Farming the High Seas:

An adaptive approach for the inhabitation of oceanic recirculation gyres

by

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Author’s Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Ocean management authorities predict that global fish stocks will be severely depleted by mid-century unless commercial fishing practices are greatly modified. This thesis considers aquatic architecture in general, and explores in particular an experimental design for floating colonies that follow oceanic circulation gyres for the development and management of high sea fisheries. Because these colonies would be isolated from other human communities for much of the time, they would need to be capable of being self-sustaining. The colonies could provide all of their own power, shelter, food and water, but they have been designed to generate a surplus of energy and protein. In the interest of diversifying the resources available to their inhabitants and reducing pressure on wild fish stocks and non-renewable energy sources, the colonies could trade fish and power with coastal nations as they travel around the gyres. Geopolitical ramifications of High Seas inhabitation are also considered.

A range of books, journals, websites and documentaries were studied in order to gain a broad understanding of the historical, ecological, and political context of drifting High Seas resource and research stations. The design of the structures presented is informed by environmental factors such as wavelengths in stormy weather, psychological and physiological concerns such as isolation from society, exposure to an extreme and highly changeable environment, fish behaviour and nutritional requirements of aquatic species at various trophic levels. The location of the project has been chosen based on current and historical environmental and political conditions such as fish migration patterns and the slow rate of change for international law.

Acknowledgements

Many thanks to my supervisor, Elizabeth English, for guidance, patience and support, to my committee member, Simon Courtenay, for insight and encouragement, to my readers, Terri Meyer Boake and Margaret Ikeda, for generously agreeing to examine this thesis, and to Val Rynnimeri for suggesting ocean fisheries as a research subject. Much gratitude to Eddy Edgar for technical and emotional support throughout the thesis writing and assembling process, and to Susan Davies and Bentley Jarvis for editing and encouragement.

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There is something immediate about living on water. It is the constant motion of waves, currents, tides, and winds. A motion not so much observed as it is felt. One is not surrounded by it, but is part of it, in it. Because of the ever-changing character of water – whether it be daily tides, flood conditions, drought or seasonal weather changes – one's houseboat is always responding to its environment.

Mark Gabor, Houseboats, p.6

"What we've got up here is an entire industry in a mad scramble to cut its own throat."

A Scottish fisherman's opinion on the North Sea fisheries, as quoted on p. 216 of Seven Tenths, by James Hamilton-Paterson

"We feel that the sea age is soon to come."

Jacques Cousteau, The Silent World, p. 222

Chapter 1
Introduction

The relationship between the oceans and human beings is a longstanding one. For millennia, we have taken advantage of many useful attributes of these large bodies of water, especially their capacity to nourish us and to facilitate travel. However, the rate at which technology has advanced in recent years has been such that we now have the noticeable ability to alter our surroundings on local, regional and global scales.

If we could be absolutely sure of the consequences our actions have on our environment, and be confident that the decisions being made by governments and corporations were made with the best interests of all humans, and by extension, all living organisms, then humanity's ability to modify the planet might be seen as an entirely positive force. But, that is not the case. In fact, the effects of global warming can be seen clearly all around the world, requiring all humans to reconsider the ways we interact with our environment and the various systems we have put in place.

Unfortunately, the reality is that the actions and reactions between human and natural forces within our ecosystems are so varied and complex that all we can really hope to do is make educated predictions, predictions which we cannot realistically hope will be any more accurate than those made by weather forecasters, as meteorological studies are only one facet of the systems which must be examined in order to gain a better understanding of the implications of our actions. When designing for a particularly unpredictable environment such as the High Seas, a flexible and adaptable approach helps to deal with unexpected changes that will inevitably occur. This thesis considers aquatic architecture in general, and explores in particular an experimental design for floating colonies that follow oceanic gyres for monitoring oceanographic conditions, the development and management of high sea fisheries and energy farming. Travelling without a fixed destination or working comfortably without a feeling of clear, linear progression is not common in the modern world, but makes sense if one wants to live in a sustainable fashion.

Sustainability, when looked at spatially, is all about loops, and on one level the cyclical paths followed by the floating communities proposed in this document could be seen to be physically tracing out an approach to living; a way of life. Since no large-scale high sea aquaculture or power generation facilities exist today, design precedents for the structures proposed in this thesis come from a range of different types of structures, vehicles and aquatic organisms. Some of the most influential objects have been fishing smacks, space stations, off-shore fish farms, oceanic drifter buoys, and siphonosphores, (defined on pages 33 and 34, and in the glossary).

Linear economic models are not serving us well on personal or global scales. As Tony Juniper noted in his 2014 article in *The Guardian*, “[t]he fact that the now dominant capitalist economic system is unsustainable is not in doubt. It has contributed to the breaching of several ecological boundaries, in relation to climate change, biodiversity loss and nutrient enrichment. At the same time as damaging the natural systems that sustain it, capitalism is also leading to increasing inequality, in turn creating social tensions that make it still more exposed” (Juniper, 2014).

Taking into account the serious ecological and economic problems associated with the majority of current fishing practices, this study looks at past and present human relationships with the sea, and explores possible large-scale oceanic interventions, offering a new approach to resource management.

Many of the fish that are caught on the High Seas, particularly the scarce and expensive bluefin tuna (*thunnus thynnus*), cannot be raised profitably or sustainably in conventional fish farms. As aquaculture typically takes place in inland or coastal areas, farmed tuna are at risk for disease. It has been found that the farther offshore fish pens are located, the lower the risk of disease (Kirchhoff et al., 2011). In addition, farmed tuna require extremely large amounts of feeder fish to survive, which makes conventional farming very expensive.

Since conventional tuna farming is expensive and difficult, and there is a high demand for bluefin tuna, the wild populations of tuna are being overfished. The overfishing is being exacerbated by the fact that the price consumers are willing to pay for these fish is increasing as their availability decreases. Currently there are restrictions on how many fish may be harvested per year, but it is difficult and impractical to patrol the high seas, and it is likely that imposing greater restrictions on the number of luxury fish that may be harvested will only serve to increase illegal fishing. It has been reported that Japan, for example, has a well-established black market for fish (Ellis, 2008).

Like ocean fisheries, current methods of energy production and consumption create global ecological problems of sustainability. The impending energy crisis publicized by high profile environmentalists such as Greta Thunberg and David Suzuki has alerted the general population to the need for a global shift in the ways in which we produce and consume energy. Harnessing the ocean's power through the use of wind and wave turbines, among other techniques, is becoming not only increasingly popular, but increasingly promising as a way to generate power in a sustainable manner (Archer, 2004).

This thesis will be divided into 3 main sections. The following chapter begins with a historical timeline for the development and modification of fishing practices around the world, followed by a review of the current socio-political concerns affecting fisheries around the world. Other business sectors facing similar challenges will also be discussed, to provide context and examples of how people are successfully and unsuccessfully attacking similar problems.

The next chapter presents the project site, ecological factors specific to the site, precedents for the structures designed, and the design drawings. These drawings will not be a complete set of working drawings. Instead, they will be a series of experiential and diagrammatic visual aids.

Because of the experimental nature of the design, creating a set of working drawings at this juncture is not feasible or realistic. Many of the techniques, materials, and locations proposed in this design have not been used in conjunction before, so there are no clear precedents or models to follow, or case studies to consult. Instead, the structures proposed are meant to act as a catalyst, a thought experiment, to promote future work on the High Seas, to provoke meditations on what fishing and research on the High Seas could look like in the near future.

The fourth section discusses ways in which the project presented could be developed further and highlights adjacent areas of study which could be examined in future papers or design projects.

Chapter 2
Literature Review and Analysis

In my literature review, I am addressing the work that has already been done in the field of deep sea fish farming and in related disciplines. I am also looking at other nomadic land and water-based communities, historical, existing, and theoretical.

Fishing and Fish Habitat

Early Fishing

Fishing has been practised by hominids since prehistoric times. In fact, based on new discoveries, some scientists have recently challenged the theory that humans evolved on the savanna. Evidence has been found to suggest that early hominids fished using their hands and the same tools they used to hunt land animals. It is interesting to note that although the prevalence of hunting decreased with the development of agriculture, subsistence fishing has persisted until the present day. Socially, hunting became a high status sport, a pastime for the wealthy, and with the exception of sport fishing, small-scale fishing became associated with lower-status people; poorer people who had to fish to survive (Sahrhage and Lundbeck, 1993).

Fishing with hand-held or hand-deployed tools to support oneself and one's immediate social group is likely the most ancient type of fishery. The tools and methods used by small-scale subsistence fisheries are the most stable and relatively unchanged fishing apparatus used throughout the ages. For centuries, spears, rods, and traps were the primary tools used by subsistence fishers (Roberts, 2013). Small boats, ranging from logs, rudimentary rafts to open sailed or paddled boats were a major innovation which allowed small-scale fishers to increase their fishing range, thereby increasing the potential for greater and more diverse catches. About 100 000 years ago, during the Paleolithic age, it appears that most fish were caught by hand, possibly aided by stone barriers placed in streams and rivers to direct the route of fish to be caught (Sahrhage and Lundbeck, 1992). By 50 000 years ago, humans had started to use wood, horn, ivory and bone to fashion sharpened and barbed tools to help facilitate both fishing and large game hunting. Fish lances began to be used during this period, but it is unlikely that hooks and lines were used this far back. “Real” harpoons may have been used during this period as well, but there is no clear evidence that lines were attached to the hunting lances.

It is worth noting that looking to historical fisheries and hunting practices as models for sustainable fisheries of the future is not necessarily a good idea, since many, if not most, of the fishers and hunters of past ages were not concerned with sustainability, and did not necessarily practice managed or limited harvests by choice. In the past, fishers and hunters were not as efficient as they are today, so they typically did not cause devastation and alteration of ecosystems as rapidly as in the modern age. However, despite using less efficient harvesting methods, there are historical examples of mass extinctions caused by humans who appeared to be unconcerned with their environmental effects. Overfishing and overhunting have been happening for millennia.

For example, 40 000 to 50 000 years ago, hunters arrived in Australia, and exterminated many species. Eleven thousand to 13 000 years ago, there was a mass extinction of large mammals in North America, which also corresponds with the arrival of humans (Pauly, Watson and Alder, 2005). More recently, it has been well-documented and is common knowledge that in recent centuries humans have expedited the extinction of species such as dodos, certain types of whales, and many smaller, less publicized organisms. These species had to contend with other adverse factors as well, but there are clear correlations between the appearance and interference of humans, and the decline and sometimes total extinction of other organisms. Creatures which evolved apart from humans can be seen to be especially vulnerable to human influence. Since humans are the most efficient, effective predators on the planet, creatures which evolved without any human exposure are especially vulnerable to rapid, mass extinction. This has been very apparent for land animals, but the destruction of marine wildlife is perhaps even more of a concern, since there are so many unstudied and understudied parts of the ocean. Because we do not know what’s there, we are potentially decimating or wiping out entire species before we even realize that they were there.

Large-scale Fishing

Improvements in ship-building techniques made large-scale, commercial or government-run fisheries increasingly viable options. The further and faster ships were able to travel, the greater the opportunities to harvest greater quantities of fish, and more diverse types of sea creatures. Some fleets developed systems where the vessels catching fish would stay out for multiple weeks. Other boats would bring supplies out to the fishing boats and take the catch back to shore. Some of the fisheries and resource extraction operations were driven by innovation in other sectors.

A few centuries ago, for example, whale oil became highly sought-after as lamp fuel, and whale bones became useful for corsetry, prompting large-scale whale hunts around the globe. Whales have been hunted off the coasts of what is now known as Norway and possibly Japan for over 4000 years, but it did not become a global phenomenon until the 1700's. "Whaling in the United States hit its peak in the mid-1800s. New technologies, including gun-loaded harpoons and steamships, made whalers around the world more efficient. The American whaling fleet, based on the East Coast, operated hundreds of ships in the South Atlantic, Pacific, and Indian Oceans. Whaling was a multi-million dollar industry, and some scientists estimate that more whales were hunted in the early 1900s than in the previous four centuries combined" (Marrero, 2011).

Inland fisheries currently account for only a small portion of total global catch, but they are still worth mentioning to provide a more comprehensive view of the world's fisheries. In 2016, 12.8 percent of total global catches came from streams, rivers, lakes, and other inland bodies of water. Eighty percent of these catches were in Asia (FAAUN, 2008, p.5).

Aquaculture

Aquaculture is an ancient pursuit; for centuries people worldwide have been farming aquatic plants and animals. Historically, aquaculture, and indeed any sort of agriculture, was practiced in order to improve the quality of life: it increased the amount of food available locally; it required less energy to harvest and ship food than to gather plants or hunt animals; it made the food supply more predictable and reliable because food could be stockpiled and allowed greater control of food quality.

The earliest records of fish farming date back to 3500-4000 BCE. in China, where carp in particular were farmed. The earliest known publication dealing with aquaculture is also Chinese; around 500 BCE Fan Li wrote a manual called "Fish Husbandry". Li's writings were brought to Europe after the Roman Empire had stretched its influence as far as China, and from the 5th to 15th centuries, carp farming was practiced in and around monasteries in order to help meet the Roman Catholic Church's requirement for the consumption of fish on Fridays. Fish farming was also conducted by secular groups during that time; Charles the Great (circa 800 CE) ordered the construction of fishponds during his reign in order to decrease pressure on producers of other meat products (Taube, 1951).

Modern fish farming still has a strong eastern bias. Over 90% of global aquaculture production and 80% of total production value is Asian. Europe is the second greatest aquaculture producer. In 2000, it was projected that by 2030, the human global population would grow by 36%, from 6.1 billion in 2000 to 8.2 billion in 2030. According to most fisheries experts, oceans can sustainably support capture fishing of 80 to 100 million tonnes of fish per year, but if we continue to catch fish at our present overfished rates, a global shortfall of 50 to 80 million tonnes has been projected.

In addition to being environmentally unsustainable, current capture fishery practices are financially unsustainable; globally, catching fish costs 25% more than their market value, so that many fishing operations are heavily subsidized by governments (Tibbetts, 2001). Examples of a modern type of aquaculture enclosure used for raising oceanic fish can be seen in the following photograph (Fig. 2.1).

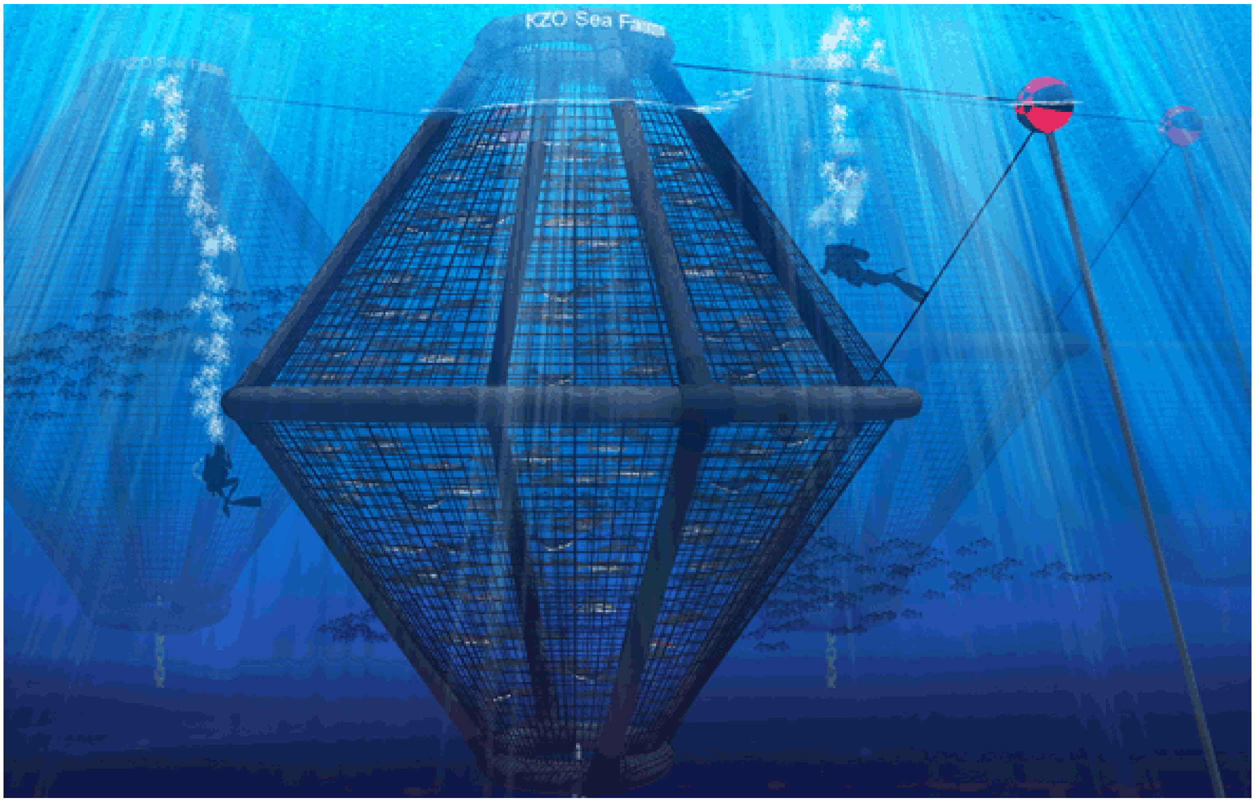


Fig 2.1 Modern aquaculture netted enclosure. Fish enclosures of this type are typically anchored in shallow water near the shore.

Modern Industry Reviews

In recent years, there has been growing concern about the critical state of the global fisheries. Two books that even-handedly and precisely lay out the extent to which global fish stocks have been depleted are *The End of the Line* (Clover, 2006) and *Tuna* (Ellis, 2008). In this thesis, my research and design will be focussing on fish in the North Atlantic, particularly on the food chain comprising plankton, herring and bluefin tuna. I have chosen these species because they are an important, representative food chain in the North Atlantic. Tuna is a keystone species; even small changes in the tuna population can have a profound effect on species further down the food chain, resulting in lower biodiversity. I chose bluefin tuna in particular because this species is currently the focus of widespread popular concern. Projects such as the one proposed in this thesis have a greater chance of of gaining popular attention and political support than projects that have lower visibility.

Philosophical and geopolitical concerns

The United Nations Convention on the Law of the Sea, or UNCLOS, is the current document governing the High Seas. UNCLOS was put into action in 1982. Even though it is not quite forty years old, UNCLOS is in need of major revisions to address how it is currently being interpreted and to take into account new data concerning global warming, depletion and range of fish stocks, and other phenomena influenced by human activity on the High Seas.

For example, when UNCLOS was signed, it seemed inconceivable that humans would one day be able to mine the ocean floor, and fishing on the High Seas was minimal, so the statement that the ocean floor and all its resources were the 'Common Heritage of Mankind', to be enjoyed equally by all, seemed like an uncontentious statement, meant to help facilitate naval travel. However, this portion of UNCLOS only protects non-living resources, leaving fish stocks and any other resources in an exploitable loophole. "Essentially, the international legal principle of 'freedom of the high seas', intended to protect navigation rights, risks generating a 'free-for-all' on exploitation" (Watson, 2019).

At the moment, work is being done to amend UNCLOS, adding provisions and clarifications to close the loopholes. This is not a quick process, and has its pros and cons. Although the drawn-out nature of international policy making will allow for continued exploitation and unequal use of resources until the amendments are ratified, some of the effects of a slow modification process are positive. There is still time to involve more stakeholders in the decision-making process who are typically excluded, be it intentionally and unintentionally. There is still time to try out alternative fishing models, such as the one proposed in this thesis. If these alternative, experimental approaches to managing fish stocks can be shown to be more effective than the current approaches, there might be time to include details in the new legislation which favour new fishing styles over some of the large-scale exploitive ones.

The UN's 2018 report on the state of world fisheries and aquaculture opens with a statement about the 2030 Agenda for Sustainable Development (2030 Agenda), which

> offers a vision of a fairer, more peaceful world in which no one is left behind. The 2030 Agenda also sets aims for the contribution and conduct of fisheries and aquaculture towards food security and nutrition, and the sector's use of natural resources, in a way

> that ensures sustainable development in economic, social and environmental terms, within the context of the FAO Code of Conduct for Responsible Fisheries (FAO, 1995).

This statement is in line with the recommendations being made by international non-governmental organizations such as the International Institute for Environment and Development.

Some of the stakeholders who might be involed in future international management strategies are small fisheries that have not been taken into account in international censuses, such as undocumented workers and female subsistence fishers. Despite many attempts to register fishing efforts in many countries, there are many fisheries which are not accurately recorded for a variety of reasons. Scale of operation, sexism, and location are three notable factors. In many developing nations, collecting molluscs and other tidal fish is considered 'women's work', something done to supplement the diet of families, but not done commercially. Even though there is often a significant impact on the delicate coastal regions where this sort of subsistence fishing/gathering takes place, there aren't any records kept of how many fish or other aquatic organisms are harvested and the manner in which it is done, because this type of fishing or gathering is not done for commercial gain.

Operations of this sort account for a significant portion of the the economy (in a literal sense) of coastal communities. The Merriam-Webster dictionary defines economics as "a social science concerned chiefly with description and analysis of the production, distribution, and consumption of goods and services". This definition acknowledges food production for personal use as well as for sale or trade with other people. Subsistence fishers may not be making money, but they are providing the nutritional bedrock of many coastal communities, and so documenting this economic activity would be beneficial for creating more accurate economic models.

The International Institute for Environment and Development, or IIED, is a multinational independent research organization which strives "to build a fairer, more sustainable world, using evidence, action and influence, working in partnership with others" (IIED, 2019). The institute "works at the intersection of social and environmental justice – where poverty reduction meets climate action; where the preservation of the natural world meets the need to protect local natural resource rights underpinning thriving communities" (IIED, 2019).

The IIED concerns itself with international policy and governance systems for natural resources and the people who access these resources. Especial attention is paid to the most vulnerable people working in capture fisheries and aquaculture, as in the past national and international legislation has not considered and therefore protected these people.

The IIED has published several reports and papers outlining current issues with the way fisheries act and are governed around the world, and suggests policy changes that could protect environmental resources more effectively and ensure a more equitable allocation and access to organic and inorganic resources in international zones. Of particular note is the importance of small-scale fisheries and projections made for the future management of the world's aquatic resources.

In her 2019 paper 'Action for an Ocean for All: Rethinking the blue economy to be inclusive, sustainable, fair and for everyone', Maggie Watson draws attention to how the wealth disparities between different nations affect the the degree to which nations are able to access resources in international waters. It is posited that unless regulations are put in place to enforce equal access to resources, the disparity between the wealth of nations will continue to grow. At the moment, 10 nations harvest 71% of fish caught in international waters and hold 98% of the patents for marine genetic materials. However, 96% of fishers are small-scale fishers who only operate in coastal waters, which are all under the jurisdiction of nations. Over 90% of these small fishing operations are in developing nations, and don't have access to the large, open-ocean-going vessels that trawl the High Seas. Eighty-six percent of governmental subsidies go to large-scale fishing fleets, and most of these fleets are private sector operations with headquarters in developed nations. Additionally, the effects of climate change will likely continue to have a greater impact on developing nations, further exacerbating the resource inequalities (Cheung et al., 2019).

The effects of ocean acidification will be especially significant for coastal fisheries. "Coastal communities, especially in developing countries, are particularly vulnerable to global problems, such as ocean acidification, pollution and climate change" (Watson, 2019). The more vulnerable a nation, or any people group, is, the less resilient it will be. Quality of life will deteriorate.
For these reasons, organizations including the IIED have been paying particular attention to working with and studying current conditions for subsistence fishers in developing nations. At the 'Towards an Inclusive Blue Economy' conference hosted by the IIED in February of 2019,

participants discussed ways "to support coastal fisheries to become resilient for the benefit of present and future generations, and show how coastal and marine ecosystems are connected to activities in the high seas" (Watson, 2019).

Given the lessons of history, and judging by the way things are unfolding in our time, it seems likely that the "blue economy" will resemble resource extraction models of the past and present, unless policymakers and those in the private sector with disproportionately large amounts of power, such as international corporations and extremely wealthy individuals, make a conscious, concerted effort to include people from developing nations and other underrepresented groups at the decision-making table.

In 'Future scenarios and projections for fisheries on the high seas under a changing climate', Cheung et al. forecast three different ways in which High Seas fisheries could be developed over the next 30 years. The first scenario, Charting the 'Blue Course', shows how the fish stocks and revenue from these stocks would be affected if a wide variety of people were to be given access and a say in governance. The second scenario, Regional Rivalry and Rough Seas Ahead, explores the ecological and financial effects of increased nationalism, authoritarianism, and the protection of regional economies while disregarding cumulative and synergistic effects of fishing practices. The third scenario shows what could happen if current levels of marine resource extraction and consumption are maintained, but large investments in new tech-based solutions are made to mitigate the effects of our currently unsustainable practices.

In all three scenarios, oceanic resource extraction becomes less economically viable over time. In the first scenario, catches increase and there is less global wealth disparity than at present, but fisheries would operate at a net loss if national subsidies were removed. In the second scenario, catches would also go up, and deregulation and the use of slave labour would provide some financial gains at first. However, fishing beyond economically-viable targets in order to match growing demand would drive up the total fishing cost. In the third scenario, ocean fisheries would appear to be profitable over the mid-term, but over time the subsidies and investment in new tech-based ways needed to meet demand would overtake profits (Cheung et al., 2019).

Challenges faced by people in the tech sector could provide insight into effective and ineffective ways to deal with global-local challenges and disconnects, as similar problems are faced with data management and legislation for the internet. At present, both the High Seas and the web fall in a grey area in terms of monitoring and oversight.

At the moment, the rate of change and innovation in the tech sector has meant that it has been challenging and sometimes outright impossible for legislation to be relevant to the way the internet is being used, protect users and treat users fairly. Similarly, the laws governing and protecting the High Seas are very slow to be formulated and ratified by all of the national and international governing bodies, so corporations that are able to adjust to new or more expediated fishing and mining opportunities made possible by new and improved tools and technology are able to exploit the oceans in ways that were not even considered possible when the laws for High Seas governance were put in place.

In the tech sector, individual nations are starting to hold CEOs and other people in the upper management of international corporations responsible for their part in supporting or enabling murder and genocide. Complacency, lack of oversight, and lack of monitoring by international tech companies are three examples of bad behaviour that are no longer being tolerated in some nations. In 2019, following the Facebook livestream of a shooting at a mosque in New Zealand and the revelation of personal information of Australian citizens given to Cambridge Analytica, the Australian government is working on legislature that will "result in penalties of the greater of three times the value of any benefit obtained by misusing information or 10% of annual domestic turnover" (Caruana, 2019). Policies of this sort have caused tech companies to start being more proactive with their own policing. In a more idealistic world, such punitive tactics would not be necessary, but if even a few coastal nations had the authority to hold the leaders of large fisheries and resource extraction facilities personally accountable, it might dissuade these fisheries from abusing the international loopholes.

Biota Considerations

In order to create a design proposal which is supported by or challenges models of governance for the High Seas, it is helpful to have at least a cursory understanding of how various aquatic organisms behave and interact. The following section provides examples of creatures commonly found in the north Atlantic. These creatures are representatives of three different trophic levels. Relationships between different fish, such as how location of prey dictates location of predators, are discussed.

Plankton

Plankton are small aquatic organisms that drift with ocean currents, because they are either non-motile or too weak or small to swim against currents. Plankton is a food source for small pelagic fish such as herring, which are in turn eaten by larger fish such as tuna. (Bottger, 1982) The ocean currents that make up the North Atlantic Recirculation Gyre travel vertically as well as horizontally, bringing nutrients up from the deeps and making them accessible to plankton near the surface. Since ocean currents determine the speed and location of the plankton, deploying fish monitoring/harvesting stations that drift with the currents and therefore follow the plankton is a useful strategy. Due to increasing climate fluctuations caused by global warming, it has become increasingly desirable to design structures that can adapt to extreme, unpredictable change. Figure 2.2 shows the current plankton distribution in the North Atlantic Ocean.

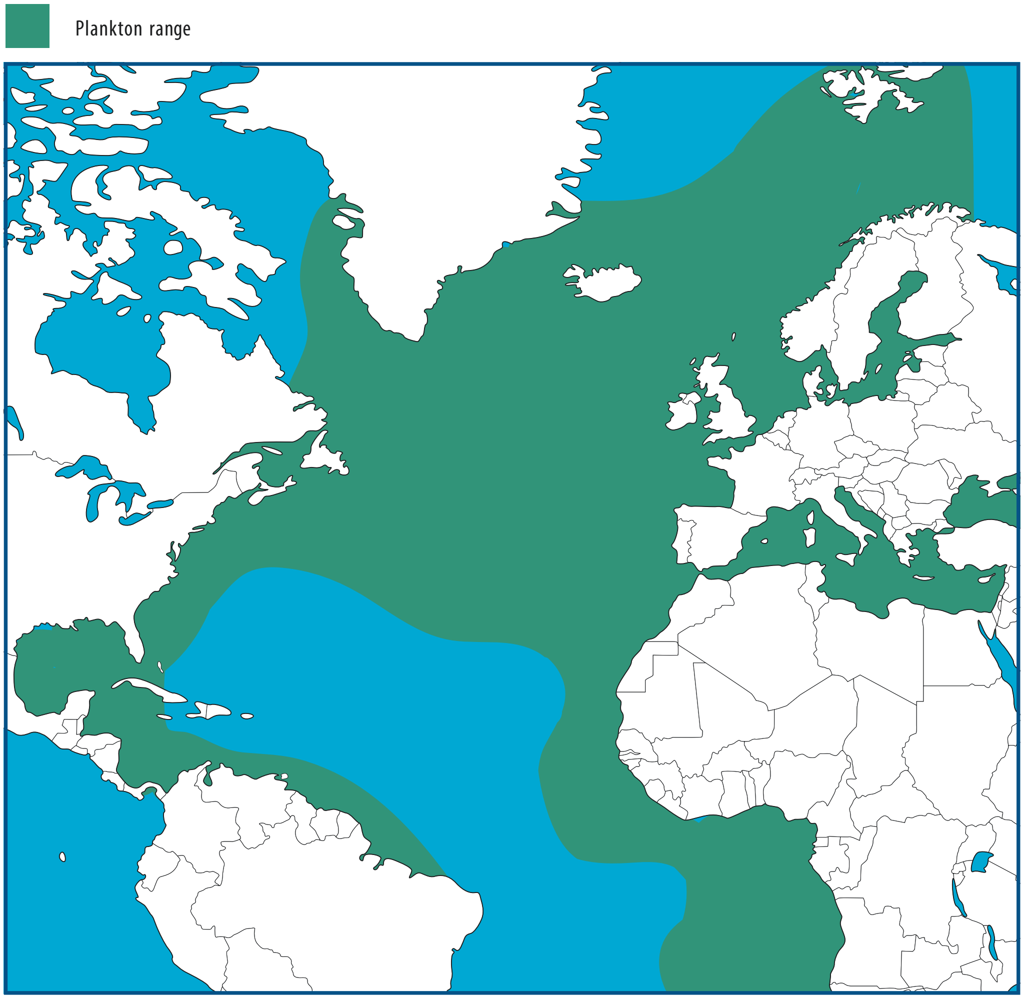


Figure 2.2 Plankton Range. Locations where plankton is typically found in the North Atlantic Ocean. Adapted from Roxana Tiron et al.

Herring

Herring (*Clupea harengus*) is one of the most abundant types of fish in the North Atlantic. Herring thrive in mixed waters and transition zones, such as nutrient-rich threshold areas caused by the interactions of cold and warm currents. (Maravelias et al., 2000) Figure 2.3 shows the current herring range in the North Atlantic Ocean.

In the past, there was relatively little concern about diminishing stocks of herring. However, even this abundant fish species is now showing signs of strain. For example, spring spawners have been in decline in the Gulf of St. Lawrence and in four areas off the coast of Nova Scotia since 2001 (Fisheries and Oceans Canada, 2015, March 6). Since herring are one of the main forage fish eaten by keystone predators such as tuna, a significant decline in herring stocks could trigger a serious decline in ocean biodiversity.

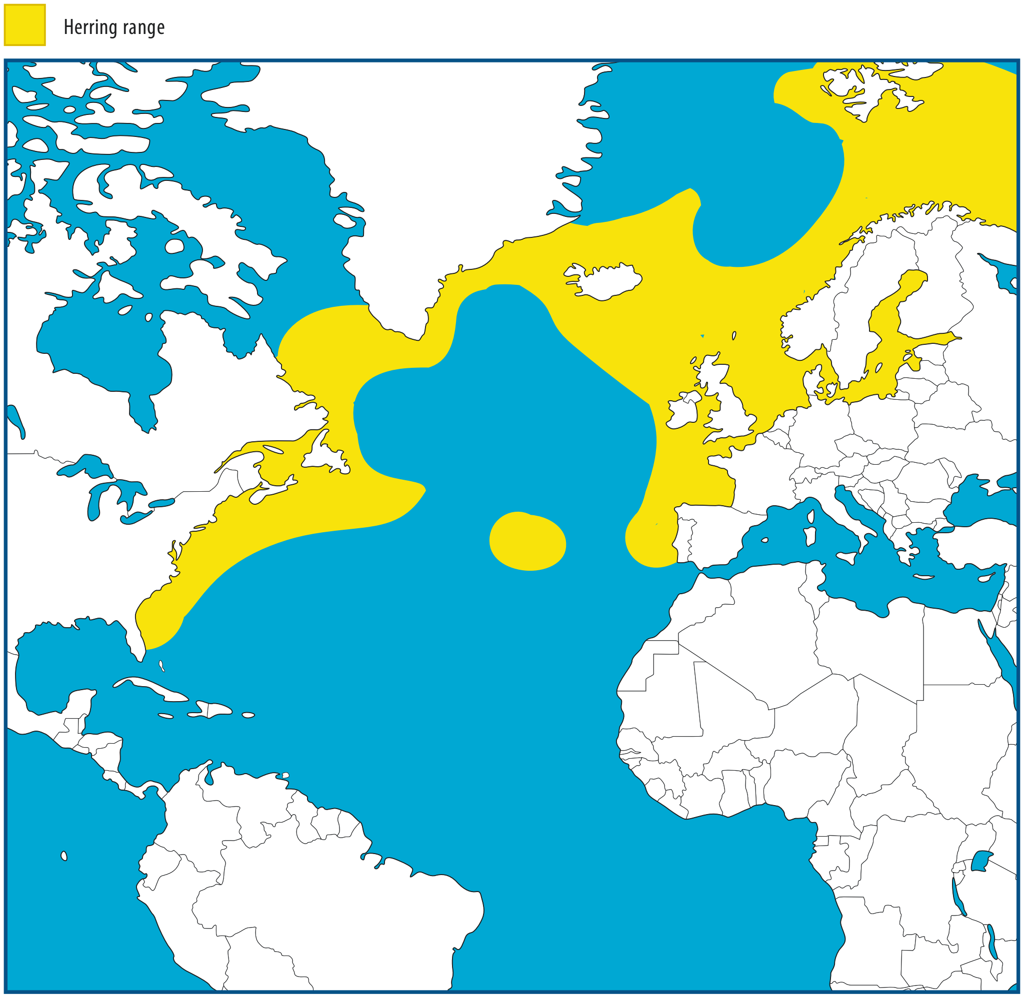


Figure 2.3 Herring Range. Locations where herring is typically found in the North Atlantic Ocean. Adapted from Misigon.

Bluefin Tuna

Bluefin tuna (*Thunnus thynnus*) is one of the most significant declining keystone species in the North Atlantic (Christensen et al., 2003). Atlantic bluefin tuna is considered an endangered species (Collette et al., 2011). Two of the primary goals of the project proposed in this thesis are the monitoring and attempted stabilization of the atlantic bluefin population. Figure 2.4 shows the current range and spawning grounds of bluefin tuna in the North Atlantic Ocean.

In 1969, the International Commission for the Conservation of Tunas was established for the management of tuna, swordfish, and other large pelagic fish. Pelagic fish are all fish that live in the upper, sunlit layers of the open sea (Fishery Bulletin, 2003). All Atlantic ocean waters, including Exclusive Economic Zones (see Fig. 2.6), coastal waters and the High Seas, are considered to be under the jurisdiction of the commision.

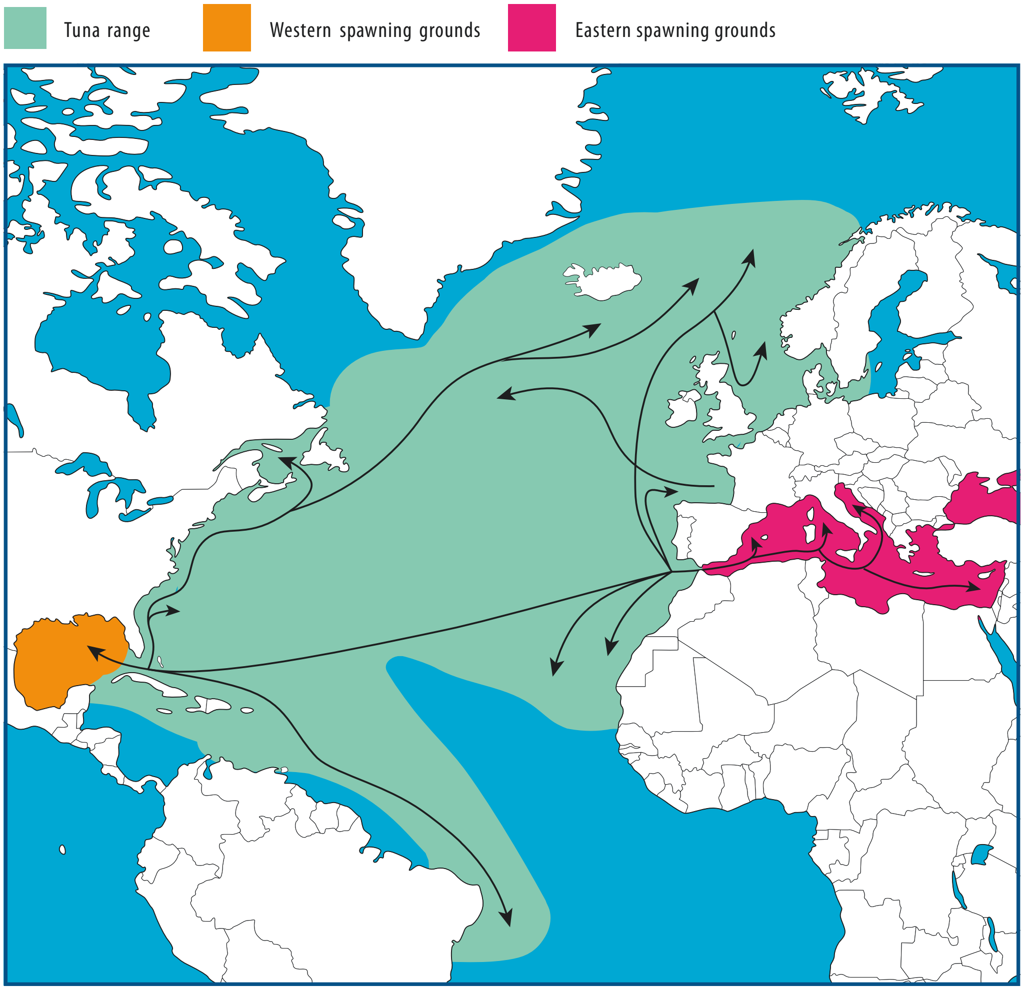


Fig 2.4 Tuna range, including spawning grounds. The arrows denote common travel routes for Western and Eastern spawners. Note the intermixing of both adult populations. Adapted from Tag-A-Giant-Foundation and Stanford University

Figure 2.5 Bluefin Tuna. Photo credit: Tono Balaguer

In 2016, the commission started tracking the international trade of Atlantic bluefin tuna. It is to be hoped that this multinational tracking system will help reduce overfishing, especially black market trade. One of the main reasons bluefin tuna is overfished is because it has such high commercial value. The average price of a single adult bluefin (see Fig. 2.5) is typically between $30 000 and $50 000 US (Nickson, 2016).

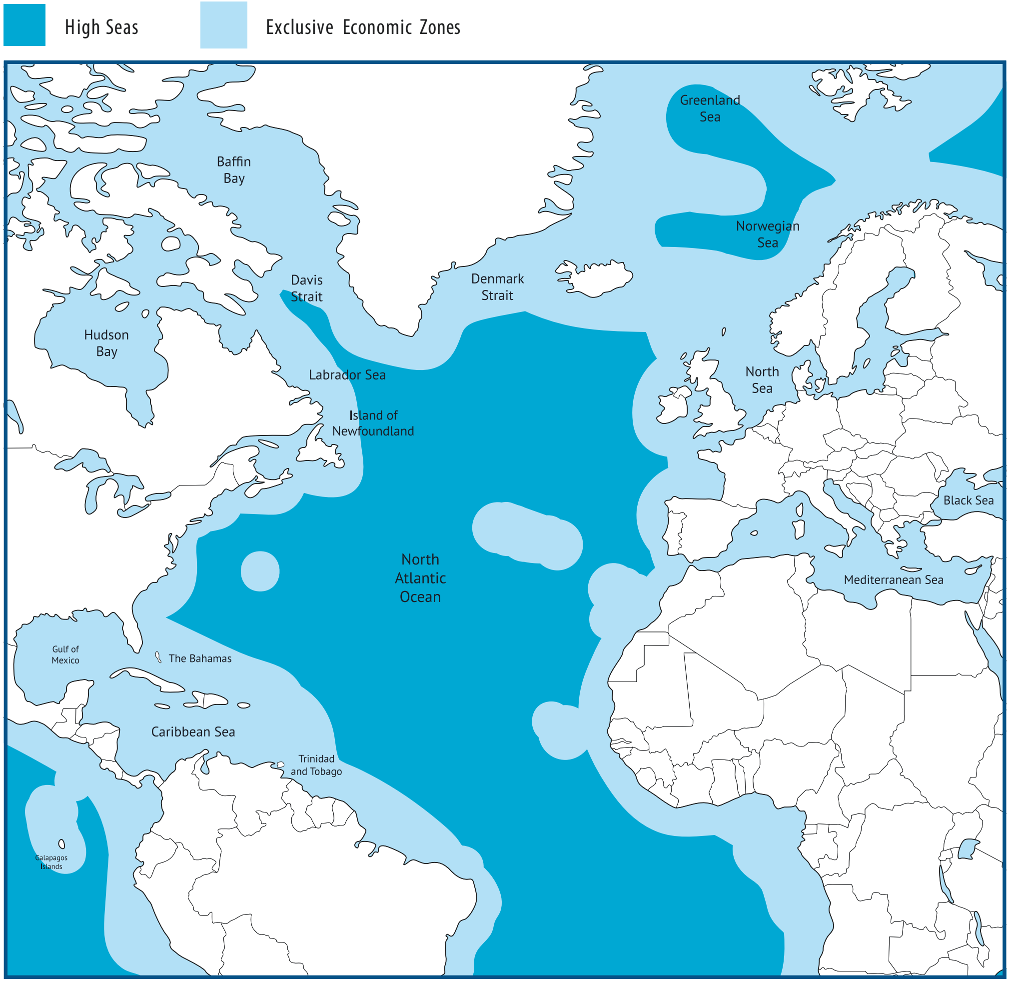


Fig 2.6 Exclusive Economic Zones (EEZs). The EEZs of coastal nations typically extend up to 200 nautical miles (370 km) offshore (Prescott, 1992). Adapted from Flanders Marine Institute.

There is another significant factor contributing to both the environmental and monetary cost of the bluefin tuna fishery: the time and resource-intensive way the fish are handled after they are caught. After the tuna are caught in the north Atlantic (Figure 2.7), many of them are flown to fish markets in Japan, sold to both local buyers and people who have flown to the market from around the world, and then driven or flown to the vicinity in which they will ultimately be consumed.

Fig 2.7 Bluefin tuna next to fisherman. Photo credit Steve Brackmann

"The rising global popularity of sashimi will surely be the downfall of the bluefin tuna" (Ellis, 2008, p.155).

Fig 2.8 Bluefin tuna sushi. Photo credit: Ethan Miller

The most expensive restaurant in New York, and possibly the world, is Masa, a sushi restaurant (Figure 2.8). Part of the cost is due to the cachet of the chef, but much of what is being paid for by diners is the cost of airlifting bluefins and other fish caught off the eastern coast of North America to Japanese fish markets, and then flying the fish back again (Ellis, 2008).

Globally, some of the most effective recent ecological conservation and rehabilitation efforts have focused on helping a specific species or protecting specific locations such as breeding grounds or coral reefs. Conservation aims to maintain current stocks and rehabilitation attempts to increase stocks to a sustainable level.

Narrowing the scope of one's efforts might seem ineffective and short-sighted but this narow focus has proven effective in helping not just a keystone species or a vulnerable location, but ecosystems as a whole. Moreover, it is much easier to rally public support for a small-scale intervention than to try to convince people that they should be fighting for an apparently overwhelming problem like the depletion of the ocean's fish stocks.

Notable examples of targeted conservation approaches are Greenpeace's Save the Whales campaign (Greenpeace, 2018) and Sylvia Earle's Hope Spots (Mission Blue, 2017).

The iconic Save the Whales campaign rallied millions of supporters worldwide, leading to a global ban on commercial whaling in 1986. Enacting anti-whaling legislation was a necessary first step and the campaign was responsible for significant change and reduction in whale hunting. It is worth noting, however, that the problem is a complex one that involves many factors. Whales are still at risk, due to illegal hunting for sale on the black market; being killed as by-catch when caught in nets meant for other aquatic creatures; accidental ingestion of plastic trash; and unavoidable ingestion of airborne chemicals and pesticides (Greenpeace, 2018). Some countries, notably Norway and Japan, continue to challenge whaling restrictions by arguing that whaling is a cultural activity (The Guardian, 2016).

In 2014 Dr. Sylvia Earle, former chief scientist at the National Oceanic and Atmospheric Administration (USA) released Mission Blue, a documentary about Earle's relationship with the ocean and the striking loss of marine plants and animals she has witnessed over her career as an oceanographer and marine biologist. In the film, Earle and her Mission Blue Team document their efforts to create marine reserves around the world. These reserves are known as "Hope Spots", which are defined as special places that are critical to the health of the ocean (Mission Blue, 2017).

Protected marine areas, including Hope Spots, currently comprise only 6% of the global ocean, but according to findings presented at the 2017 United Nations Ocean Conference, the coverage of marine protected areas has increased by 30% in the past three years, and the amount of coverage is expected to continue to grow (Ocean Conference, United Nations, 2017).

Many of the journal articles reviewed for this thesis were highly specialized scientific treatises prepared for academic audiences. Although my background is limited in biology and hydrology, I observed several overall patterns: there is much confusion about the actual number of fish in the sea, and no reliable way currently exists to monitor highly mobile populations that cover such vast areas. For example, it has long been assumed that fish spawning on the western shores of the Atlantic did not cross to the eastern shore and vice versa. (Offshore/Inshore Fisheries Department, 1988). It is now known, however, that some fish, for example tuna, cross the oceans in both directions. Consequently, some fish are being counted twice. Even if it were possible to track these mobile populations, food fraud occurs on a massive scale, with fish being caught illegally and therefore not counted (Ellis, 2008).

The mobile communities that are proposed in this thesis would travel with the fish around the Atlantic. By being in close proximity to the fish, the communities proposed would help track fish movements, help estimate population numbers more accurately and deter poaching in much the same way as neighbourhood crime is reduced by having “eyes on the street” (Jacobs, 2002).

Monitoring and Research

Integrated Global Observing Strategy

In 1998, The United Nations implemented an Integrated Global Observing Strategy (IGOS). The IGOS links “the major satellite and ground-based systems for global environmental observations of the atmosphere, oceans and land in a framework that delivers maximum benefit and effectiveness in their final use. It is a strategic planning process, involving many partners, that links research and operational programmes as well as data producers and users” (IGOS Executive summary, October 1999).

The primary focus of the IGOS is observation for data collection and distribution. The data collected is made freely available not only to researchers and policy-makers, but to the general public as well.

Global Ocean Observing System (GOOS)

The Global Ocean Observing System is the ocean-based component of the Integrated Global Observation Strategy. The GOOS is managed by the United Nations' Intergovernmental Oceanographic Commission (UNESCO-IOC). "GOOS is a global network of ships, buoys (fixed and drifting), subsurface floats, tide gauges and satellites that collect real time data on the physical state as well as the biogeochemical profile of the world's oceans" (Intergovernmental Oceanic Commission, Aug. 5, 2019). The GOOS is a fluid, regularly evaluated and modified network comprising

> a measuring subsystem, a data and information management subsystem, and a subsystem for contributing to the production and diffusion of various kinds of products: measurements and forecasts of changes in water level, positions and strengths of currents, wave heights and forecasts of unusually high waves, sea ice measurements and coverage, rainfall measurements and forecasts (droughts and floods), maps and forecasts of harmful algal blooms, assessments of the vulnerability of fish stocks and farms, forecasts of likely weather-or-climate-related disease (Intergovernmental Oceanic Commission, Aug. 5, 2019).

Argo

One of the key components of the Global Ocean Observing System is the Argo program. The Argo program uses autonomous drifters to measure the temperature, salinity and velocity of the upper 2000 metres of the ocean. The data recorded is relayed to satellites and made publicly available within a few hours of collection. The first Argo drifters were deployed in 2000. Nearly 4000 drifters are currently deployed, in order to achieve continuous, nearly complete, ocean coverage. Floats typically stay in service for up to five years, but inevitably some floats will be lost or disabled before their hoped for end-of-service date (Argo International Program, 2018). Roughly 800 new floats need to be added each year by national programs around the world to ensure that ocean coverage is maintained by the array (Scripps Institution of Oceanography, 2018).

Although it is unfortunate that so many floats are go out of service each year, the rapid turnover also allows for frequent updates and upgrades to float design. The floats of the first array, deployed nearly two decades ago, were only designed for the parts of the open ocean which don't ice over seasonally or contain large densities of islands or other surface obstacles. As well as the standard floats which dive down to depths of 2000 metres, the current Argos array contains some specialized floats. Deep Argo floats can descend three times deeper than standard floats, down to 6000 metres, collecting data near and at the ocean's floor. Biogeochemical Argo floats can measure a wider range of conditions than standard floats, including oxygen, nitrogen and pH, information that is useful for monitoring/building a picture of ocean acidification and mapping out zones with low oxygen. "Argo leaders hope to integrate as many as 1,250 Deep Argo and 1,000 biogeochemical Argo floats into the global array to bring its total size to 4,600 floats in an effort beginning in 2020" (Scripps Institution of Oceanography, 2018).

Opportunities for Enhanced Monitoring

"Almost all our observations of the ocean now come from satellites, drifters, and autonomous instruments. Fewer and fewer observations come from ships at sea" (Stewart, 2006, p. 20).

Although the integrated global observing strategy provides us with a great deal of data, there are a number of serious oceanic ecological concerns that are still poorly understood. One concerning trend is the formation of "dead zones" in the ocean, areas with low or no oxygen, creating an environment that is lethal to fish. Dead zones are created by the influx of nitrogen and phosphorus from fertilizer run-off in coastal waters. Plankton eat nitrogen and phosphorus, triggering a plankton population boom. After the plankton dies, it falls to the ocean floor, where it is eaten by bacteria which use up all the oxygen in the vicinity. Dead zones are broken up by hurricanes or dissipate over winter, when no new chemicals are poured into ocean by farmers, so it is likely that the formation of dead zones is linked to human activity (Mitchell, 2010). Systems like those proposed in this thesis would increase the possibilities for monitoring and research so that the causes, effects and extents of dead zones could be better understood and remediated.

Ideally, the colonies proposed in this project would link into and augment the Integrated Global Observing Strategy. Having human observers to make connections between data collected by autonomous floats and satellites could provide valuable insight into ocean conditions, and data could be analyzed in situ. Also, the colonies could aid with the deployment and retrieval of ARGOS floats. Since the colonies would benefit from having on-board workshops for maintenance and fabrication of equipment, it is possible that some repairs to ARGOS floats could be done at sea, rather than having to take them back to the original facilities where they were made.

Another alarming and undermonitored oceanic transformation which has occurred in the past few decades is the increasing acidification of the oceans. In the past 20 years, living coral has been destroyed 5 times faster than tropical rainforests (Mitchell, 2010). Increased amounts of carbon dioxide in the oceans increase oceanic acidity, making calcium less available to all aquatic organisms. Consequently, bone production in fish is compromised and coral reef growth is diminished (Mitchell, 2010). Some of the coral reefs documented in the last five years have been seen to transform from healthy habitats to dead zones in less than half a year, such as the one pictured in Figure 2.9 (Chasing Coral, 2017). Acidification is compounding the trauma to oceanic ecology caused by overfishing. Compromised bone production in fish and reduced coral growth caused by increased acidification need to be far better understood if we are to hope to manage them. The colonies described in this thesis could provide the ability to study vast areas of the ocean continuously over extended periods of time in order to gain a far greater understanding of the problems we face.

Fig 2.9 Healthy, bleaching and dead coral. Photo credit: The Ocean Agency / XL Catlin Seaview Survey

Precedents and Design Influences:

A body of work exists that discusses current fishing techniques, survival in adverse nautical conditions, and small-scale off-shore experimental fish farming. However, sustainable fish farming on the high seas appears to have been only marginally explored. For this reason, most of the literature consulted has dealt with aspects of high sea fish and sustainable oceanic design rather than high sea farms already in existence.

Since no large-scale high sea aquaculture or power generation facilities appear to exist today, design precedents for these structures come from a range of different types of natural and man-made structures. Objects which have influenced the project design are unrealized experimental floating communities, off-shore fish farms, siphonosphore colonies, space stations, sailing ships, coral reefs and oceanic drifter buoys.

Precedents

Unrealized Experimental Floating Communities

The idea of creating new settlements on the open ocean has appealed to people for many years. Some of these schemes have been extravagant or idealistic dreams too impractical to actually build (Wankhede, 2017), but others have been more pragmatic utopias (Ingels, 1999; Savage, 1992; Seasteading Institute, 2018).

Freedom Ship

Freedom Ship is a floating city idea being promoted by Freedom Cruise Line International. Despite being designed by a cruise ship company, Freedom Ship is a not a cruise ship, but a 25 storey-high skyscraper-esque structure that aims to include “residential space, a library, schools, and a first-class hospital in addition to retail and wholesale shops, banks, hotels, restaurants, entertainment facilities, casinos, offices, warehouses, and light manufacturing and assembly enterprises” (Freedom Ship International, 2017).

Freedom Ship is designed to be over 1300 metres long, 200 metres wide, and 100 metres high. Aircraft and hydrofoils would ferry residents and visitors to and from the floating community. Freedom Ship is intended to be constantly in motion, passing by most of the world’s coastal regions (Freedom Ship International, 2017).

In Freedom Cruise Line International’s promotional material, the company states that Freedom Ship is not meant to be a new nation or a tax haven. Although Freedom Ship is meant to behave more like a city than a cruise ship, it is technically considered a vessel, and would be subject to international law (Freedom Ship International, 2020).

Fig 2.10 Freedom Ship. Photo credit: Freedom Ship

Freedom Cruise Line first started touting the Freedom Shup idea in the late 1990's, but it is doubtful that it will ever be built. In 2017, the cost for building this massive structure was estimated at over 10 billion dollars, and it is unlikely that construction will begin in the near future due to cost and concerns about workability (Wankhede, 2017). Figure 2.10 shows a conceptual rendering of what Freedom Ship could look like.

Aquarius

Aquarius is a theoretical floating city project proposed in the 1990's. This design was based on a book called *The Millennial Project* by Marshall Savage (Savage, 1992). The city was to be built in a modular fashion with hexagonal Biorock buoyancy tanks, and linked together to form a larger structure. The city would be powered by ocean thermal energy conversion (OTEC) generators. The Aquarius Project was one of the sources that influenced my decision to use modular design, the choice of Biorock as a primary material, and the use of OTEC as one of several power generation systems. Figure 2.11 shows a conceptual rendering of the Aquarius Project.

Five different phases for Aquarius have been conceived. The first iteration of Aquarius is the Initial Moored Phase. In the first phase, the first modules for Aquarius would be built in a sheltered, coastal area (Hunting, 2006). Aquarius would either be tethered to the shore or anchored very near to the shore.

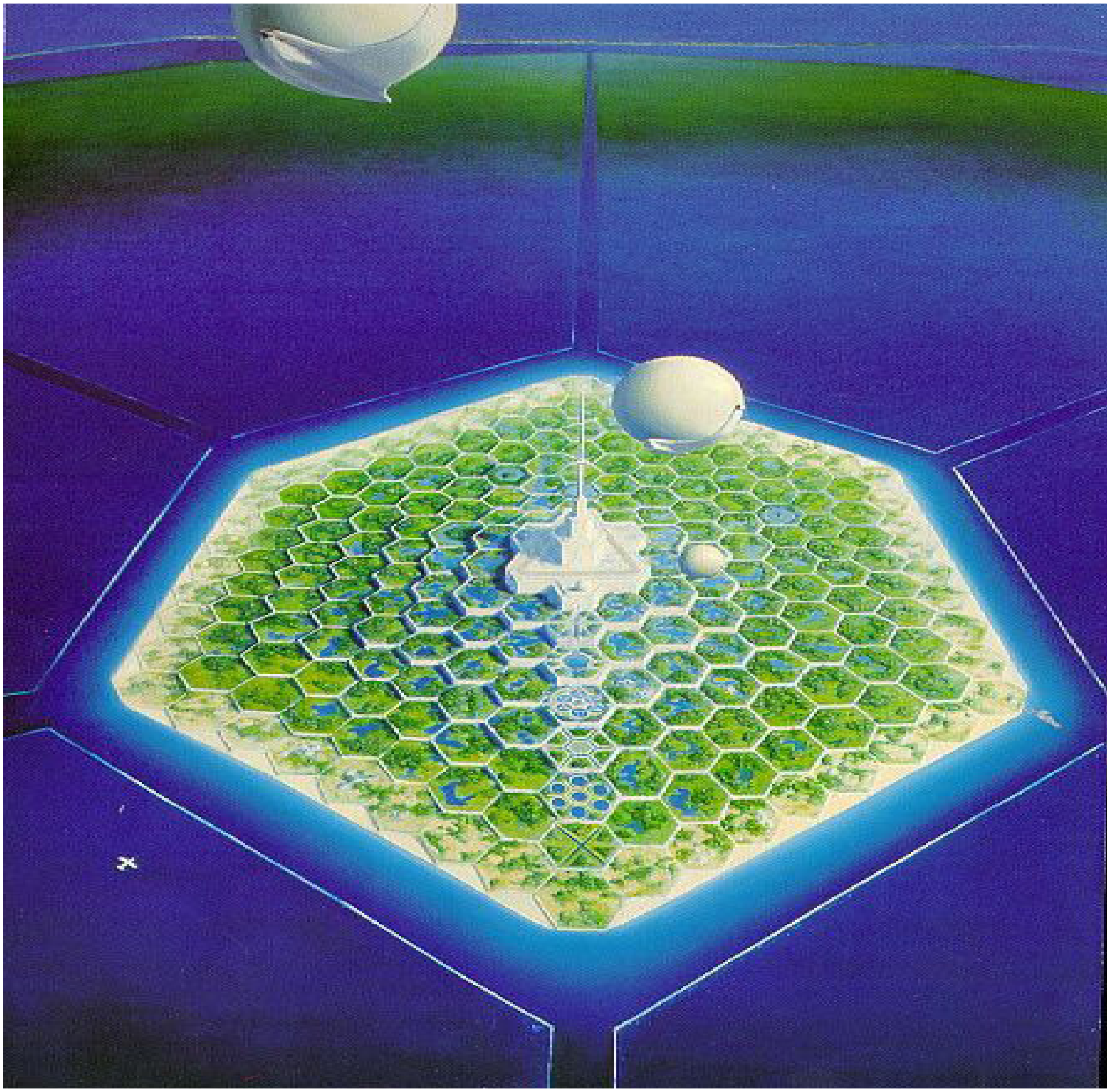


Fig 2.11 The Aquarius Project. Conceptual rendering. llustration credit The Living Universe Foundation

The second phase of Aquarius would be the free-floating stage. During the free-floating stage, Aquarius would be moved out to deeper coastal waters to allow for more expansion. Aquarius would no longer be tethered or moored, and would practice active station-keeping in order to maintain its position. Boats would be used to ferry people to and from Aquarius. The move out to deeper waters would also provide greater protection from storms. “During hurricanes the greatest threat comes not from wind but from storm surges which primarily only effect fixed moored structures at or near shore where the storm drives waves to crash against the shore and raises water levels to dislodge marinas and docks and throw vessels and debris onto the shore. Tsunamis pose a similar threat. Sufficiently far away from shore, the tsunami wave is virtually imperceptible" (Hunting, 2006).

The third phase of the project would be the platform transition phase. During the third phase, the colony units would start to swap out static floats for pneumatically stabilized platform systems Later stages of the project would see additional modules added and then the whole colony eventually being moved to an equatorial location.

The fourth phase would be the migration phase. During the migration phase, the colony would start moving out to sea, and colonies which started off seperately might meet up and join together.

The fifth and final phase would be the full equatorial colony phase. In this phase, Aquarius would reach its final location and become stationary once more. In order to maintain connections with the rest of the world, airports would be constructed, with the hope to one day replace airplanes with airships, as they have a signifigantly smaller ecological footprint.

Seastead

Fig 2.12 Seastead conceptual rendering. Illustration credit: The Seasteading Institute

Of the projects I examined, one of the ones that is most closely-related to my proposed project is Seastead, an aquatic community model created by the Seasteading Institute. The Seasteading Institute has put forward an intriguing proposal, a plan for a floating community that may actually start construction in the near future (Seasteading Institute, 2018). A conceptual rendering of a potential first Seastead iteration is seen in Figure 2.12.

The Seasteading Institute is an organization founded by Patri Friedman and Peter Thiel in 2008. Currently the Institute is working to build an initial floating island moored in a protected harbour. The ultimate goal of the Institute is to develop floating communities for the High Seas that are completely independent of all land-based nations, but as a first step, they are working in collaboration with the government of French Polynesia to build a "special economic seazone" off the coast of Tahiti. The Institute states that its plan is "to build seasteads to host profitable aquaculture farms, floating healthcare, medical research islands, and sustainable energy powerhouses. Our goal is to maximize entrepreneurial freedom to create blue jobs to welcome anyone to the Next New World" (Seasteading Institute, 2018).

A cursory viewing of the Institute's promotional material gives the impression of a very inclusive and hopeful project. However, delving a little deeper into the project as described by both the Seasteaders and others, the project is revealed to be not quite the egalitarian paradise it purports to be. The project has been dubbed "libertarian island" by some critics (Lynch, 2015). According to the promotional material, an entry-level residential unit would "only" cost as much as a Manhattan condominium.

Work towards these communities is being developed collaboratively through the production of on-line drafts of a book and a series of design competitions. Although there is a decidedly idealistic libertarian bent to this project, the Institute nonetheless presents a realistic, multi-stage deployment strategy and provides many examples of past, present and theoretical attempts at living on the water (Seasteading Institute, 2018).

Experimental Off-shore Fish Farms

Kampachi Farms

Nearly a decade ago, Hawaiian aquaculture company Kampachi Farms started experimenting with drifting fish farm enclosures. The fish enclosures are copper mesh spheres, 30 metres in diameter. The spheres are populated with fingerling yellowtail amberjack (Seriola rivoliana), also known locally as kampachi, attached to a sailboat, and allowed to drift between 3 and 150 km off the coast of Hawaii. In 2012, Kampachi's Drifting Fish Farm was listed as one of Time Magazine's

"Top Inventions of the Year". According to Kampachi Farms co-CEO Neil Anthony Sims, "The fish thrived in the research net pen far from shore, with phenomenal growth rates and superb fish health, and without any negative impact on water quality, the ocean floor, wild fish or marine mammals" (Undercurrent News, November 5, 2012).

Yellowtail amberjack are considered a sushi-grade fish, with a similar flavour to tuna. Successful cultivation in drifting tanks of amberjack bodes well for the colonies proposed in this paper. Given the successful coastal experiments which have already been carried out with yellowtail, one might think it would make more sense to propose studying and cultivating them instead of bluefin tuna for my project. However, yellowtail is a species of least concern (Herrera and Smith-Vaniz, 2015), unlike the endangered bluefin, and yellowtail prefer tropical and sub-tropical coastal waters (Myers, 1991), making them unsuitable candidates for a High Seas venture such as the one proposed in this thesis. It is also worth noting that amberjacks are quite a bit smaller than most tunas, including bluefin, and the size of enclosures they are raised in reflects this. The enclosures used by Kampachi for raising amberjacks are merely 6.7 metres in diameter (Coxworth, 2011). Moored offshore enclosures successfully used for bluefin tuna off the coast of Japan have been 70 metres in diameter (Hays, 2012), which suggests that the enclosures notionally designed with a diameter of 120 metres for this project are potentially of a reasonable size.

I have looked at articles written by advocates, detractors and seemingly impartial sources. It appears that the presumably impartial sources, which include Time Magazine, Undercurrent Journal, and the University of Hawaii, see Kampachi's experiments, namely the early, drifting ones, as positive, and worthy of recognition and further research. The more recent, moored experiments have met with more resistance, especially the moored experimental farm proposed for the Gulf of Mexico. There was less opposition when farms were proposed for and launched in a more sparsely inhabited area, but now that there is an attempt being made to moor an experimental farm off the coast of the mainland United States, petitions are being launched to fight it. Some of the concerns of the project's detractors are that it would open the door to more widespread, exploitive techniques with a greater environmental impact, as well as providing competition for capture fisheries. Additionally, the near-shore aquaculture companies have a vested interest in promoting their methods, and appear to be concerned about the competition.

Project Med 5

In recent years, there have been a handful of moored commercial open ocean fish farms around the world. A farm called Project Med 5 that was moored off the coast of Israel looked intriguing. According to the manufacturer's website, the farm was the largest open ocean farm in the world at the time of its decomissioning in 2018 (GiliOcean Technology, 2018). Project Med 5 had a single mooring point on the ocean floor, and the fish pens were able to swing freely with the currents. The rotation of the pens allowed for greater water flow through the enclosures and less concentrated impact on the surrounding environment than an enclosure with multiple moorings. In rougher weather, the fish pens could be lowered for better protection from storms.

Some near-shore aquaculture enclosures, such as those manufactured by Stormsafe Enclosures, also descend deeper when it storms (Stormsafe Submersible Cage System, 2020). It is uncertain why Project Med 5 was decommissioned, but unreliable sources stated that it was decommissioned for political reasons. These unreliable sources were comments posted on videos on the manufacturer's website that have since been removed (GiliOcean 2019). In an interview with Undercurrent Magazine, GiliOcean's CEO, Josef Melechner said that "gaining government permits to start mariculture, rather than technological capability, is the main challenge that is holding back an "explosion" in offshore aquaculture" (Craze, 2019).

Buoyant Ecology Float Lab

The Architectural Ecologies Lab at the California College of the Arts has designed and built a Buoyant Ecology Float Lab, a "a prototype for a new kind of resilient coastal infrastructure. It merges expertise from design, advanced digital fabrication manufacturers, and marine ecologists to imagine a floating architecture of the future that can exist productively with its surrounding environment" (CCA Architecture, 2020). The float lab comprises a floating breakwater which can be moored near the shore and provide a growth medium for biofouling organisms such as banrnacles and kelp. The floats enchanced by biofouling agents in turn provide an enriching environment for pelagic fish and other aquatic organisms.

Fig 2.13 Antarctic laboratory. Photo credit World Meterological Association

Existing Isolated Communities

In order to compare the effects of life at sea with other situations involving isolated lifestyles, I reviewed reports written by the inhabitants of space stations and polar research labs.

Antarctic research stations, such as the one shown in Figure 2.13, and space stations such as the installation shown in Figure 2.14 provide good examples of compact, modular design. Because they are located in extremely isolated places and have to be able to cope with extreme conditions without the likelihood of external assistance, they are designed with many intentional redundancies to minimize the occurence of catastrophic events.

For example, antarctic research stations comprise numerous modules. In the event that one of the modules becomes unuseable, the faulty module can be partitioned off from the rest of the station.

Fig 2.14 Space Station and Canadarm. Photo credit: NASA

Design Influences

A design philosophy that was an underlying influence for this thesis is that put forward by architect William McDonough and chemist Michael Braungart in their book *Cradle to Cradle: Remaking the Way We Make Things* (2002). In this book, McDonough and Braungart advocate a holistic way of thinking about how we construct, use and dispose of manufactured products, including buildings, and provide case study examples to illustrate how the life cycles of manufactured products might be made more sustainable. This book influenced the choice of materials specified in my design. As far as possible, I attempted to select materials that had a cumulatively positive or at least neutral effect on the biosphere.

Siphonosphores

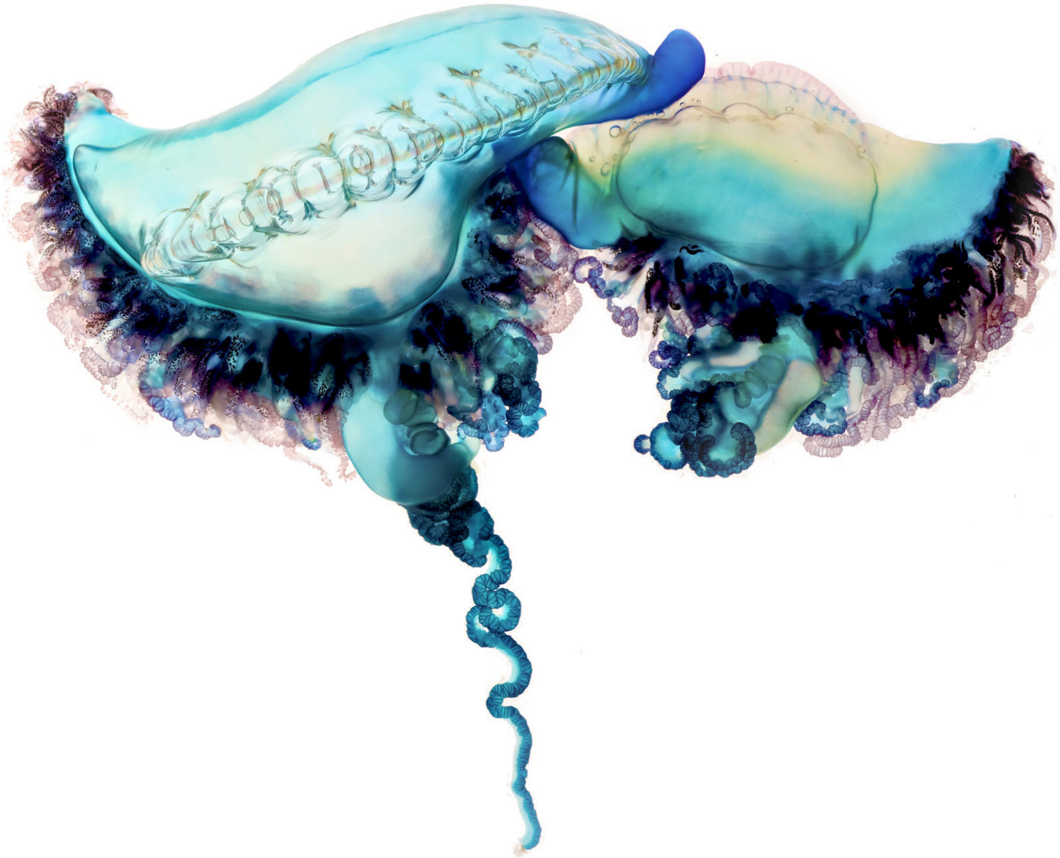


Fig 2.15 Portuguese Man-of-War. Photo credit: Aaron Ansarov

The Portuguese Man-of-War is a siphonosphore colony – groups of jellyfish-like creatures that are genetically identical, but specialized to perform different tasks. Some grow tentacles, others grow feeding bodies, floats or reproductive structures. When there is a severe storm, the siphonospore colony breaks apart into smaller subgroups to prevent damage to the individual organisms (Lee, 2014). The ability to break apart into smaller units to prevent damage is a feature I incorporated into the colony design for my project.

Figure 2.13 shows a siphonosphere colony called a Portuguese Man-of-War. The Portuguese Man-of-War is so-named because it resembles the Spanish version of an 18th century class of sailing warship known as the Man-of-War (Grzimek et al., 2003). The float portions of the Portuguese Man-of-War are typically around 30 centimetres long and 13 centimetres wide. The tentacles can grow to be over 50 metres long (National Geographic, 2020).

Self-sufficiency and Redundancy

In order to gain a better understanding of life at sea, I read several accounts of sailors and other people who have spent a considerable amount of time at sea. Although idealized or glorified views of life at sea are plentiful, it is also possible to find seemingly candid accounts of shipboard living. *Two Years Before the Mast* chronicles the nautical experiences of Richard Henry Dana, a 19th century Boston law student who, after having his vision temporarily impaired by scarlet fever, spent two years as an ordinary seaman on fur-trading vessels on the Californian coast.

Dana presents a frank, unromantic account of life at sea. Much of the book deals with the way in which the author and the other people on the boats Dana served on dealt with adverse weather conditions, confined quarters, limited food and fresh water supplies, and officer and crew relations (Dana, 1937).

Another insightful record of life at sea is *Sailing Alone Around the World*, by Joshua Slocum. This book chronicles the adventures of Slocum, the first person to sail single-handed around the world. Slocum circumnavigated the globe twice between April 24, 1895 and June 27, 1898 (Slocum, 1997). A drawing of Slocum's boat, The Spray, is seen in Figure 2.14. At many points during his voyage, Slocum encountered severe weather conditions. However, because his boat was small, it was able to ride out storms that severely crippled or destroyed larger vessels (Slocum, 1997).

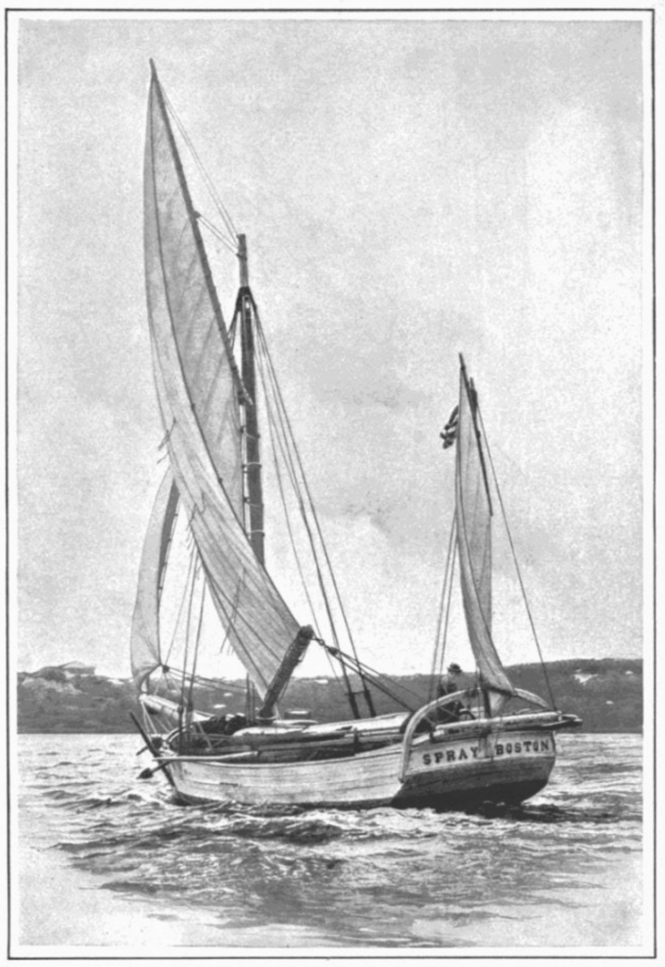


Fig 2.16 The *Spray*. Illustration of the boat in which Joshua Slocum completed the first solo sailing circumnavigation of the globe. Illustration credit: Joshua Slocum

A modern account of life at sea is provided in Derek Lundy's *Godforsaken Sea*. This book chronicles the 1996-1997 Vendee Globe, an extreme, single-handed sailing race in which participants circumnavigate the world, in a journey that lasts over 100 days and involves spending many days sailing in the highly dangerous Antarctic Ocean. In order to make the boats as light as possible, very few repair materials or other back-up supplies are carried. Consequently, when the boats capsize or are damaged, their capability to make repairs is severely limited. Unlike Slocum, who was able to single-handedly repair storm damage and continue his journey unaided, the racers competing in the Vendee Globe frequently had to abort the race and be rescued (Lundy, 1999). Some of the racers and their ships, including canadian competitor Gary Rouffs and his boat, Groupe LG 2, pictured in Figure 2.15, have been lost at sea during the race.

Fig 2.17 Groupe LG 2. One of the yachts that competed in the 1996-1997 Vendee Globe. This yacht and its skipper, Gerry Roufs, were lost at sea. (Lundy, 1999) Photo credit: Jacques Vapillon

The colonies proposed in this thesis will potentially be far from external supply and maintenance sources. These accounts of life at sea make very clear the importance of building in redundant systems to allow colonies on the High Seas to be self-sufficient.

Chapter 3
Design

This thesis proposes an experimental design for floating colonies that follow oceanic recirculation gyres in order to monitor oceanographic conditions, develop and manage high sea fisheries and farm energy.

As stated in the introduction, the drawing set created for this project is notional rather than a complete set of working drawings. This is because the proposed colonies are theoretical/experimental, drawing on a variety of influences, some of which are architectural, some of which come from the natural world. Whereas a fishing colony or research station anchored offshore in coastal waters would have to comply with the rules, regulations, building codes of their host country, structures on the High Seas sit somewhere between ships and buildings, and would likely have more latitude in terms of what materials, structures, and so forth would be permissible.

Although safety and resiliency of High Seas structures would remain important, it would also be possible to try out experimental forms of construction which aren't permitted in other places. Things like passively self-healing or self-growing buildings could be attempted. Various types of solar, wave and wind power could be explored. In order to have reliable power acquisition, the colonies could employ a combination of tried and tested solar/wind/wave energy generation methods and more experimental ones. The power grid could be set up in such a way that the more traditional power sources would be sized to provide adequate energy for the colonies, and the experimental ones would supplement the energy supply.

Study Site

The project is sited in the North Atlantic Gyre, a collection of ocean surface currents that create a loose and ever-changing loop, as seen in Figure 3.1. The currents that compose the North

Atlantic Gyre include the Gulf Stream in the west, the North Atlantic Current in the north, the Canary Current in the east, and the Atlantic North Equatorial Current in the south.

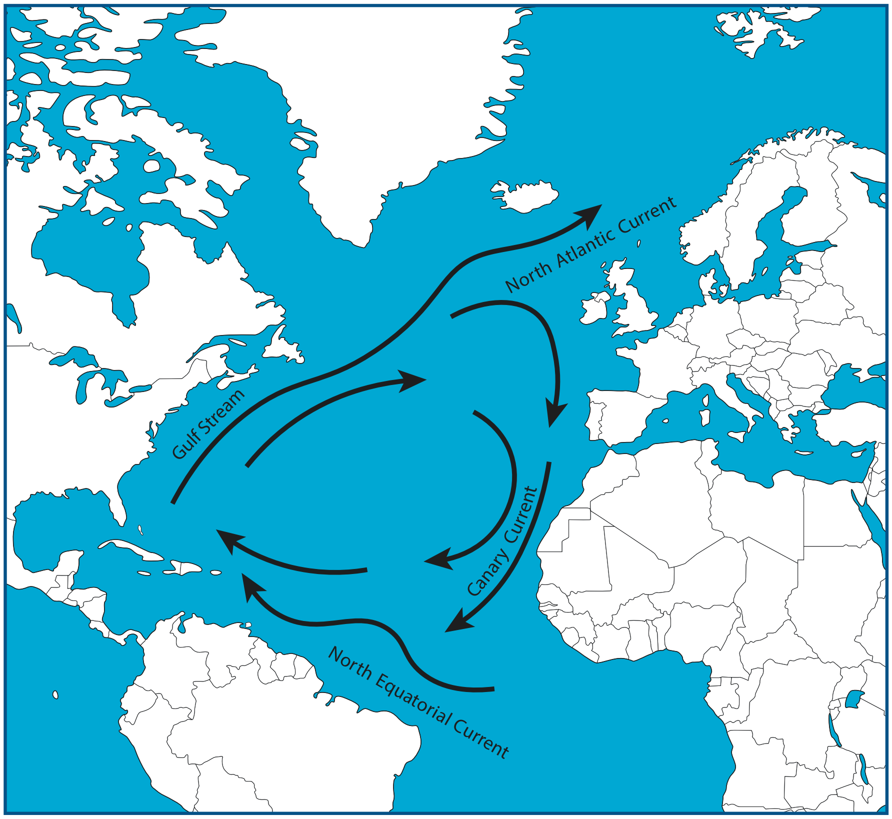


Fig 3.1 North Atlantic surface currents. Adapted from Encyclopeadia Britannica

Ocean Currents

The Atlantic gyre is linked into a global system of ocean currents, and so consideration of how this gyre fits into the global context is helpful. Additionally, because the ocean is a three-dimensional entity, it is important to consider the vertical motion of water as well as the horizontal. Each of the three main oceanic divisions - Atlantic, Indian and Pacific - are on average 1000 times wider than they are deep, and horizontal currents have much higher velocities than vertical currents. "Even over distances of a few hundred kilometres, the vertical velocity must be less than 1% of the horizontal velocity" (Stewart, 2006, p.25). That being said, even though the vertical currents are much lower than the horizontal, they have a large influence on turbulence.

The earth's systems of air and water flow are inextricably linked. "The sun and the atmosphere drive directly or indirectly almost all dynamical processes in the ocean. Because the atmosphere drives the ocean, and the ocean drives the atmosphere, we must consider the ocean and the atmosphere as a coupled dynamic system" (Stewart, p. 39).

Within the world's oceans, there are 5 major gyres: the North Atlantic, South Atlantic, North Pacific, South Pacific, and Indian Ocean gyres. Each gyre is bordered by a strong, narrow western boundary current and a weak, broad eastern boundary current (Ross, 1995).

Surface currents, including the currents which make up the north atlantic gyre, are wind-formed currents. Surface currents occur in the top 200 metres of the ocean (European Space Agency, 2020). Gyres in the northern hemisphere travel clockwise, and gyres in the southern hemisphere travel counter-clockwise (Ross, 1995). Deep currents, such as the currents comprising the oceanic conveyor, pictured in Figure 3.2, travel in the opposite direction to the surface currents above them (Encylopaedia Britannica, 2020).

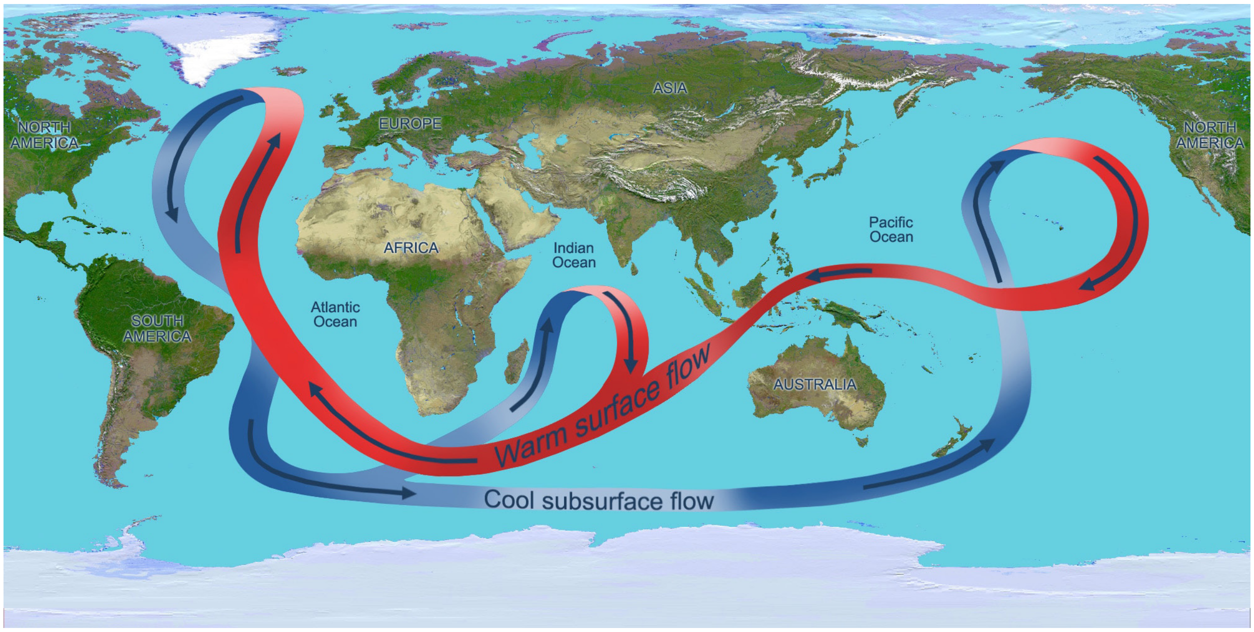


Fig 3.2 Oceanic conveyors. Major currents of the world. Image credit: NASA/JPL

Adaptability

A compelling reason for having mobile high seas fisheries/research stations is the variability of ocean current positions. Ocean currents, being quite literally fluid, shift constantly. The fluctuations happen on multiple scales. There are daily fluctuations, such as temperature variation caused by the diurnal cycle, seasonal fluctuations, and longer-scale changes due to external forces such as global warming.

Some of these fluctuations are fairly predictable, but others, such as changes due to global warming, are harder to predict. This could lead one to think that there is no point in even attempting to predict what could could happen regarding ocean currents. However, there are some general trends from which we can reasonably extrapolate predictions. Technological advances and the creation of global monitoring networks have made predictions easier and more accurate.

Go With the Flow

Rather than fighting or trying to overcome forces such as the wind, waves, sun, or temperature variation, the proposed colonies have been designed to work with these unstoppable forces. Instead, these environmental forces are harnessed to aid transportation and energy and food production. Unlike human beings, who frequently try to conquer nature, most living things tend to follow the path of least resistance; most plants and animals do not have the abundance of choice available to humans, or the ability to make conscious modifications to their surroundings, as far as we know. The organisms to be studied and harvested in this project provide good examples of this path-of-least-resistance approach. Plankton simply drifts along with the ocean currents, small fish follow the plankton, and larger fish follow the smaller fish. Figure 3.3 illustrates the overlap between the locations where ocean-dwellers at the bottom and the top of the food chain can be found in the North Atlantic ocean.

Surface current speeds within the north atlantic gyre vary from 0.1 to 2 m/s (Gyory et al., 2013; Rowe et al., 2013). The average speed of the currents in the gyre is roughly 0.78 m/s (Gordon and Cenedese, 2018; Gyori et al., 2013; Rowe et al., 2013). Drifting at a rate of 0.78 m/s, an object would travel 24 598 km in a year. The distance covered for a full circumnavigation of the gyre is around 20 000 to 25 000 km (Gordon and Cenedese, 2018). Therefore, in ideal

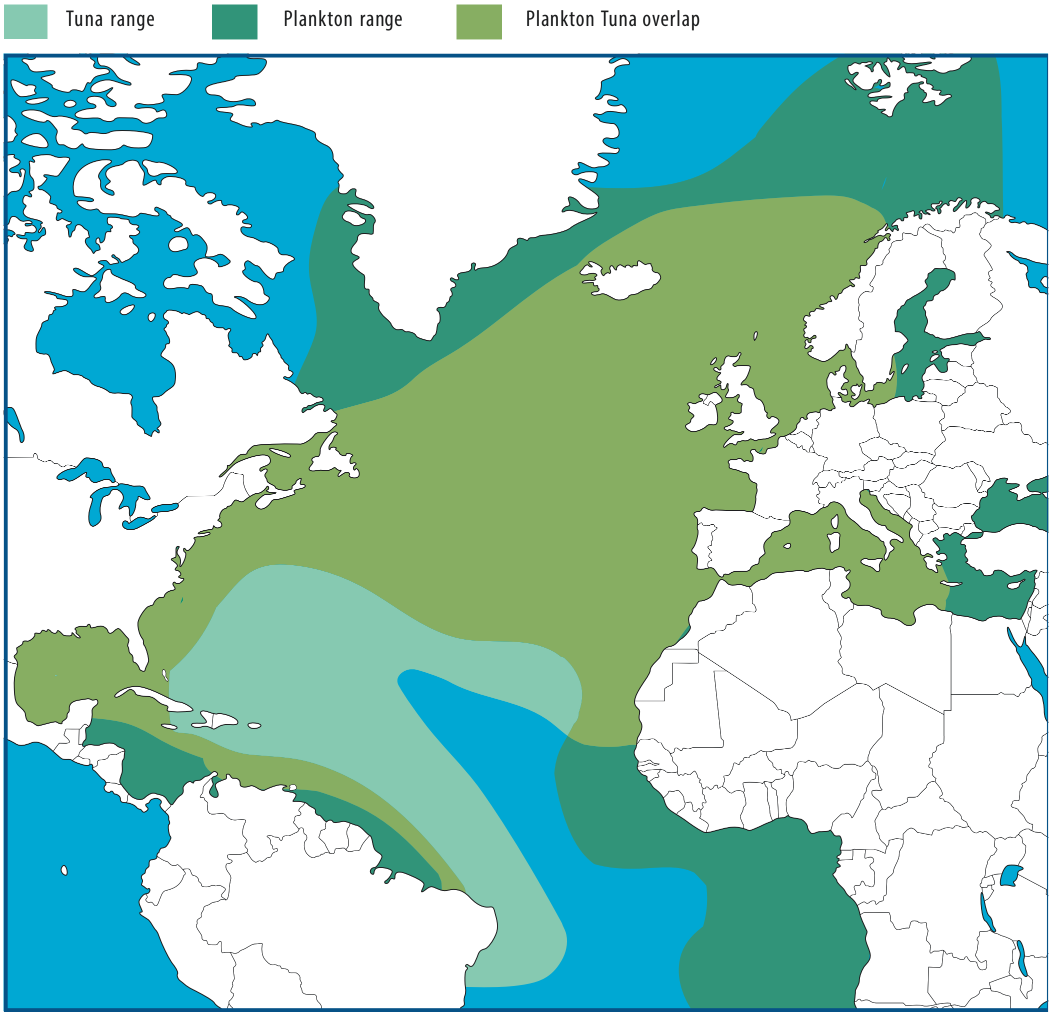


Fig 3.3 Tuna and plankton ranges. Note the large degree of spatial overlap between tuna and plankton.

conditions, the colonies proposed in this project would be able to complete a full rotation of the gyre annually simply by drifting with the currents.

Of course, there are factors that would prevent a large floating structure from going completely with the flow. Air resistance, for example, acts opposite to flow velocity, and would cause the drifting communities to fall behind the currents. In order to catch up to the currents, a system of sails and rudders could be employed. Using sails for course correction would be most efficient when travelling with the wind, but even travelling against the wind it would be possible for the colonies to use sails to course correct using a zig-zag manouevre called 'tacking' (Bond, 1992).

Materials/Biorock

I am proposing to build floating structures using a material that is in harmony with the idea of going with the flow. This material, Biorock, extracts carbon dioxide and calcium from the water and combines them to make calcium carbonate, a material similar to concrete. Biorock is grown in seawater and can be used to remediate aquatic environments and build structures for people.

The process of creating Biorock has a positive rather than a negative impact on ocean quality. The oceans are a big carbon dioxide sink, the biggest on the planet, in fact. Industrialization, including the production of buildings made with concrete, releases CO2 into the atmosphere, much of which ends up in the oceans, so continuing to build with conventional concrete will keep contributing to global warming and to the acidification of oceans. Building with Biorock, however, pulls the CO2 out of the ocean and locks it into floating or anchored structures, in much the same way as plants lock up CO2 and other contaminants in wetlands such as the one pictured in Figure 3.4 (Goreau, 2003).

Fig 3.4 Wetland at edge of lake. The plants in this wetland are a natural precedent for Biorock.

At present, Biorock is being used to help re-build coral reefs by creating structures that promote coral growth. For some of these remediation projects, biologists and engineers collaborate with sculptors to construct elaborate and fanciful structures that attract people as well as fish.

These remediated reefs are becoming ecotourism hotspots for divers and tourists in glass-bottomed boats in addition to acting as tools for ecosystem stabilization. The positive effects are manifold: the reefs are rebuilt, the ecosystem of fish and other organisms that depend on the coral habitat is remediated, tourist dollars enrich the area, and public awareness and appreciation for delicate and dynamic ecosystems is increased.

Fig 3.5 Biorock coral-growing medium. Photo credit: EunJae Lin

Biorock is created by forming a wire mesh, immersing the mesh in sea water, and running a low electrical current through it. The electrical current promotes the accretion of calcium and other minerals on the mesh, meaning that you can essentially grow your own limestone. The electrical current used to accrete Biorock is low enough that it does not harm living organisms (Biorock, 2017).

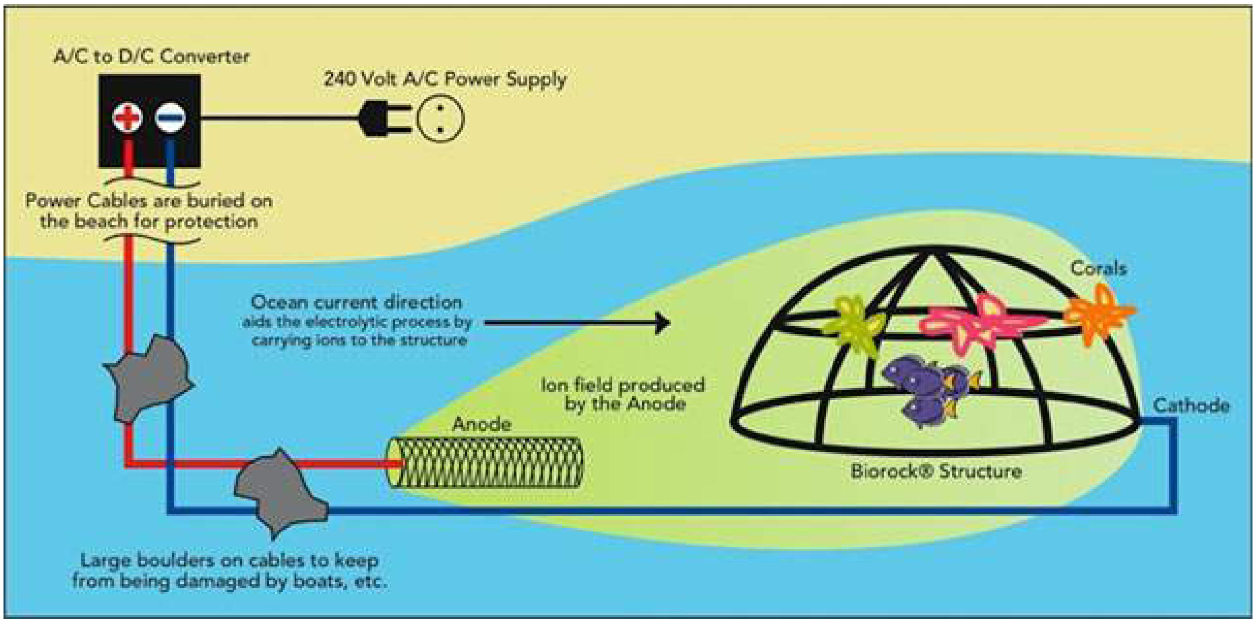


Fig 3.6 Biorock system. Image credit: Biorock Indonesia

Not only can Biorock be used for the initial construction, it can also be used for future maintenance of the structures. Biorock encourages adaptive, self-repairing design. Since the colonies would spend the majority of their time far away from land, repairing or modifying the structures with conventional materials could prove challenging. Boats and other floating structures typically have a great deal of flexibility and redundancy built in for temporary repairs, but the open ocean research stations and colonies I am designing would have the additional benefit of being able to re-grow damaged portions or strengthen weakened sections with materials extracted directly from the sea, creating permanent rather than temporary repairs.

Meshes for Durable, Watertight Construction

Biorock meshes designed to function as growth mediums for coral are typically designed to only grow a thin layer of calcium carbonate, so as to allow plenty of space for corals to establish themselves between Biorock-coated members. Since Biorock accretes quite slowly and the modules used to build the structures proposed in this thesis would need to be watertight, it would be advantageous to employ finer, denser meshes than those used for reef rebuilding. Two useful features of a dense mesh are: 1) it is less susceptible to catastrophic damage than a more open mesh made up of larger-diameter rods or cables, and 2) less time would be needed to grow or repair structures.

Additionally, it has been shown that high current densities cause accretion to happen more rapidly, but give lower strength (Hilbertz, 1981). That is to say, the slower the accretion process, the stronger the resulting Biocrete. Therefore, in order to maximize strength and durability, and minimize construction time and the amount of steel used, it would appear to be desirable to run a very low current though a closely-packed mesh of thin rods or cables. The following diagrams show some potential mesh layouts, including comparative mesh densities.

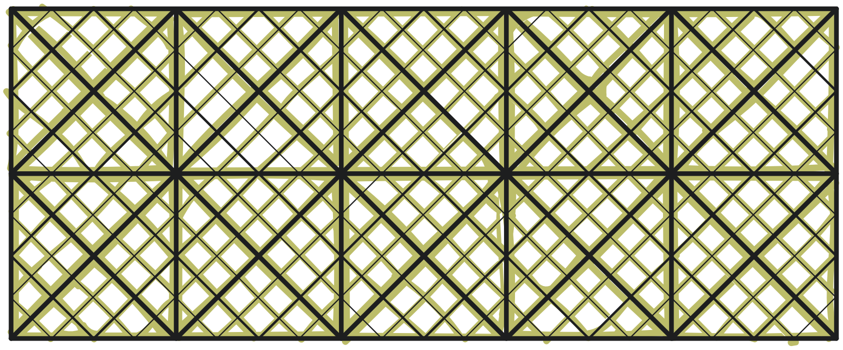


Fig 3.7 Biorock grown on a loose mesh.

A comparable amount of steel is used for both meshes, but the biorock accretion process fills in the finer, denser mesh (Figure 3.8) more quickly than the thicker, looser mesh (Figure 3.7).

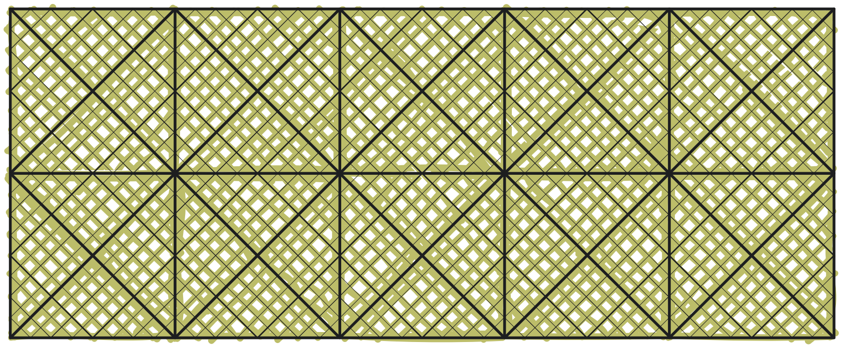


Fig 3.8 Biorock grown on a dense mesh.

Although it would be cheaper to use only straight rods, using curved rods would provide additional strength in a variety of directions. Interweaving the grids to make up box girders or space frames could also be done for added strength, and to potentially leave space within the structure for air pockets for additional buoyancy. Cables or thin filaments could also be used instead of rods for some portions of the Biorock acretion structures. To create strong, dense Biorock, it is best to run a very low current through conductive metal, so that the Biorock accretes at a rate of approximately 50 mm per year. This means that in order to grow a solid Biorock skin within a year, the accretion surface would need to have spaces no larger than 50 mm between its closest members. Figure 3.9 shows a potential layout for a mesh which could be used to grow a solid Biorock-clad surface in about a year. As well as helping to knit the mesh together, the undulating woven pattern would promote biofouling by uncultivated species, adding to the biodiversity of the drifting community.

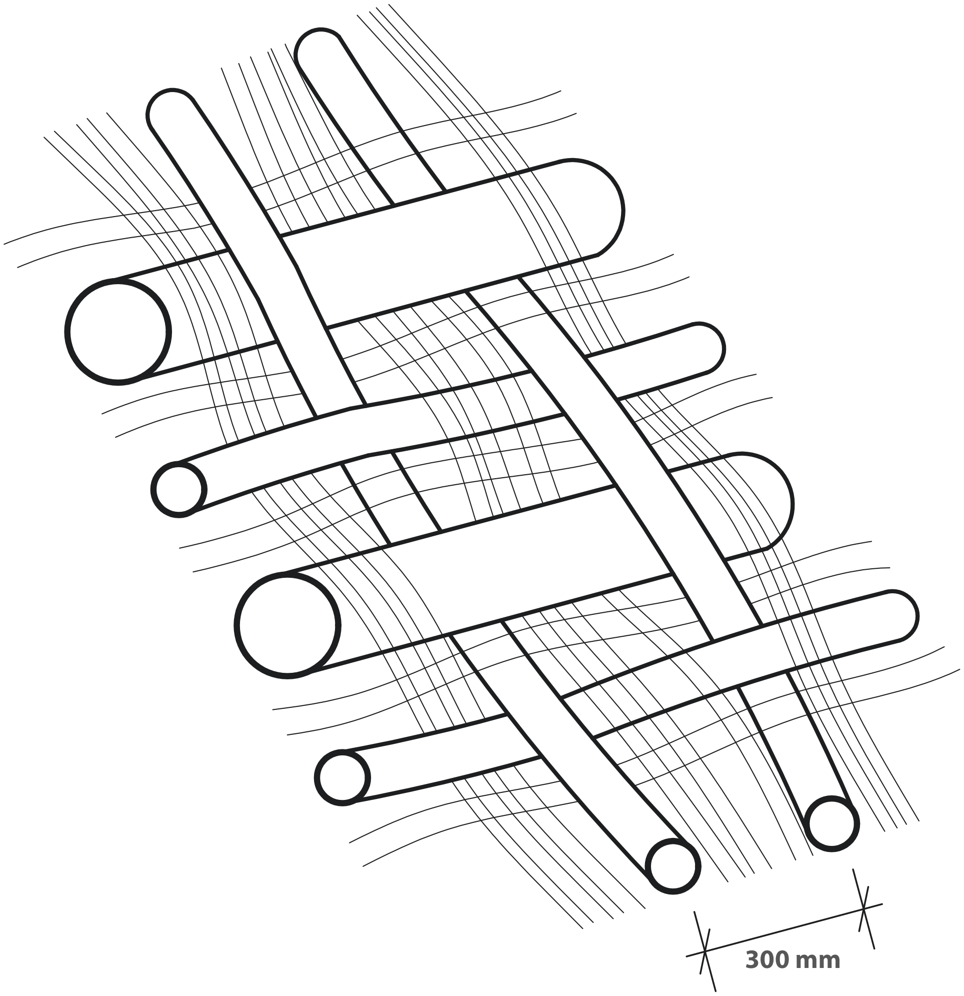


Fig 3.9 Sample section of Biorock growth mesh, showing structural steel rods and wire filaments with under 50 mm spacing.

Modular Adaptive Design

Adaptability is one of the key features of this project. The primary material chosen permits a high degree of adaptability. Flexible, open-ended solutions for projects that don't end with the completion of a building, ship, or other floating structure are explored as a viable approach in this thesis. Figure 3.10 shows the topography of the North Atlantic ocean's sea floor. The water over the pink areas is the continental shelf, and is less than 250m deep. At their deepest, the structures designed for this project have a depth under 200 metres, so the drifting communities would be able to chart courses anywhere outside of the pink zones.

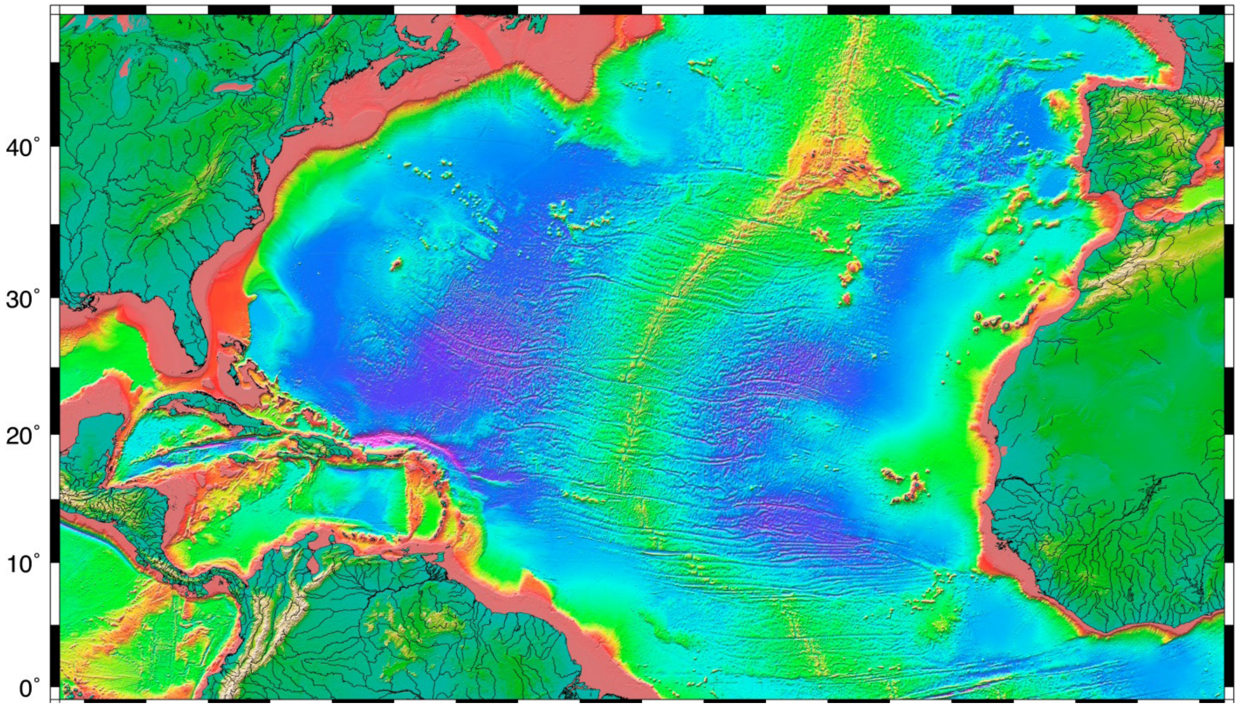


Fig 3.10 The topography of the Atlantic Ocean sea floor between 0° and 50° north. Image credit: NASA/CNES

Because the drifting structures would not be able to enter coastal waters safely, it would be necessary to have intermediary transport in order to connect with coastal communities. Using ships would be energy efficient, but significantly slower than using helicopters or other aircraft. Conversely, using aircraft would be temporally efficient but significantly less energy efficient.

One solution might be to set up a series of floating deepwater trading centres moored on the edge of the continental shelves. The drifting communities could dock at these trading centres, and people from coastal communities would have a fixed location to drop off and acquire goods.

Figure 3.11 illustrates potential monthly locations for the colonies. Half of these locations are near the edge of the continental shelf, so moored trading stations could be set up at those points.

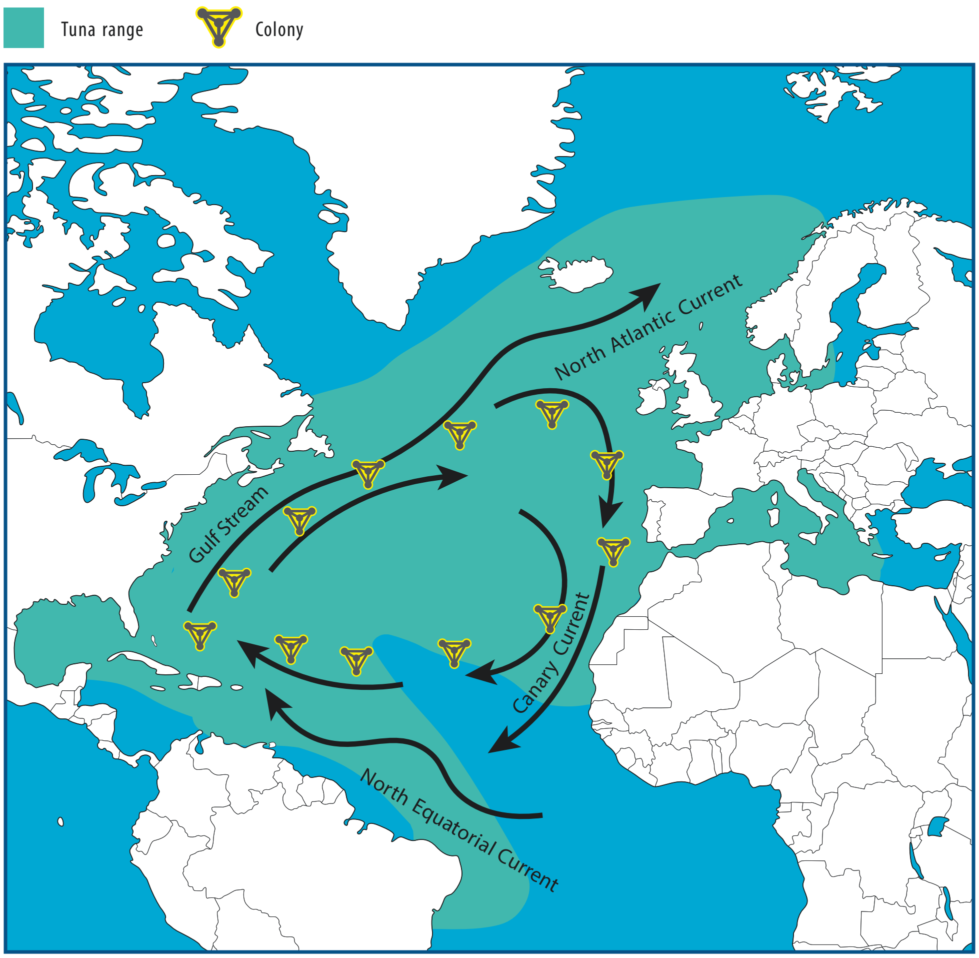


Fig 3.11 Potential monthly locations of colonies.

The structures proposed in this document are always moving, but not towards a final destination. Perhaps they will travel for a year, perhaps for a century. Mapping out time in a cyclical rather than linear manner is not the norm in the modern world, but it could be beneficial for promoting a more sustainable approach to living in harmony with our environment.

For instance, it is impossible for a classical capitalist economy to be truly sustainable, as continuous growth is necessary for its success. A linear growth-based economic model is doomed to fail one day. Oil will stop being an economically viable, efficient fuel source. Fish stocks will be depleted to the point where even total government subsidization and control will not be enough to make it possible to catch or raise enough fish to feed all the piscavores on our planet.

Living in the middle of the ocean can be dangerous and unpredictable. However, very frequently the most dangerous part of the ocean is the coastline. Tsunamis, for example, are often only noticeable once they reach continental shelves, where wavelengths shorten and wave heights increase. When conditions get rough, boats moored just offshore typically slip their moorings and head out to sea to ride out storms (Parker, 2010).

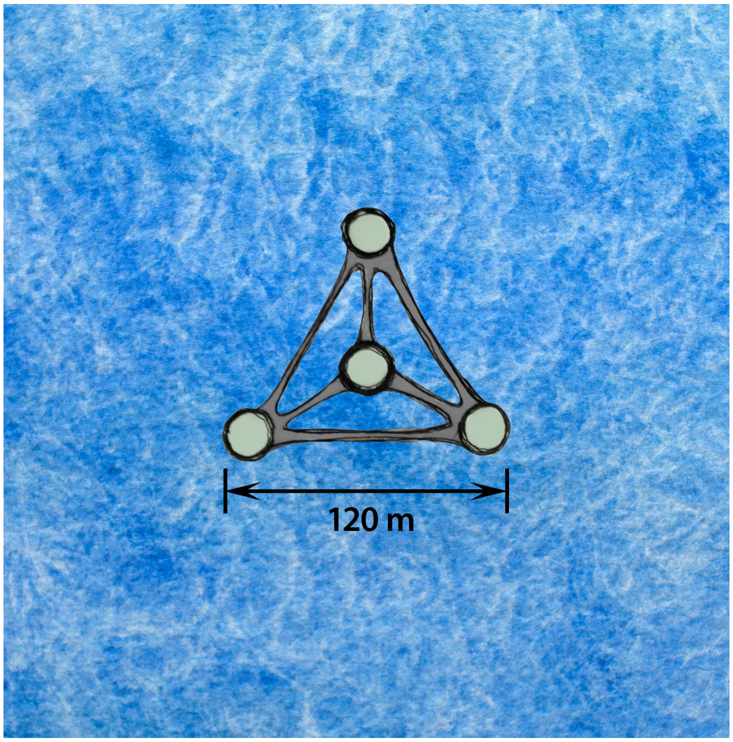


Fig 3.12 Base unit, plan view.

Even in the middle of the ocean, storms are still a serious concern, and my design takes this into account. Large, inflexible structures are more susceptible to damage, because the larger an object is, the greater the force of inertia. In other words, the larger an object on the sea is, the less able it is to adapt to changing forces. In my design, I propose creating structures which are either fairly small or can be broken down into smaller units when a storm hits. The wavelength of wind waves on the open ocean are typically 60 to 150m long. The average wavelength in the Atlantic Ocean is 120m. When detached into smaller components, the longest length of the structures proposed in this document is 120m.

Since wavelength increases with wind strength, waves would be longer than the individual floating units in gale force winds. Therefore, when conditions get rough, and the floating structures break apart, all units will be shorter than the storm waves, making them less susceptible to storm damage than larger vessels or aquatic structures such as drilling rigs or stationary breakwaters would be in such conditions (Parker, 2010).

This adaptive approach is inspired by both human-built and natural techniques for dealing with unstoppable forces. Control joints in concrete are a good example of a technique used in human-built structures to absorb and moderate the expansion and contraction of concrete caused by thermal forces. Since it is inevitable that these forces will occur, causing the concrete to crack, building designers will sometimes specify locations to be scored and therefore weakened in order to control where the inevitable cracking will occur.

Siphonosphore colonies are an interesting example of organic structures with built-in control joints. When there is a big storm, members of the siphonosphore colony break apart to prevent damage to the individual members (National Ocean Service, 2015).

Building on the principle of control joints, this thesis proposes the construction of floating, self-sufficient elements that can be linked together in a variety of formations and then unlinked to ride out storms.

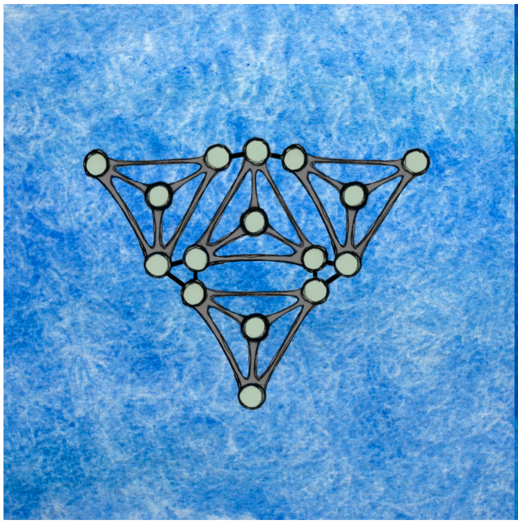


Fig 3.13 Four colony base units, joined.

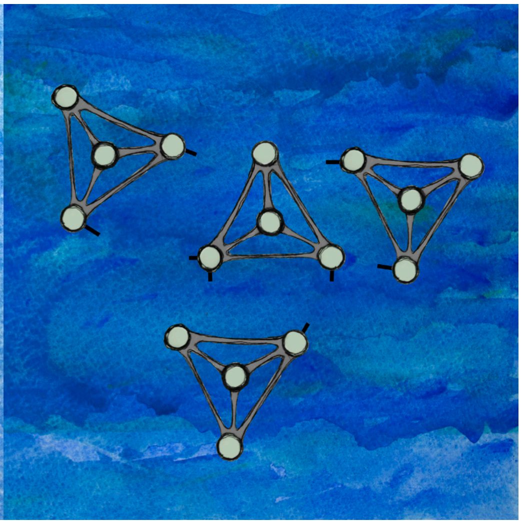


Fig 3.14 Four colony base units, detached for storm management.

Wave test experiment

In order to test how well the proposed structures would follow this principle, scale models were constructed and then subjected to wave action. As predicted, the units broke apart into base units, and remained relatively stable even when subjected to an approximation of gale force winds.

Wave test methodology

I built 1:1000 scale models of three base units. The models were constructed using closed cell foam insulation for the the living modules, wooden dowels for the vertical spindle rods, and nylon twine for the tension cables.

Buoyancy was tested and calibrated by placing one of the models in a tub of water and allowing it to float freely. The structure was observed to ride higher in the water than desired, so lumps of modelling clay were attached at the locations of the underwater viewing platforms. The same buoyancy calibrations were then performed on the other two model units. Once the correct buoyancy was achieved for all units, lengths of plastic-coated electrical wire were inserted into the styrofoam modules of the outrigger spindles to simulate the walkways which would connect the base units together to create a triangular formation. Figures 3.15 and 3.16 show connections between model base units.

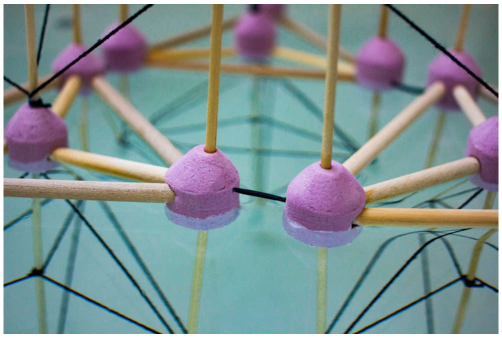


Fig 3.15 Aerial vew of model control joint.

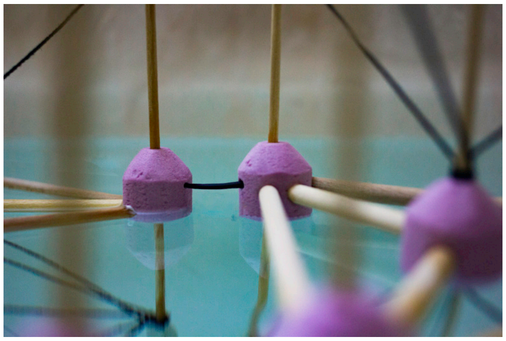


Fig 3.16 Elevation view of model control joint.

The 3-unit formation was then observed and video-recorded under three simulated sets of conditions: still water, moderate wind waves, and extreme storm conditions. Wind waves were simulated by a rhythmical hand-paddling motion at the surface of the water. Moderate waves were waves with wavelengths perceived to have distances between crests less than the length of a single base unit. Storm level waves were those perceived to have a distance between crests greater than individual base units.

In still conditions, there was no noticeable independent motion of the base units, and the three base units presented as a single, rigid object. Figure 3.17 shows a diagram of two connected units in stll water. The walkway connecting the base units is shown in red.

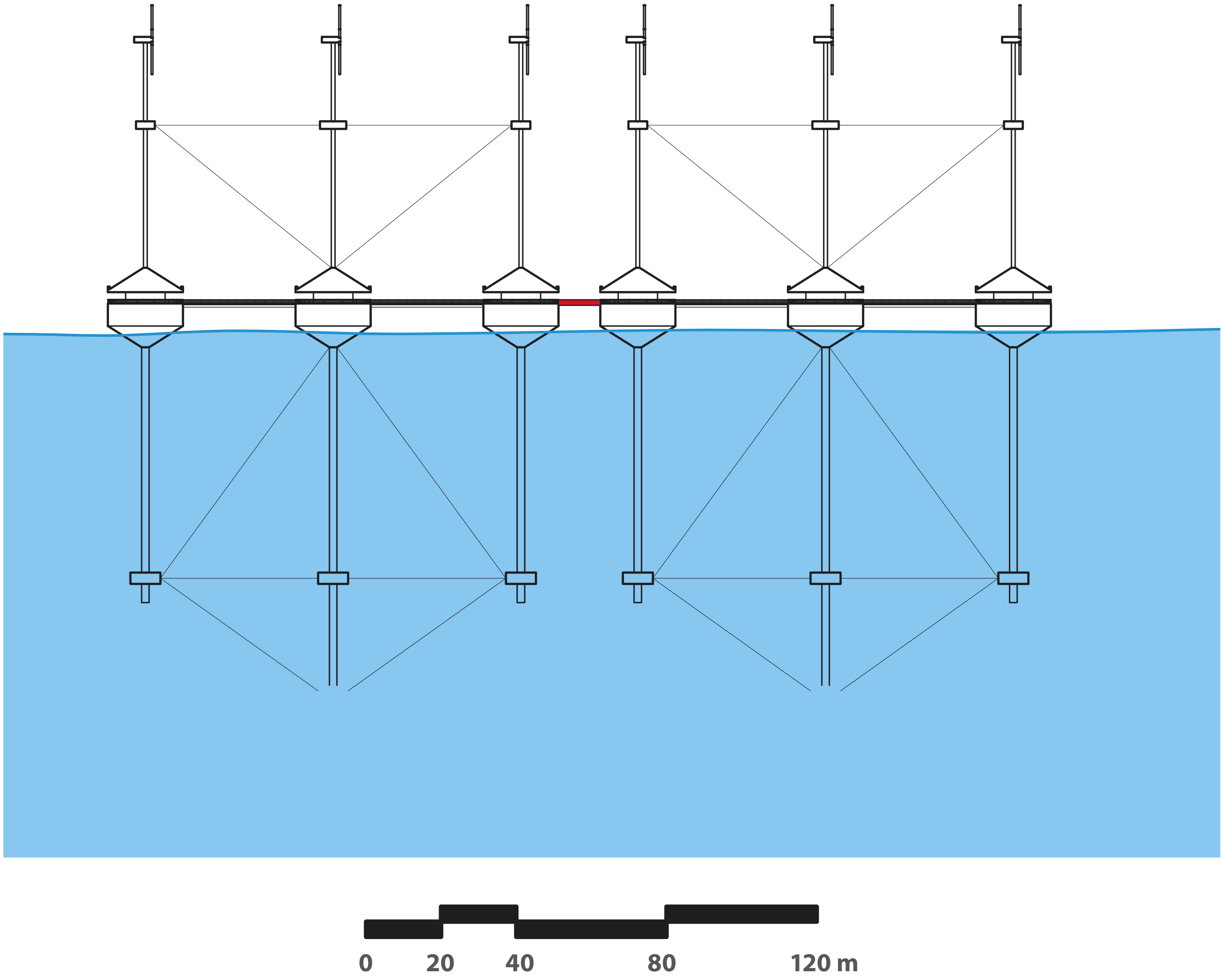


Fig 3.17 Diagram of two connected base units floating in still water.

In moderate wind, some of the force of the waves was absorbed/dissipated by the somewhat flexible connecting walkways, allowing the units to move with the waves rather than fighting to maintain one totally rigid conglomeration. Figure 3.18 shows a diagram of two connected units in moderately windy conditions.

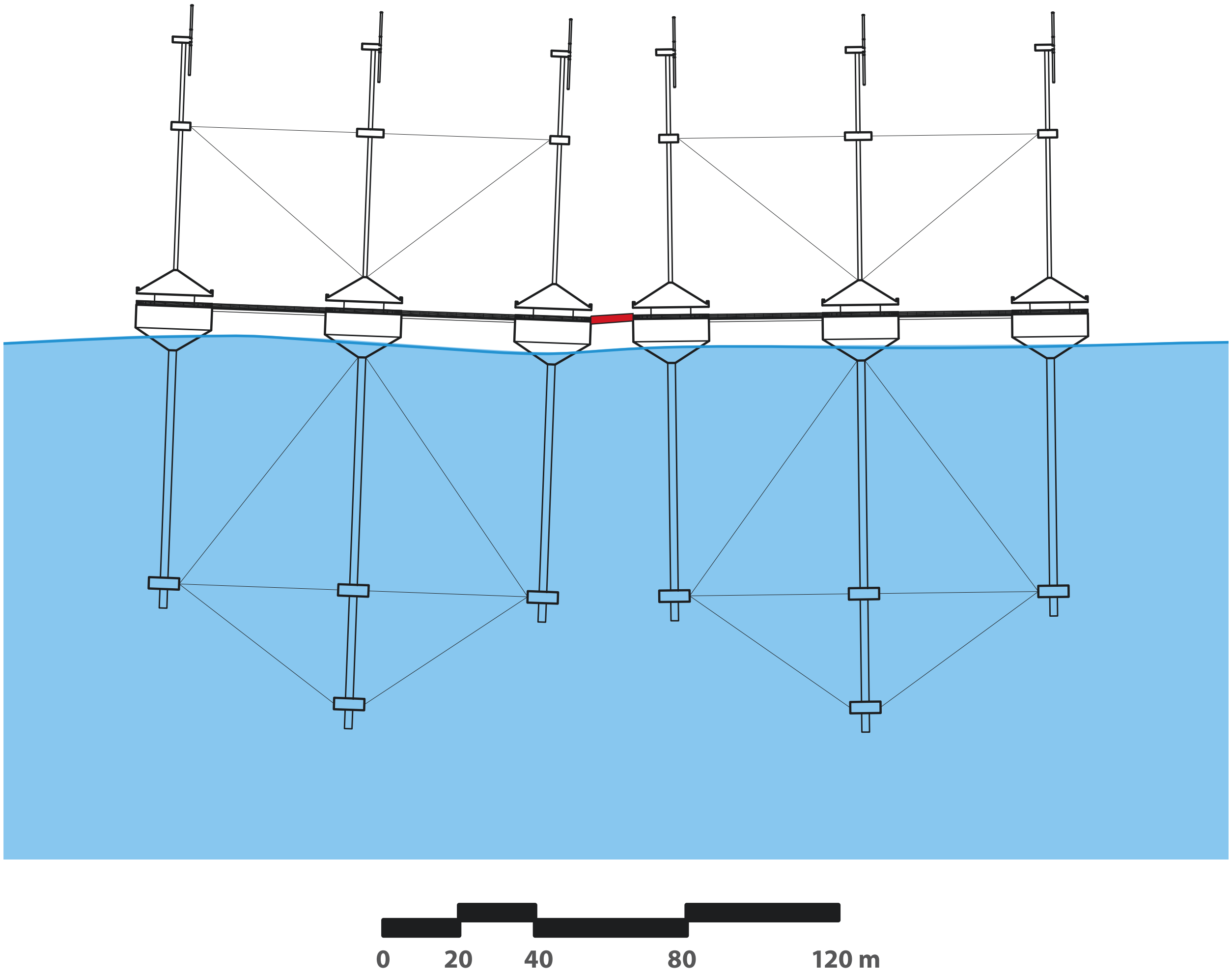


Fig 3.18 Diagram of two base units connected in moderately windy conditions.

In storm conditions, the rocking of the base units increased, causing the masts of neighbouring units to get quite close together at times. However, before the motion of waves became great enough for the masts to collide, the base units broke apart at the walkways, allowing individual units to move father apart to safely weather the storm.

Figure 3.19 shows a diagram of the units breaking apart.

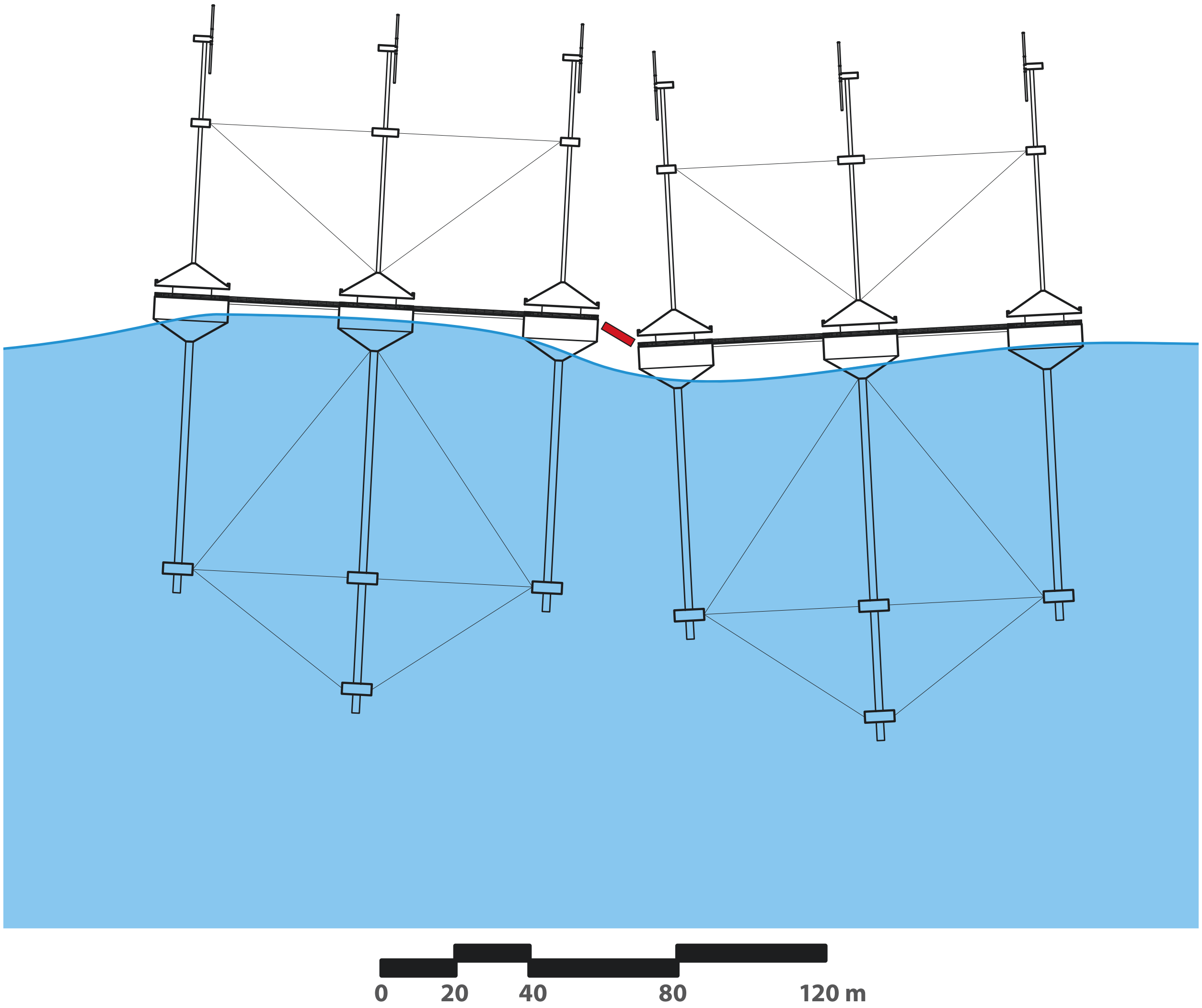


Fig 3.19 Diagram of base units breaking apart in turbulent conditions.

Ideally, the floating communities would have plenty of warning before the arrival of a storm, and the crew would be able to detach the individual units and establish adequate sea room between base units before the weather became severe enough to break apart the colony in the manner tested with the models. The "natural control joint" detachment method tested in this experiment is meant as a failsafe, a passive way for the base units to detach themselves if necessary.

Figure 3.20 shows individual units riding further apart for greater safety and stability.

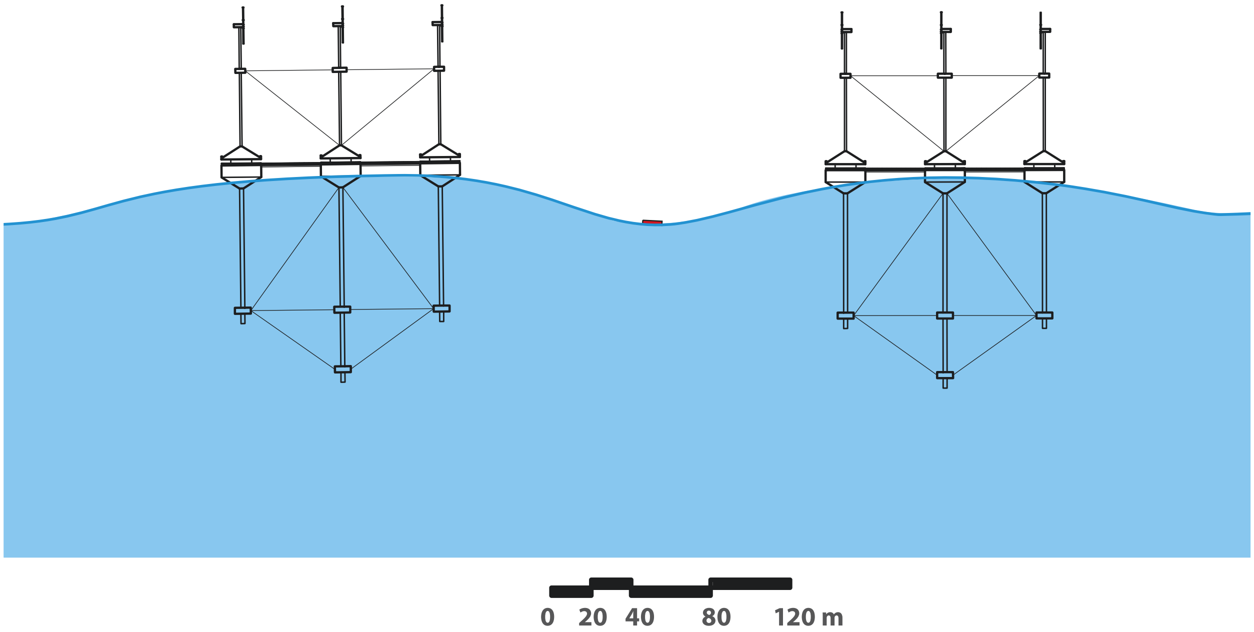


Fig 3.20 Diagram of base units riding at a distance from each other in turbulent conditions.

Figure 3.21 shows video stills of the the model breaking apart.

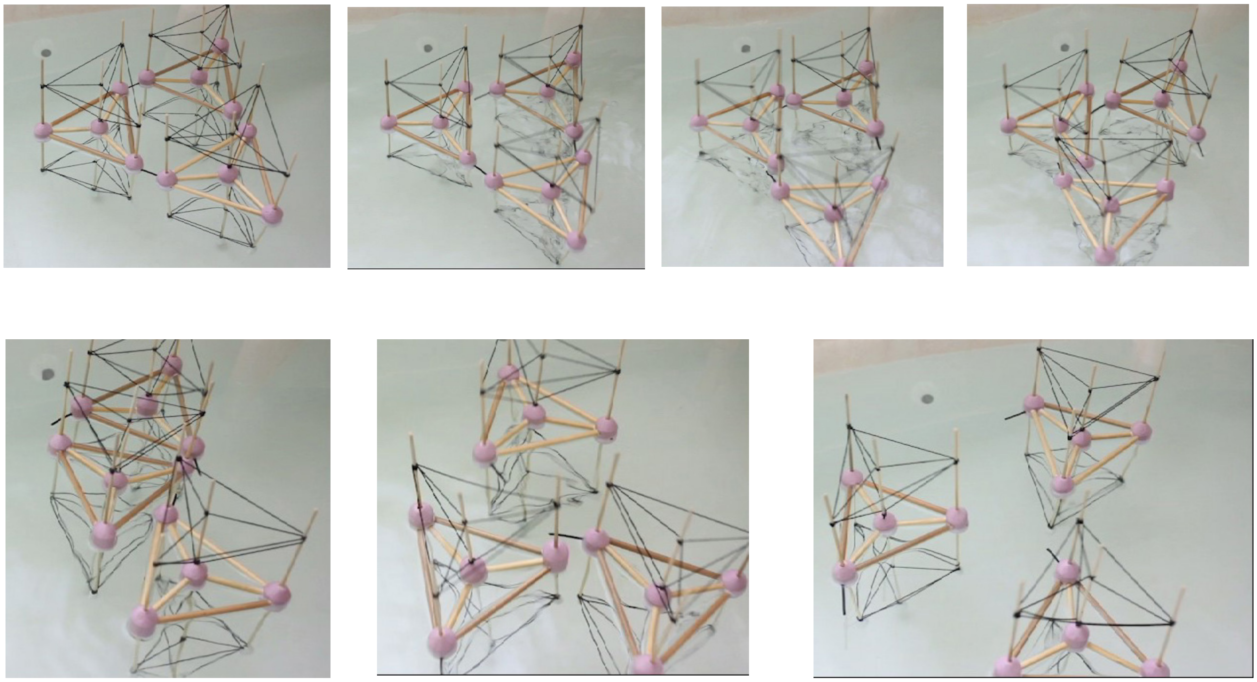


Fig 3.21 Video stills of model sections breaking apart in turbulent conditions.

Form

The spindle structures, formed by accreting Biorock on metal frames, have design elements inspired by the structure and properties of fishing floats and oceanographic drifter buoys.

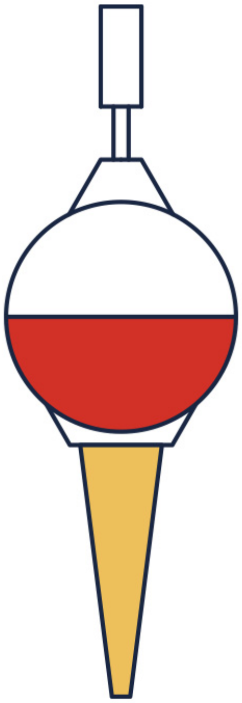


Fig 3.22 Oceanographic drifter buoy.

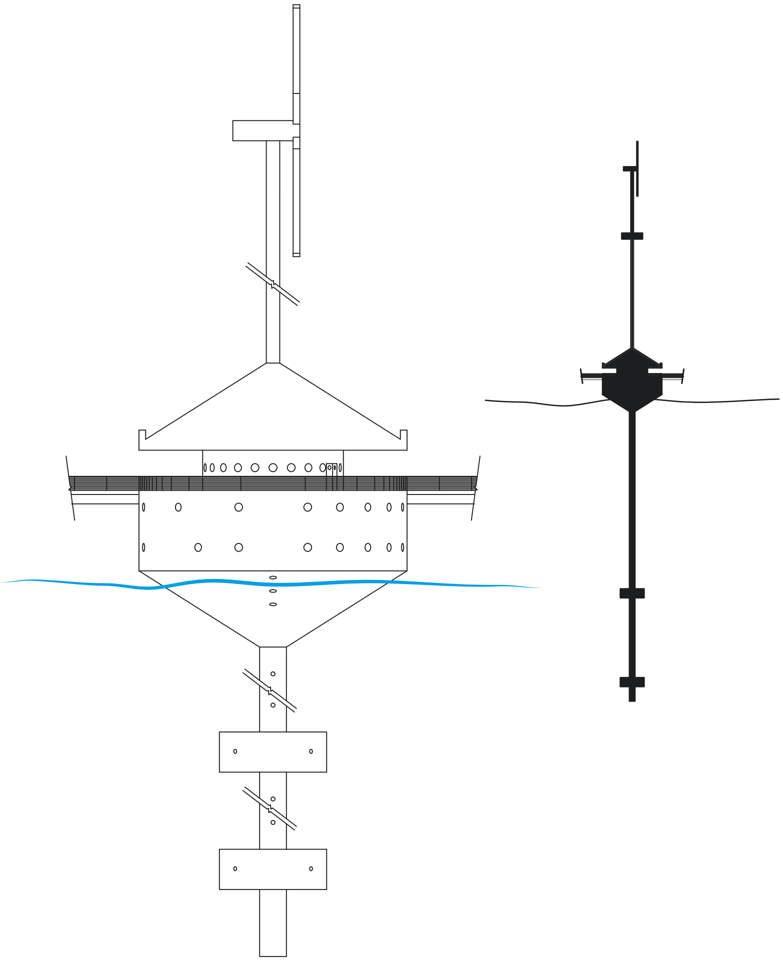
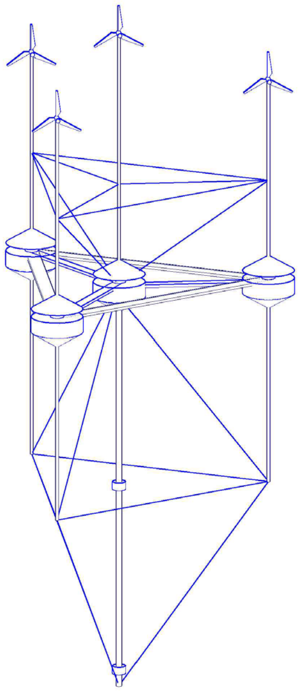


Fig 3.23 Elevation of central spindle of colony base unit (with cut lines) and central spindle silhouette to show actual proportions of spindle.

Like floats and drifter buoys, the colonies have been designed to drift with waves and currents. The base units of my design are linked spindle-shaped modules resembling elongated drifter buoys. Each spindle comprises a surface float containing living quarters and work areas, and vertical shafts extending into the air above and into the sea below. The vertical shafts of the spindles, particularly the long portions extending underwater, stabilize the structure in the same way as a keel stabilizes an ocean-going yacht. As shown in figures 3.22 and 3.23, the spindles



for the floating communities are substantially longer than the spindles on drifter buoys. If the base units for the community structures were only spindles, this would likely be an impractically elongated form. However, since the central spindles are connected to outrigger spindles with rigid walkways and tension cables, as shown in Figure 3.24, the proportions of the colony spindles should in fact be structurally feaseable.

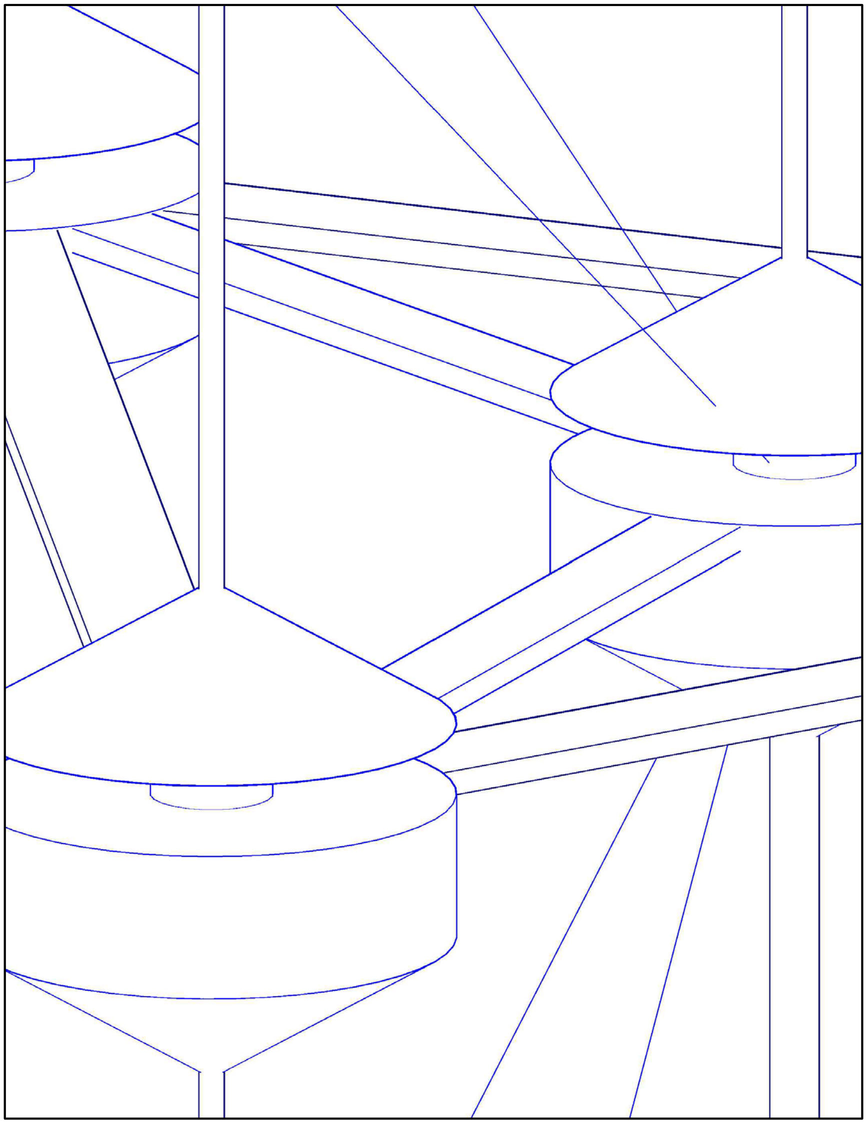


Fig 3.24 Axonometric view of one base unit and close-up axonometric of surface floats and connecting walkways.

As with floats and buoys, the rounded shape of the modules contributes to their strength, reduces drag, and avoids sharp edges which would be prone to damage. Rounded stuctures of this type reduce material cost and are energy efficient with regard to heating and cooling because they minimize surface area.

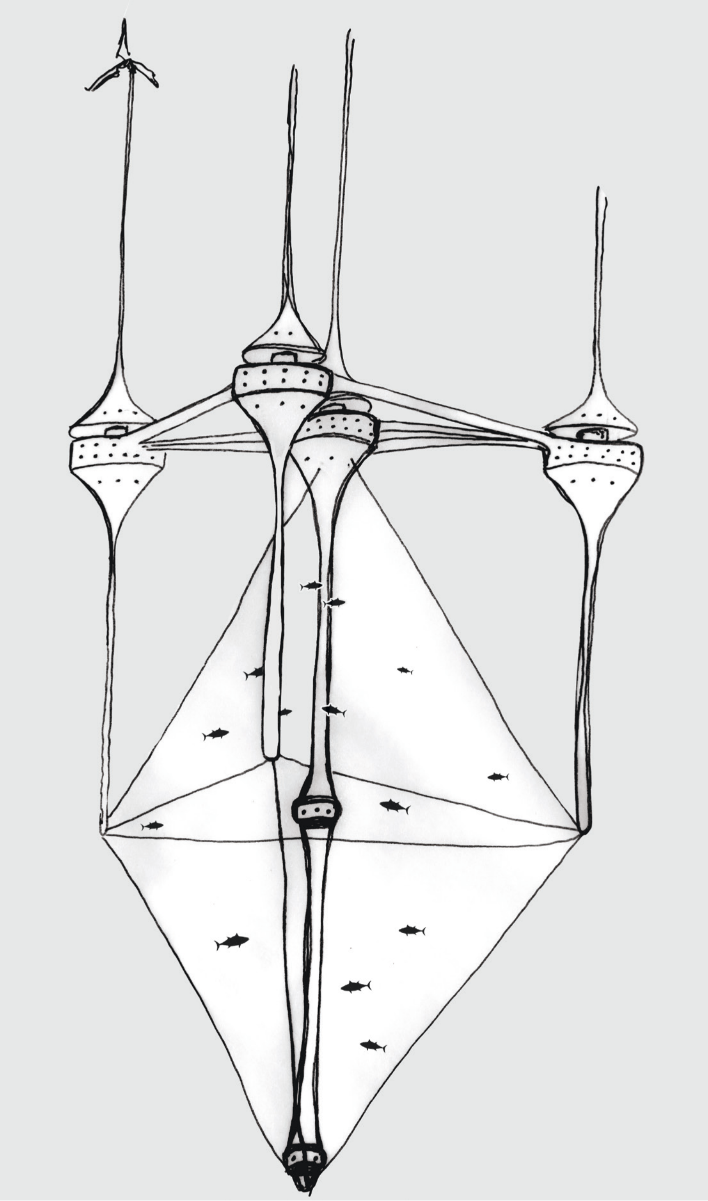


Fig 3.25 View of fish enclosure.

The spindle-shaped modules are combined into fixed groups of four to create base units. These base units could be linked to other base units to form larger colonies. In the event of foul weather, the base units would unlink to ride out the storm. The underwater shaft of the central spindle of each base unit is twice as long as those of the outlying spindles. The central spindle has viewing platforms both halfway down and at the base of the underwater shaft. These viewing platforms would be useful for oceanographic research because they allow access to deep water without the need for the diving suits and decompression chambers that are usually required. Figure 3.25 shows a view of a fish enclosure with viewing platforms both in the middle and at the bottom of the enclosure.

The three outlying spindles in each base unit act as stabilizers, as seen in Figure 3.26, like outriggers on a canoe such as the craft pictured in Figure 3.27.

The lower shafts of the outlying spindles also provide connection points for a fish farming enclosure, as shown in Figure 3.28.

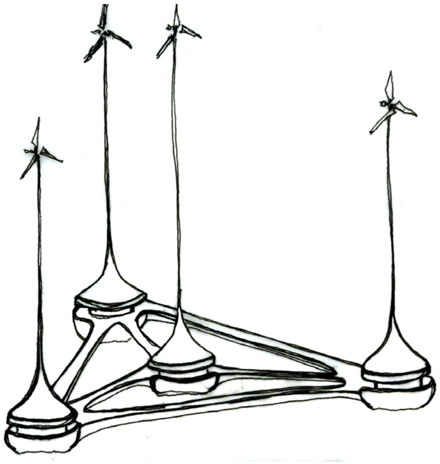


Fig 3.26 Surface view of a colony base unit.

Fig 3.27 Canoe with outrigger. Photo credit: Ken Marks

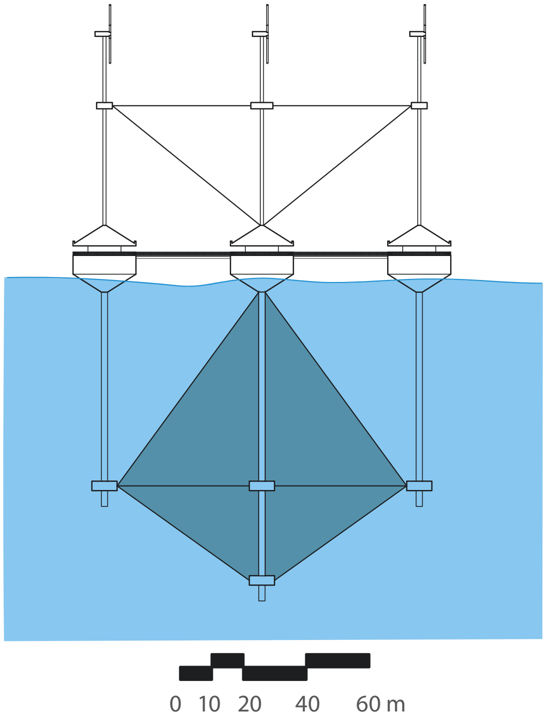


Fig 3.28 Elevation of one base unit, showing compression member walkways and tension cables above and below.

The fish enclosures have been sized to be large enough to support herring and tuna, but small enough to weather storms. Since the units are mobile, travelling with the currents and allowing the flow of plankton-rich water through the fish enclosures, the enclosures can be smaller than if the fish were raised in a closed tank system.

The spindles of each base unit are connected with Biorock compression members and steel tension cables. The compression members run from spindle to spindle at the midpoints of the surface floats forming a horizontal triangular structure above the waterline, and the tension cables form a tetrahedral structure above the water and a tetrahedral structure below. The horizontal triangular structural elements connecting the surface floats are situated above the waterline, and serve as walkways between the surface floats in addition to providing structural rigidity.

Base units could be linked to form colonies of varying sizes, depending on changing requirements. Figures 3.29 to 3.33 show examples of potential colony formations.

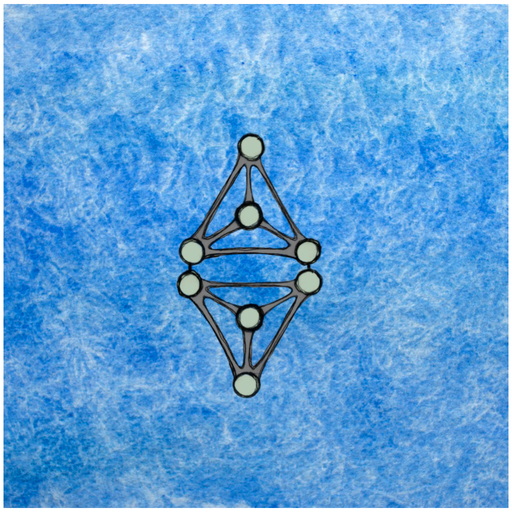


Fig 3.29 Plan of 2-unit formation.

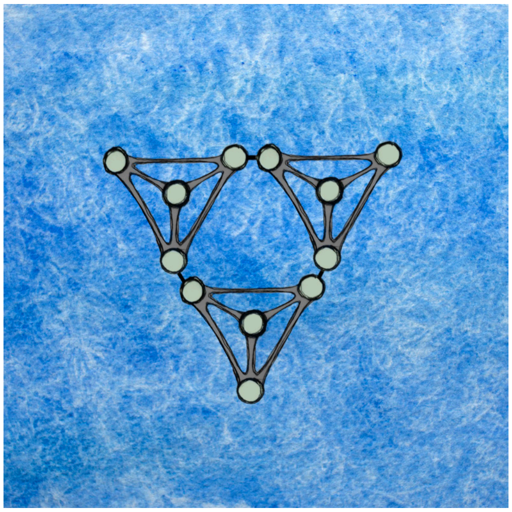


Fig 3.30 Plan of 3-unit formation.

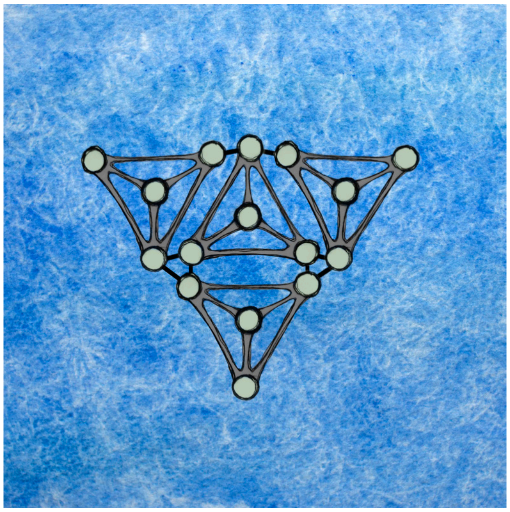


Fig 3.31 Plan of 4-unit formation.

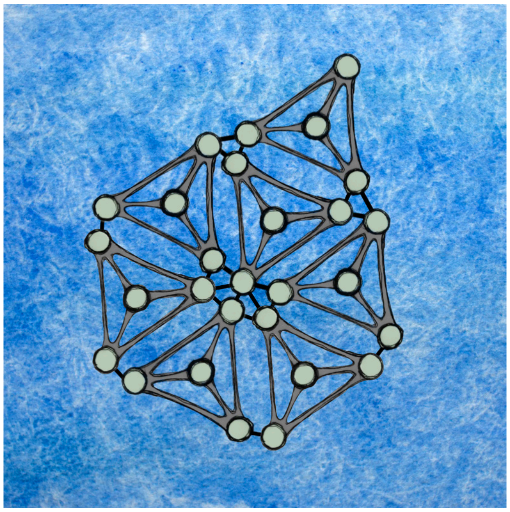


Fig 3.32 Plan of 7-unit formation.

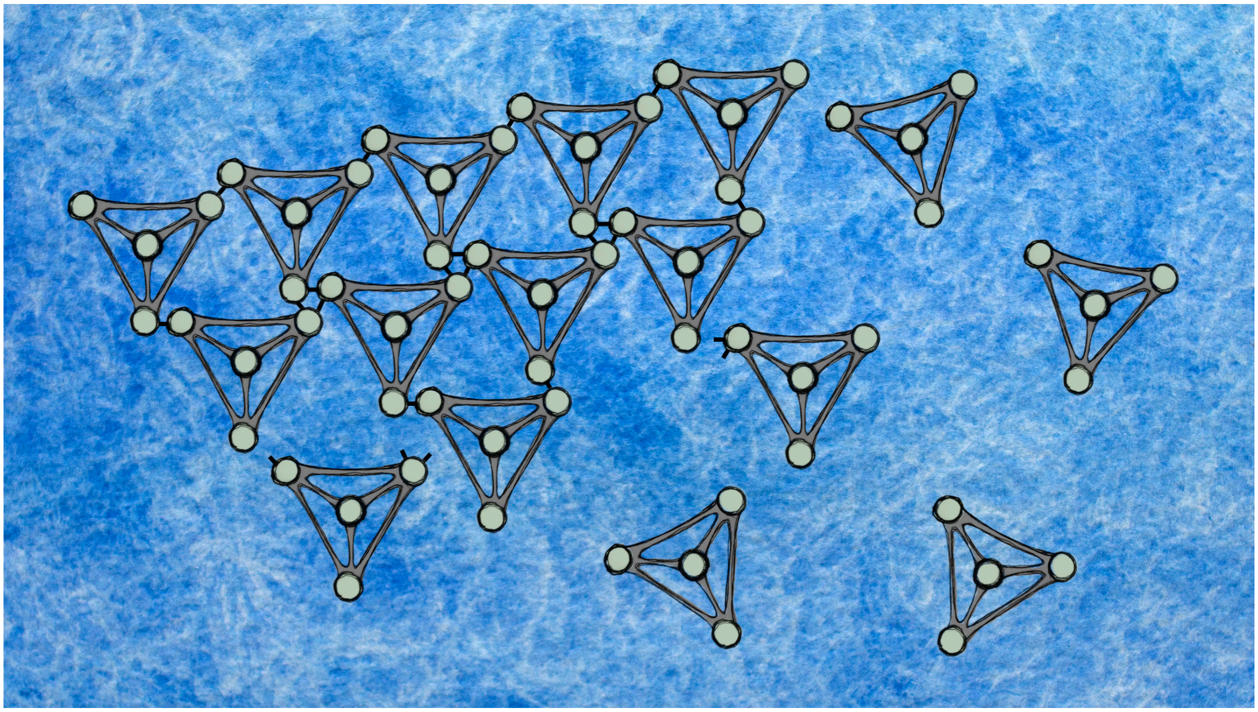


Fig 3.33 Plan of 16-unit formation in process of connecting or disconnecting.

Some groups of units might remain attached for only a few days or weeks at a time, but others might remain attached for months or years. The two main reasons for decoupling would be for sending a subgroup for a trade rendevous with a coastal nation, or for riding out a storm.

In the decoupling-for-trade scenario, likely not all units in a colony would contain tuna of a harvestable age or size at the same time, so only one or a handful of base units might detach to travel closer to shore, while the units containing immature tuna might stay further offshore to take advantage of more plankton-rich waters.

In the decoupling-for-storm-management scenario, all units would detach from each other to ride out the storm. Most major storms in the North Atlantic are hurricanes that form and travel on the eastern side of the Atlantic between the beginning of June and the end of November. There are on average 6.2 hurricanes a year (National Hurricane Center, 2020), and waves generated by hurricanes often reach heights greater than 10 metres and lengths greater than 300 metres (Wu et al., 2003), so it would be prudent for floating communities passing through the western Atlantic during the summer or fall to travel as either individual units or in small groups that could easily detach in the event of a storm. However, if a colony spent hurricane season on the eastern side of the Atlantic, it is possible that the floating community would not encounter a storm large enough to warrant decoupling for many years, and larger groupings could safely stay coupled for long periods of time.

Plans and Sections for Central Spindle

The central spindle of each base unit contains the primary living quarters and storage areas for the human inhabitants of the colonies. The central spindle was chosen for the main living quarters because it is the portion of the colonies that experiences the least amount of motion from waves. The central spindle also includes underwater observation decks at three different depths: one a few metres below the surface, another in the centre of the netted fish enclosure (roughly 100 metres below the surface), and a third at the base of the netted enclosure (roughly 200 metres below the surface).

The roofs of the spindle would house solar absorbers, energy storage cells, and rainwater collection and storage, as shown in sections G and H of Figure 3.36. Interior living spaces would not have exposed Biorock surfaces, as shown in section J of Figure 3.36. These interior spaces would have wall, floor and ceiling surfaces finished with materials one might find in the interior of a modern ocean-going sailing ship: teak or cedar planking for the floors and residential fittings, fibreglass for the walls and ceilings, and stainless steel for various work surfaces and fittings. The underwater observation decks would leave the Biorock exposed, as shown in section K of Figure 3.36. The exposed Biorock would add a cavernous aesthetic to the observation decks, and could also act as a teaching aid for accretion system demonstrations.

Although the colonies in general and the central spindles in particular would be set up to support human life for long stretches of time – years, perhaps – it is likely (and assumed) that most inhabitants would actually only stay on the colonies for much shorter periods of time – anything from a few weeks to a few months. Some of the key researchers and sailors might stay aboard for a year or two at a time, but likely even these long-term residents would leave occasionally, in order to attend conferences, visit friends, and participate directly with the rest of the world in other ways.

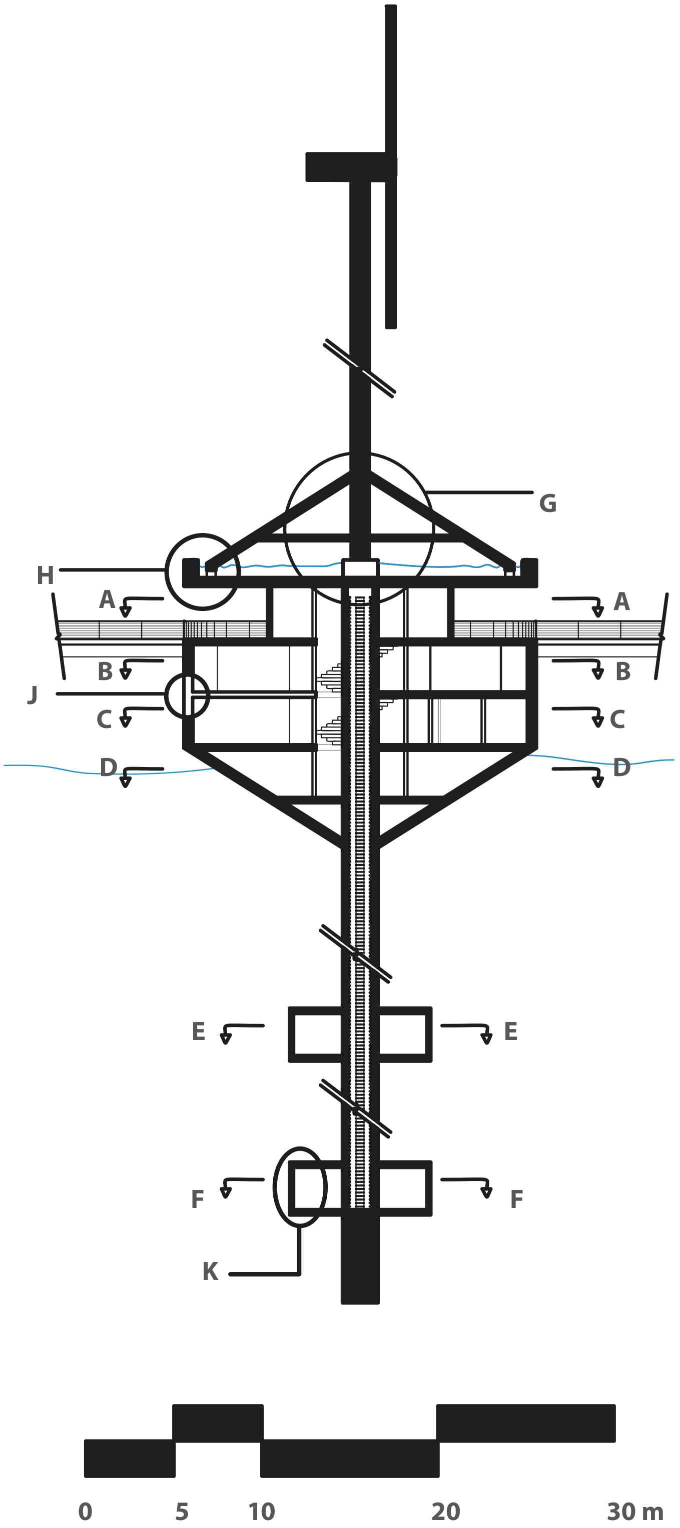


Fig 3.34 Key section of central spindle.

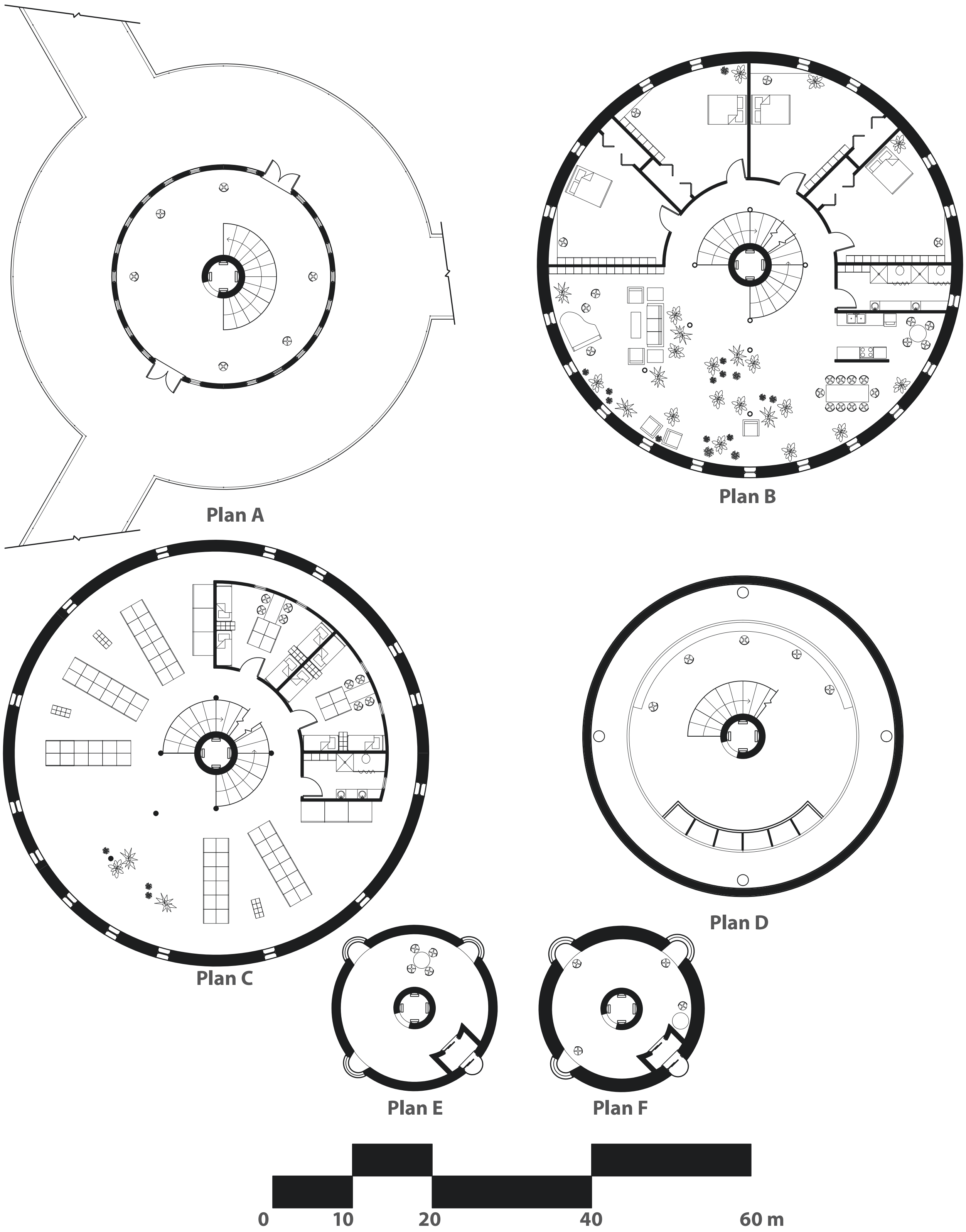
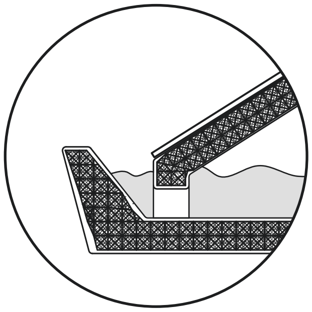
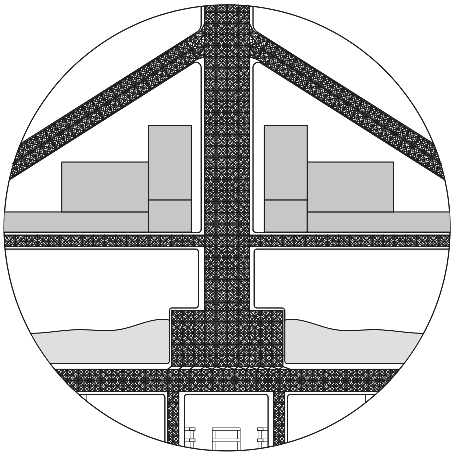


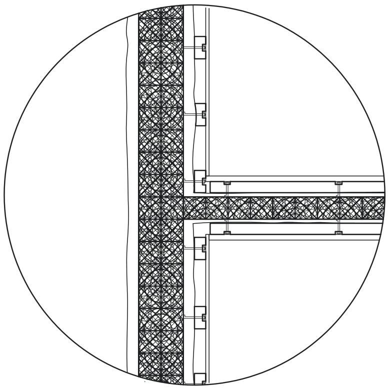
Fig 3.35 Central spindle plans A, B, C, D, E and F. These plans show potential layouts for observation decks, primary living quarters, storage, and short-term lodgings.



Section H: Central spindle section ii. Corner of roof, showing rainwater collection and solar absorbers.

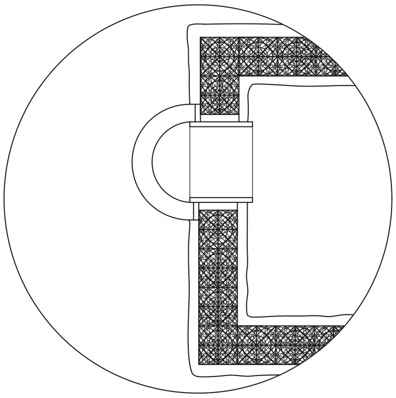


Section G: Centre of roof, showing rainwater reservoir and energy cells.



Section J: Central spindle section iii. Hull wall of living quarters and interior floor-ceiling connection.

Scale for Section G



Section K: Central spindle section iv. Hull wall with reinforced window of underwater observation deck.

Scale for Sections H, J and K

Fig 3.36: Sections G, H, J and K.

Plans for Outrigger Spindles

The outrigger spindles comprise the majority of the research facilities, including observation and monitoring stations, and tanks for juvenile fish. The outrigger spindles also include some basic, supplementary living quarters, and underwater observation decks at two different depths: one a few metres below the surface, and another at one of the corners of the netted fish enclosure, roughly 100 metres under the surface. Unlike the central spindles, there is not a third underwater observation deck, since the outriggers do not extend as deep as the central spindles.

The research facilities include tanks for spawning and observation of fry and juvenile fish. The fish being raised in the tanks would include tuna and various feeder fish, such as herring. All of these tanks would be below the waterline of the spindle, so in addition to holding fish, these tanks would also act as ballast to help maintain stability of the base units in rougher seas.

Spawning and raising sufficient quantities of herring and tuna on the colonies would likely be challenging, as the mortality rate even in conventional fish farms is quite high; currently only 1 percent of Atlantic bluefin tunas born and raised in captivity make it past the larval stage (Mann, 2018). In order to diversify stock and aquire adequate numbers of viable fingerlings, the fish spawned and raised entirely within the colonies could be supplemented with fingerlings acquired through trade.

It should also be noted that when the juveniles are transferred to the underwater netted enclosures, the herring (or any other feeder fish) would be kept in several seperate, finer-gauge enclosures within the main enclosure, until they are large enough to be released into the main part of the enclosure. The main part of the enclosure would have a heavier, looser weave, and would be primarily inhabited by the tuna. Herring would be transferred in and out of the smaller enclosures on a rotating basis so that after one group of herring is released into main enclosure, there would be another group of herring in an adjacent feeder fish enclosure that is nearly ready to be fed to the tuna.

The supplementary living quarters are meant to act as emergency living spaces in extreme situations and amenities/efficiency-boosters in regular operational scenarios. In the case of a storm which makes it unsafe to return to the central spindle, or in a very extreme situation where a base unit is fractured, people in the outriggers at the time of the emergency would have adequate supplies and facilities to ride out the crisis. In ordinary situations, the facilities in the outriggers would function as places where the crew working on the outriggers could take short breaks, rather than having to go back to the main living area for a snack, a nap or a cup of coffee, for example.

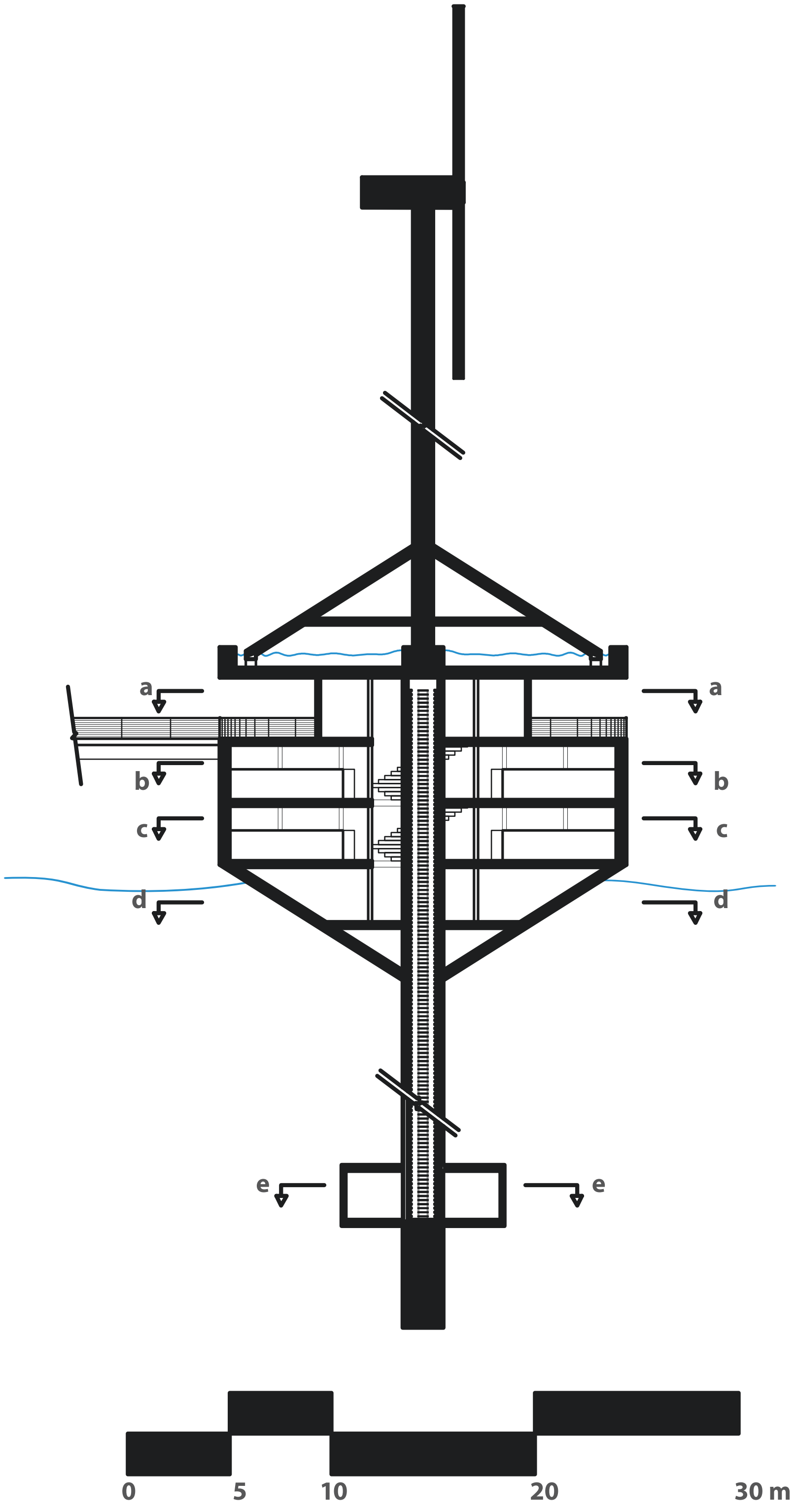


Fig 3.37 Key section of outrigger spindle.

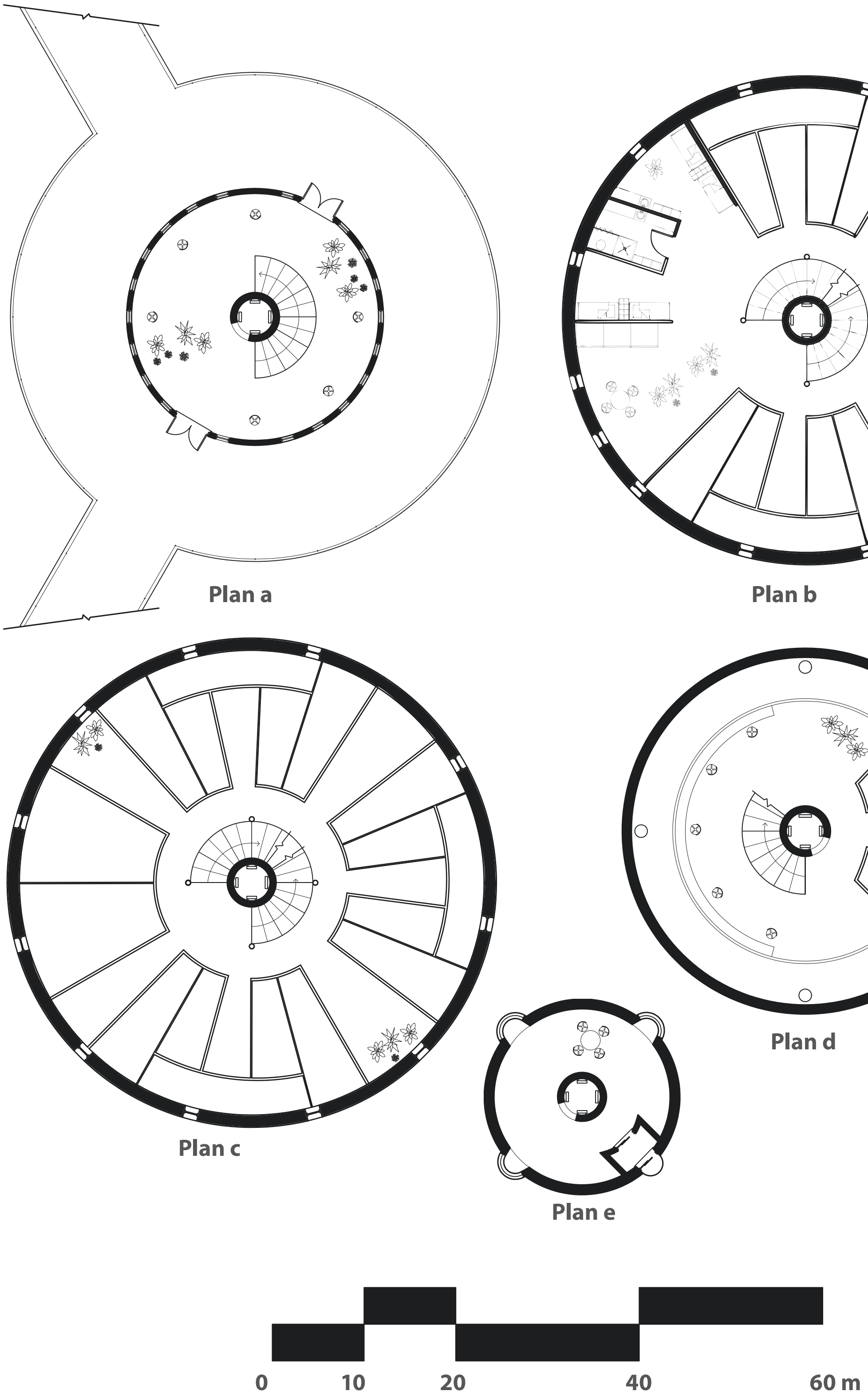


Fig 3.38 Outrigger spindle plans a, b, c, d, and e. These plans show potential layouts of observation decks, supplementary living quarters, research facilities, and tanks for spawning and raising juvenile fish.

Power Generation

Each base unit would have the ability to generate its own power from a variety of sources. Wind turbines atop the vertical shafts, solar collectors on the surface floats and heat exchange loops running along the submerged vertical shafts would work together to charge fuel cells and batteries (Hydrogen Now, 2006; British Wind Energy Association, 2006).

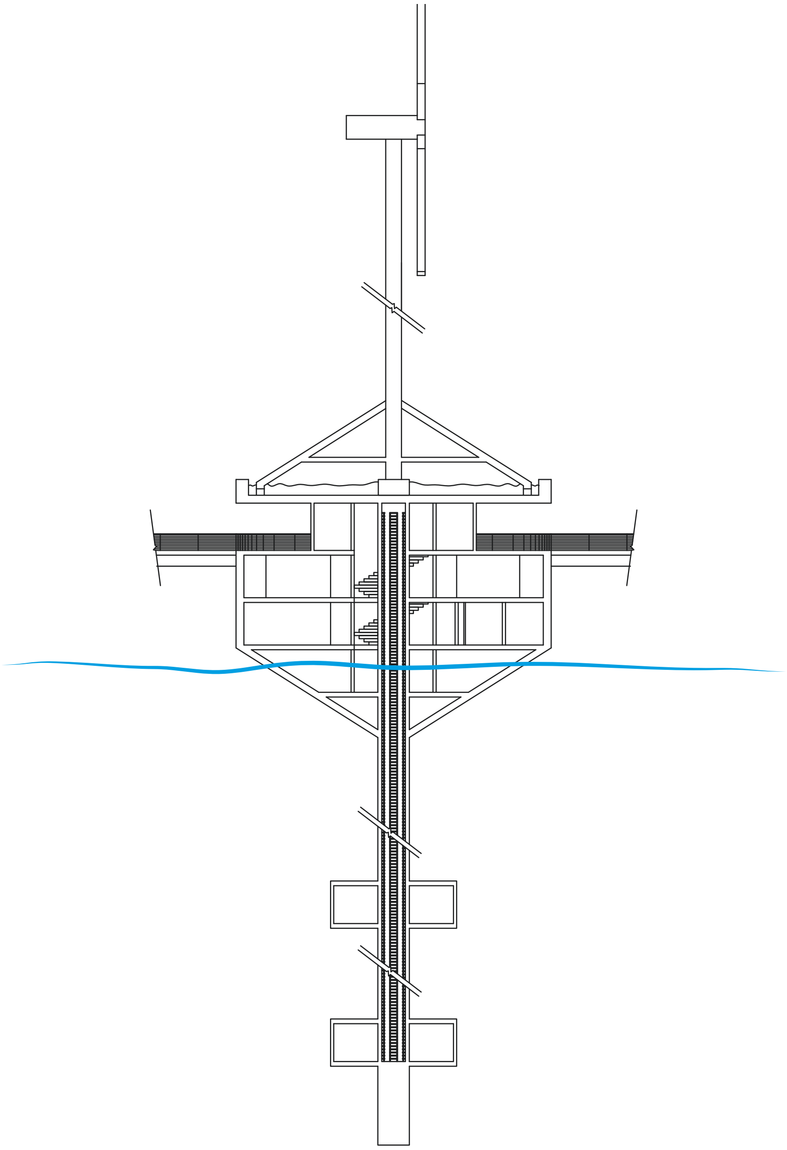


Fig 3.39 Section of central spindle of a colony base unit.

Propulsion – Sails and Motors

Ideally, the colonies would be carried around the North Atlantic by the recirculating currents, but this would not be possible all of the time. At least occasionally, course corrections would have to be made. To allow for some self-guided propulsion, the stations would be equipped with sails and and electric motors (Bond, 1992).

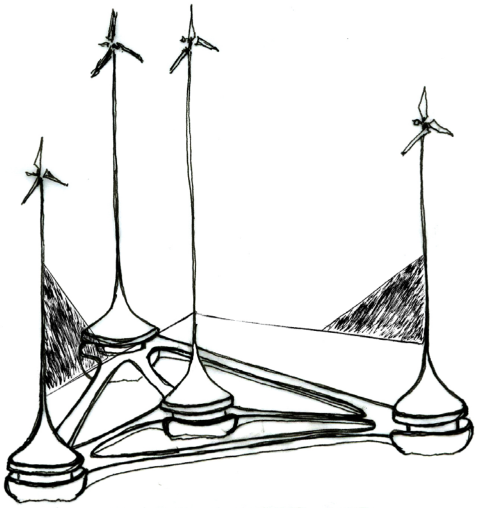


Fig 3.40 Mainsail positions. Two of three potential mainsails are shown in a raised position in this diagram. In practice, sometimes only one would be raised at a time. Three mainsail options are included for the sake of redundancy and adaptability. Triangular sails allow for sailing closer to the wind than square sails (Bond, 1992).

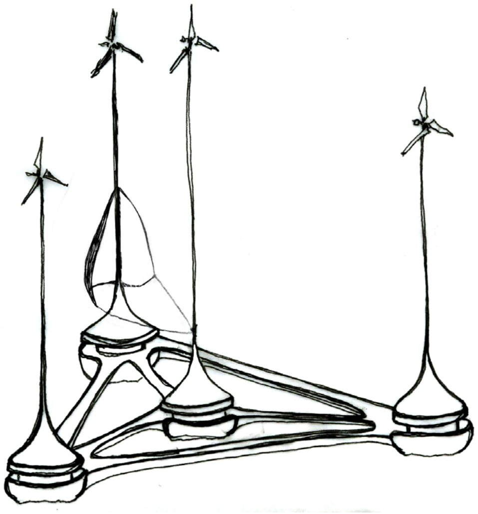


Fig 3.41 Spinnaker position. Potential set-up for sailing with the wind.

Chapter 4
Recommendations & Conclusions

This thesis set out to propose an innovative design for floating colonies that follow oceanic recirculation gyres for the development and management of high sea fisheries and energy farming. Adaptability and ecological responsibility are key features of the design. The proposed colonies are designed to adapt to changing environmental conditions and to operate in an ecologically responsible and sustainable manner.

Further Thoughts on Adaptability

The proposed colonies are adaptable on several different scales. At the largest scale, the choice to follow a recirculation gyre, rather than remaining stationary, is a design choice that has not been previously explored in fish farm design, to the best of my knowledge. The advantage of following ocean currents is that when the current-borne nutrient supply shifts, the colony follows it. At the built level, the choice of constructing the colonies from modules that can be linked or unlinked as desired adds a high degree of flexibility to the design. Base units can be joined together into larger clusters in a variety of configurations to support a variety of activities, and then unlinked as needs change or for added safety in the event of a storm. At the material level, Biorock was chosen because it enables adaptive, self-repairing design.

“The north Atlantic is the most thoroughly studied ocean basin” (Stewart, 2006, p. 192). Compared to other oceans, there is currently a wealth of data for the Atlantic ocean, and so one might wonder why a research and fishing station for this ocean is being proposed. In her book “The Life and Death of Great American Cities”, Jane Jacobs observed that neighbourhoods that had “eyes on the street” - that is, neighbourhoods in which residents could be seen to be watching what was going on in the neighbourhood, be it sitting on porch seats or talking to friends and family out of a window – had much safer streets and reduced crime rates. In fact, the streets of neighbourhoods with casual oversight were safer for children to play in than nearby parks. It is true that other oceans would also benefit from an “eyes on the street” approach, and might be in need of greater monitoring, but the colonies proposed in this thesis are meant to be a starting point, a stepping stone to other similar floating observatories and harvesting stations around the globe.

The drifting colonies /research stations proposed in this thesis are not specifically designed for the north Atlantic ocean. Rather, they are meant to be resilient units capable of deployment in a variety of locations. It is possible that customization could occur in various locations. For example, certain locations might get higher winds, rougher seas, so having a more massive underwater section could help with stabilization. To accommodate these conditions, a current could be run through the lower portions of the “bobbers”, for longer than needed for bobbers in calmer waters, promoting more accretion of seacrete where a more massive hull is desired.

Another useful modification could be setting up the colonies to descend beneath the waves when conditions get really rough. Vertical modifications for heavy weather are currently being employed by some moored fish farms, such as those manufactured by GiliOcean and Stormsafe (GiliOcean, 2018; Stormsafe Submersible Cage System, 2020). Water is good at absorbing impact from repetitive, percussive forces. In an extreme weather scenario, such as a hurricane, tsunami or some other large storm, the ability to ride out storms beneath the the surface could be beneficial.

Ecological Responsibility

At the broadest scale, following the gyres is an innovative way to promote ecosystem health. No fossil fuels are used to transport, store or process nutrients or feeder fish. On the colony itself, all power and propulsion needs are met by harnessing wind, sun, and oceanic thermal energy. At the material level, the primary building material, Biorock, has a positive rather than a negative impact on ocean quality, because it extracts and sequesters CO2 from the ocean. The designed colony meets the goals of adaptability and ecological responsibility by following an approach that is situated between hunter/gathering and farming. In other words, it falls between ocean fishing and conventional aquaculture, aiming to incorporate the best features of both. Without combining these two fishery methods, it is very difficult to farm tuna or other large oceanic fish. At present, existing fish farms for tuna are having difficulties, because they are stationary and not sustainable. Australian fish farm Clean Seas Tuna, for example, has managed to get captive tuna to spawn, but is having difficulities raising tuna to adulthood in a financially profitable way, due to the high cost of feeding such a slow-growing fish (Hays, 2012). One of the unique features of this thesis is that it offers a sustainable method for farming large predator fish.

Petitions, such as the anti-fish-farming petition currently being circulated around the internet by Friends of the Earth, are aiming to turn public opinion against projects such as the Kampachi Farms project currently in development for deployment off the coast of Florida, by equating a small, experimental project with large-scale factory farming (Friends of the Earth, 2020). We are situated at an interesting time of global change. With the help of social media and other digital tools, the actions of activists of all stripes are able to be coordinated nationally and globally in a way that was not possible even ten years ago. In many ways, this democratization of effect is a very positive, empowering development. Until the rise of social media, the propagation of ideas and information was limited to people with relatively large amounts of money and influential positions. People who did not have a way to share their opinions with the world at large now have a way to do so.

A current, close-to-home example of the way organized, nation-wide action can be arranged in a much quicker fashion than even a few years ago can be seen in the blockades set up in support of an indigenous nation which is currently in conflict with the government of Canada. The speed with which strangers living thousands of kilometres away from each other were able to work together towards a common goal was highly effective in raising awareness and support for the indigenous nation, and stopping a resource extraction project which had been allowed to proceed by both provincial and national governments (Tunney, 2020).

Often this new capability to mobilize nationally and internationally has positive effects, but it is worth noting that sometimes the quick, knee jerk reaction to support causes about which one has only read three sentences can actually be counter-productive, slowing down the achievement of results one might actually want. In the case of Kampachi Farms, despite there being many reasons why what the company is proposing is more environmentally responsible than current near-shore fish farms or less damaging than many capture fishery practices such as trawling, environmental groups and private citizens around the world are signing petitions and speaking out against the pilot project, trying to stop the test farm from even being given a trial run (Fanning, 2020).

In order for a project such as the one proposed in this thesis to stand a reasonable chance of being built, it could be beneficial to take time to explain the the positive effects of the proposed structures to environmental groups, media outlets and the general public. In the current global political climate, simply getting government sign-offs and other bureaucratic go-aheads can no longer be assumed to be adequate in order to actually proceed with projects that impact our environment. Publicizing/marketing the low ecological footprint, sustainable approach to resource production, and the monitoring and accountability provided by such a project could go a long way towards actually getting it off the drawing board and into the ocean.

Future Applications

The proposed design could be developed and expanded in a number of ways that go beyond the scope of this thesis. Colonies of a similar design could be deployed in other oceanic areas to study and protect other vulnerable fish populations.

In addition to fish farming and research, a potential use of the proposed colonies is educational ecotourism. Visitors to the colonies would have a rare opportunity to gain insights into the workings of a unique form of aquaculture and a working example of the principles of sustainable design.

The project I am proposing could work in concert with international management bodies such as the International Commission for the Conservation of Tunas and the United Nations to help track and monitor oceanic fish populations on the High Seas.

A fourth potential use of the proposed colonies could be to provide workshops or residencies for artists or writers and to provide a novel environment for people looking for retreats far from light, sound and air pollution.

Final Remarks

We are living in a time of great change. As I write this, a global pandemic, COVID-19, is currently affecting the populations of all countries on the planet. This pandemic draws attention to just how interconnected all humans are, how we are truly living in a global era requiring international co-operation to overcome global challenges. It has become apparent that the status quo is no longer serving humanity adequately, if indeed it ever really did. Supply chains are in disarray, widespread food insecurity looms, and power grids may get disrupted (Tunney, 2020).

This thesis presents a vision of a new way to approach some of the resource-related challenges we are all facing as a global community. As a species, we are facing ecological, economical and perhaps even existential crises, but I am hopeful that the local, regional and global camraderie and rapid adaptations currently taking place in the face of a global pandemic will pave the way for more egalitarian and sustainable methods of interaction with each other and our environment.

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Glossary

Aquaculture: the cultivation of aquatic plants or rearing of aquatic animals as a food source for humans or other animals

Benthic zone: the region at or near the bottom of the ocean or other body of water

Current: a continuous, primarily horizontal movement of water generated by forces including wind, the Coriolis effect, breaking waves, cabbeling, and temperature and salinity differences. Depth contours, shoreline configurations, and interactions with other currents influence a current's direction and strength.

Dead zones: areas in the ocean with low or no oxygen; a lethal environment for fish. Dead zones are created by the influx of nitrogen and phosphorus from fertilizer run-off in coastal waters.

EEZ: Exclusive Economic Zone. EEZ's are coastal sea zones in which a state has certain rights and protections with regards to the exploration and use of marine resources. EEZ's typically extend up to 200 nautical miles out from a state's shoreline.

FAO: Food and Agriculture Organization of the United Nations. The highest level of organization which deals with fisheries. It is worth noting that despite its powers in national waters, the FAO has no jurisdiction in international waters.

Forage fish: small pelagic fish preyed on by larger aquatic predators for food. Herrings, sardines, anchovies and other members of the Clupeidae family are some of the most common forage fish.

High Seas: the opean ocean; often used to refer to those parts of the ocean not under any specific country's jurisdiction

Keystone species: plants or animals that play a unique and crucial role in the way an ecosystem functions. Without keystone species, the ecosystem would be dramatically different or cease to exist altogether. Some keystone species, such as the wolf, are also apex predators, but not all keystone species are apex predators.

Pelagic zone: the upper layers of the ocean

Plankton: small plants and animals at the base of the aquatic food chain.

Ocean gyre: any large, ring-like system of ocean currents, especially those interacting with large wind systems

Ocean conveyor belt: a global system of deep-ocean circulation which constantly moves water around the world

Siphonosphore colonies: groups of jellyfish-like creatures with identical DNA. Individuals within a colony will specialize, but if separated, can still function on their own and start new colonies.

Straddling stocks: fish which range within international waters and at least one EEZ

Transboundary stocks: fish which range within the EEZ's of at least two different countries

Transition zones: mixed waters, containing nutrients from both coastal and deep waters