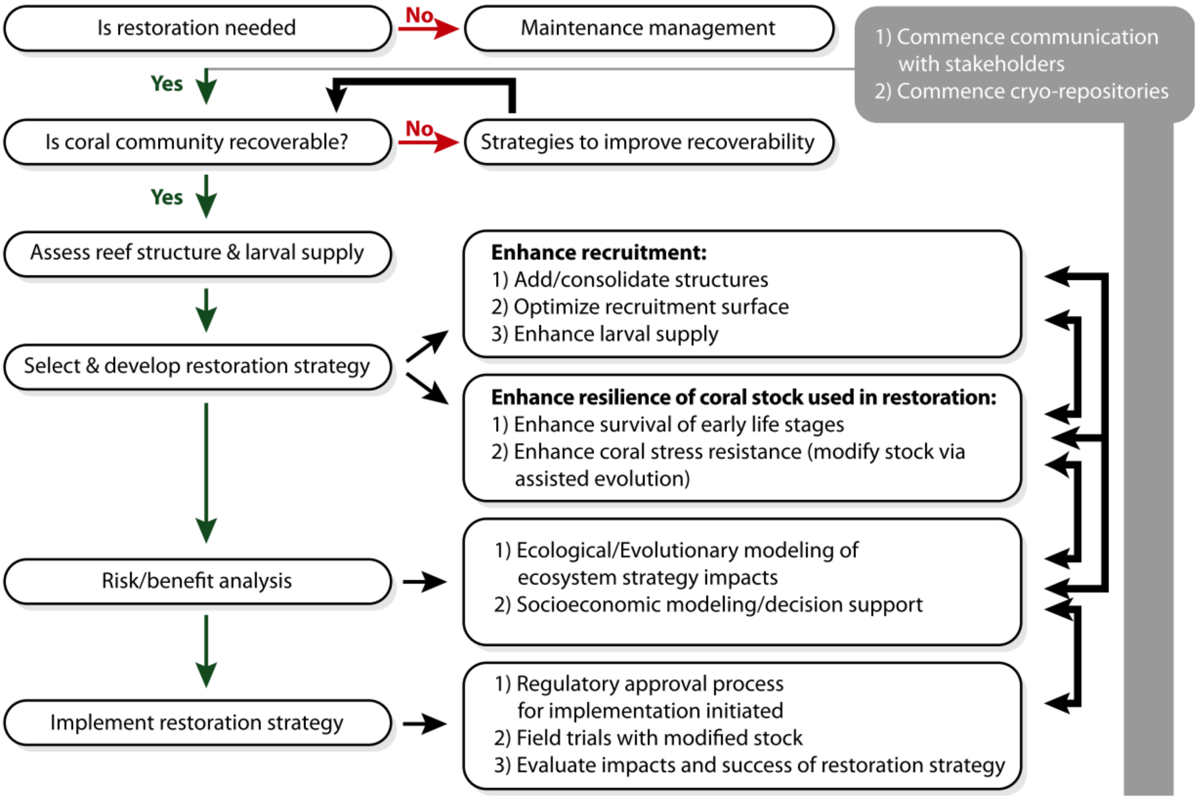


Figure 1.1:"*Proposed decision tree for coral reef restoration including assisted evolution*" - taken from van Oppen et al., 2017

5.0 Conclusion

Coral reefs are an important resource – let that be from an economic, scientific, social, or biodiversity viewpoint. Anthropogenic climate change is threatening to reduce these biomes to a level that is not sustainable for continued ecological use. Artificial reefs provide one of the best tools to help rehabilitate damaged coral environments and protect the biodiversity that rely on them. On top of backing the recommendations made by a vast majority of coral conservation papers calling for more funding, research, monitoring and large-scale action – this paper provides a basic overview of the best practice for ARs within a conservation mindset.

As such, this review's recommendations based off the literature would be to prioritize rehabilitation efforts on damaged reefs by submerging different types of structures together, close to, or on natural reefs within shallow waters. Structures should be complex, rigid, heavy, lack horizontality and provide habitat opportunities that fit local fish assemblages. Associated organisms should be transplanted or attached from the onset, but careful monitoring and management of ARs should be carried out to maintain transplants as well as provide opportunities to add loose broken corals found nearby to the structure.

6.0 Acknowledgements

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