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Turning to the Ocean to Feed Humanity

According to data from the UN's Food and Agriculture Organization (FAO), global food production accounts for approximately 50% of all habitable land use (see Figure 1) (Ritchie, 2019). Despite this immense amount of land dedicated to agriculture, food scarcity and insecurity has been an important concern for economists and policymakers alike. This concern is exacerbated as one observes population growth and projects what future global population numbers may look like. Numerous calls advocating for increasing global production have been made, and some sources suggest food production needs to double to sufficiently feed the 9 billion people that will inhabit Earth in 2050 (Alexandratos et al., 2006). While others suggest aiming for a 50% increase in food production by 2030 (Rosengrant et al., 2006). However, simply growing more crops and rearing more livestock is not a complete solution. The World Resources Institute estimated that in 2016 agricultural activities accounted for approximately 18% of global greenhouse gas (GHG) emissions, a year when GHG emissions totaled 49.4 billion tonnes of carbon dioxide equivalents (CO_2eq) (see Figure 2) (Ritchie, 2020). A very bleak picture has been painted thus far, and it is evident that sustainable agricultural practices need to be used to avoid overwhelming the planet. However, a partial solution may lie in the 71% of the world that is covered by water (Ritchie, 2019).

Golden sandy beaches, rolling blue waves, the cool ocean breeze, and an orange setting sun. These are some of the images that come to mind when a coastal ecosystem is mentioned, a place where land meets ocean. However, coastal ecosystems are much more than popular tourist destinations, and are in fact some of the most productive ecosystems on the planet. The distribution of chlorophyll A reflects the distribution and level of photosynthetic activity, and therefore primary production. Figure 3 shows this distribution and highlights the higher levels of chlorophyll A present in coastal regions on Earth (Sigman & Hain, 2012). It is important to consider primary production as it is the foundation upon which all upper trophic levels grow. This is important for human interests as fisheries are a major component of human economies that directly and indirectly provide food, jobs, and resources. They are inherently dependent on the presence of marine life that is supported by these areas of greater primary production. The distribution of fisheries and the amount of their catch shown in Figure 4 is therefore unsurprising (Watson & Tidd, 2018). Comparing Figures 3 and 4, we see an almost exact overlap in the areas of highest primary production noted in Figure 3. This discussion shows the importance of coastal ecosystems and the incumbent fisheries and showcases a potential solution for the global food crisis. However, human greed evidently knows no bounds and technological evolution had paved the way for more efficient fishing leading to record catch levels at fisheries.

While lucrative in the short term, overfishing has stripped many coastal waters of viable fish levels and led to the collapse of entire fisheries. A well-known, Canadian example of this is the collapse of the Atlantic fisheries of Newfoundland where decades of overfishing of Atlantic cod resulted in their lowest levels, approximately 1% of historical levels, in 1992 (Hamilton & Butler, 2001). Furthermore, a 2006 study published in *Science* projected that, without appropriate measures in place, by 2048 the world would experience a complete loss of fish abundance and widespread fishery collapse (Worm et al., 2006). These events have spurred on greater investment and research into ethical and appropriate fishery management, which have led to general fish stock status improvements and Atlantic cod stocks being on track to return to sustainable levels (Hilborn et al., 2019; Rose & Rowe, 2015). This greater intentionality, investment, and research into protection of fish species has led to two important innovations that allow for more concentrated conservation efforts: marine protected areas and aquaculture.

Marine protected areas (MPAs) are highly regulated areas of oceans, seas, coasts, estuaries, and lakes that are protected and restricted from human activities and interference. They can be used as effective fishery management tools to protect marine biodiversity, potentially increase fish abundance, and contribute to mitigate climate change effects (Sala et al, 2021). As of March 2021, MPAs are fully implemented in and protect only 2.7% of ocean area but an additional 4% of ocean area protection has been proposed or planned (Marine Conservation Institute, 2020). Despite protecting a relatively small area, MPAs have already proved their efficacy as fish biomasses in no-take MPAs are on average 670% greater relative to nearby unprotected areas, and partially protected reserves show a biomass 343% greater than unprotected areas (Sala et al., 2018). However, by expanding MPAs to cover 5.8% of the ocean can potentially increase food production by approximately 5.1 million metric tonnes (Sala et al, 2021). This shows that MPAs are a great tool in protecting coastal ecosystems and their services.

Aquaculture on the other hand is less focused on preservation and conservation. It is a much more intensive and focused commercial activity with the sole purpose of growing fish for human consumption. In this method, fish are grown in indoor tanks or closed sea pens where they are provided a feed to grow faster and increase the efficiency of getting the fish to market. It is a model that shows results. Figure 6 is a composite of total global aquaculture efforts and fishery catch results between 1950 and 2017 (Tacon, 2019). It clearly shows where yields from capture fisheries plateau, but at the same time aquaculture yield is continually rising (Tacon, 2019). However, before aquaculture and its reportedly immense productivity can be heralded as humanity's savior, there are many concerns that need to be considered. Two main concerns stand out: animal welfare and coastal pollution. Given their pen structures, aquacultures tend to be extremely overcrowded. This overcrowding has shown an increase in cortisol levels indicating that the fish in these aquaculture pens are more stressed compared to their wild counterparts which plays a role in making aquaculture fish more susceptible to diseases (Conte, 2004). Along these lines, overcrowding has also been correlated with an increased incidence and infection by sea lice, a parasitic copepod that latches on to the fish and can cause a host of issues such as skin erosion, hemorrhaging, gill congestion, and increased mucus production (Johnson et al., 2004). Poorly managed aquacultures can also have a negative impact on the surrounding coastal ecosystems primarily through pollution. Fecal waste from the fish and unconsumed feed eutrophicate the water leading to increased bacterial growth. This can both cause disease and lower dissolved oxygen levels leading to the asphyxiation of the fish in the aquacultures and surrounding area (Primavera, 2006).

Despite these issues, aquaculture and MPAs are significant innovations spurred on from realizing past mistakes and investing in research to correct them. Along these lines, a new form of aquaculture has been proposed: the vertical ocean farm (GreenWave, 2022). This model is similar to an aquaculture, but instead of a sea pen that is limited to the topmost layers of the water column, vertical ocean farms take advantage of the entire water column. The top-most layer is made up of sea vegetables and fast-growing giant kelp that can grow at a rate of a foot per day and are strong carbon sinks (Carroll, 2022; GreenWave, 2022). Harvesting this carbonrich kelp can then see multiple uses as biofuel, human food products, and even as feed for cattle (Carroll, 2022; Nilsson & Martin, 2022). Located below this giant kelp layer are containers holding shellfish such as mussels and scallops, and at the very bottom are crates of oysters and clams (GreenWave, 2022). While the dominant class of seafood being produced are shellfish, it should be pointed out that there is greater species diversity. This yields different types of food items for different tastes but also avoids potential monocrop type issues that traditional aquacultures and terrestrial farms face (Carroll, 2022). Additionally, by being vertical and taking advantage of the entire coastal water column, these vertical ocean farms are an incredibly efficient use of space and 1-acre of these farms can yield about 30 tons of sea vegetable and 250,000 shellfish per year (Carroll, 2022). While this may be far cry from the million of tonnes that traditional fisheries and aquacultures may produce, further research and optimization could potentially lead to better yields. Lastly, the seaweed and shellfish that make up the vertical ocean farm are natural filterers and can individually filter almost 225 liters of water per day (Carroll, 2022). When scaled up, it is not difficult to imagine that coastal regions where these vertical ocean farms are set up may be cleaner and less polluted compared to a traditional aquaculture.

Vertical ocean farms are not a novel idea, they are an evolution and incremental improvement of something that already existed. It may not show-off the same numbers and yield as fisheries or aquacultures, but it is still in its infancy and further research is required. However, it is a step in the right direction as it aims to address long-standing global food production concerns and does so in a unique, efficient, and environmentally conscious way. For that reason, it is an extremely exciting step forward and piques one’s curiosity as to how it can evolve, improve and be commercially viable.

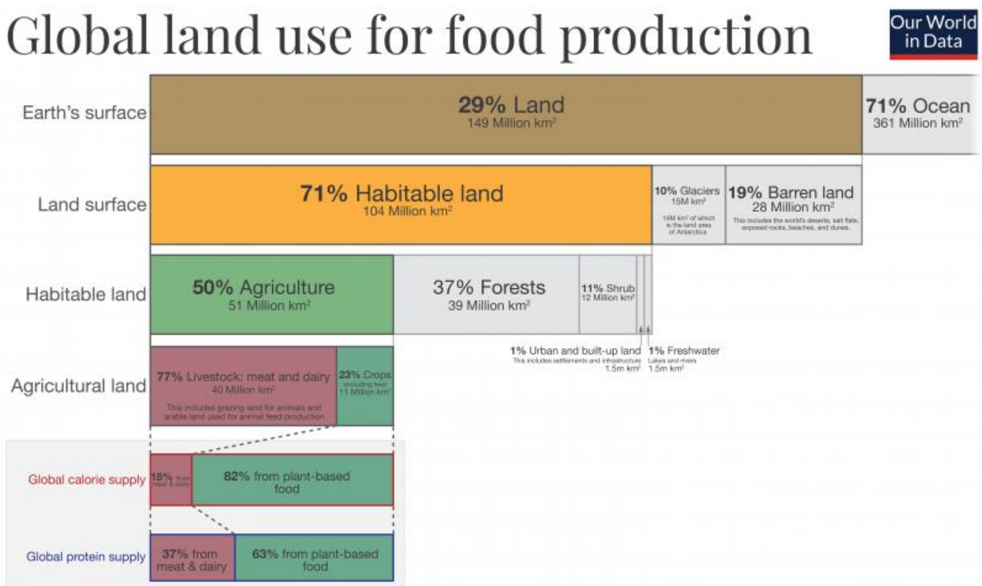

Figure 1: Global land use data according to the UN Food and Agriculture Organization (Ritchie, 2019).

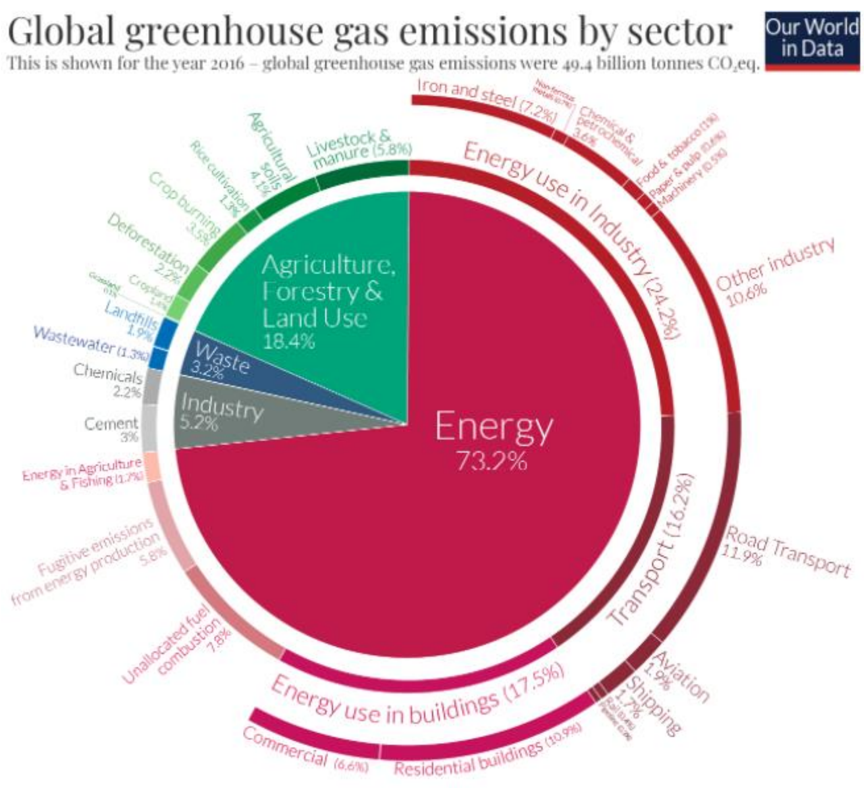

Figure 2: Global greenhouse gas emissions by sector in 2016 (Ritchie, 2020).

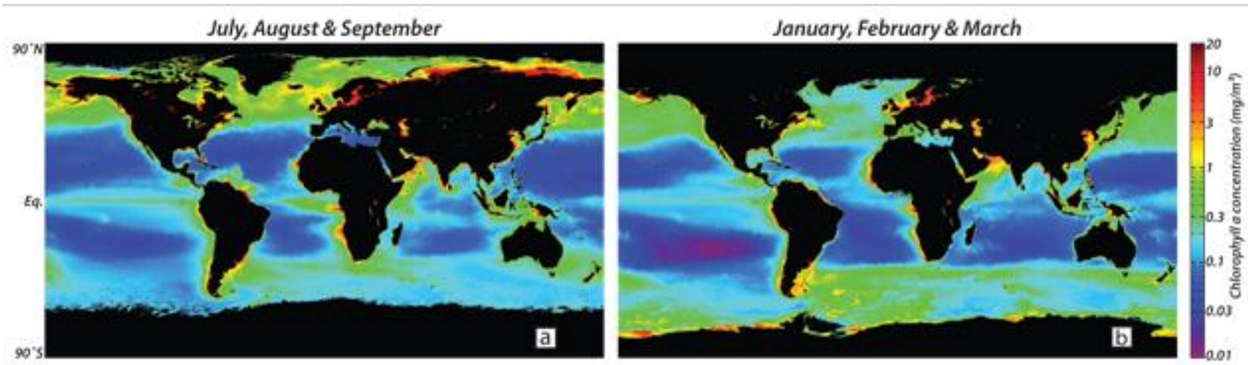

Figure 3: Distribution of chlorophyll a concentration in marine ecosystems around the world in 2012 (Sigman & Hain, 2012).

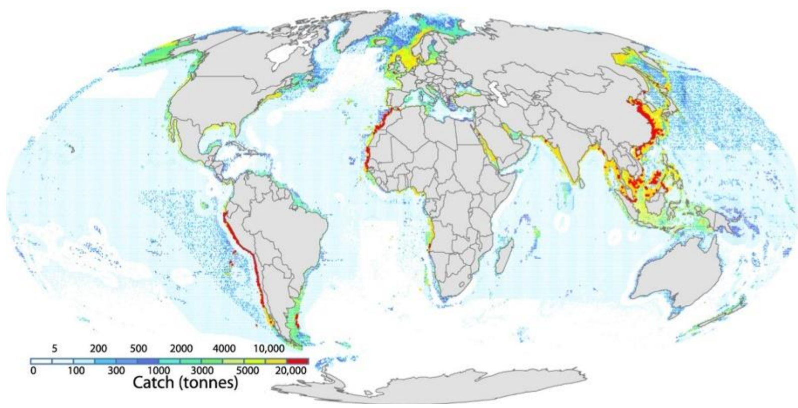

Figure 4: Graphical representation of marine catch from 2000-2015 (Watson & Tidd, 2018).

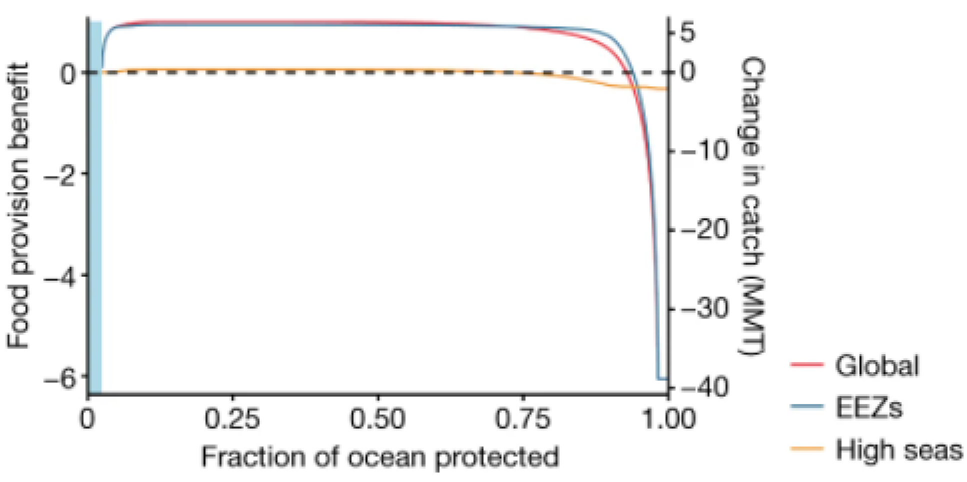

Figure 5: Change in catch as a function of fraction of ocean protection (Sala et al., 2021).

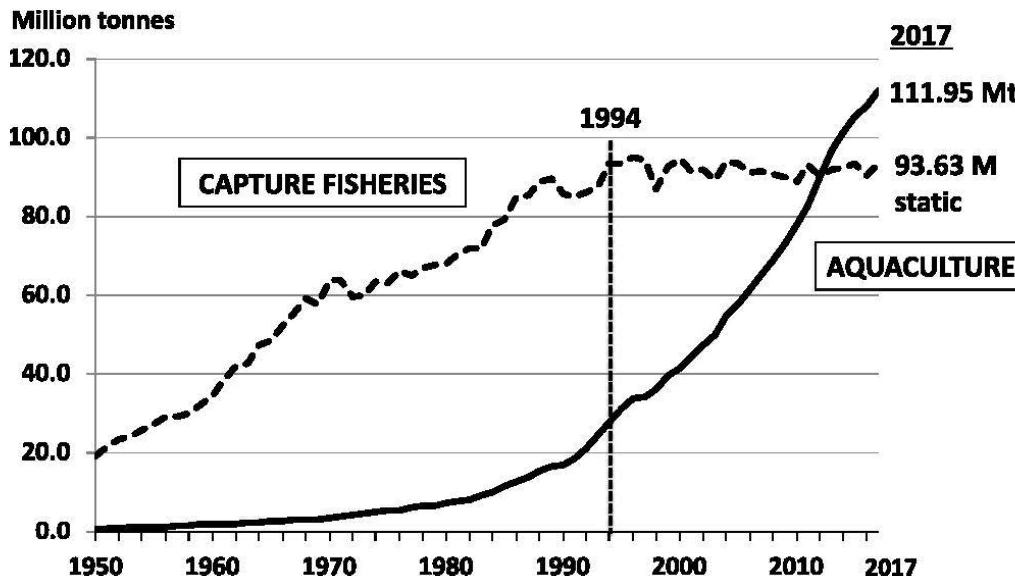

Figure 6: Total global aquaculture and fishery catch yield between 1950-2017 (Tacon, 2019).

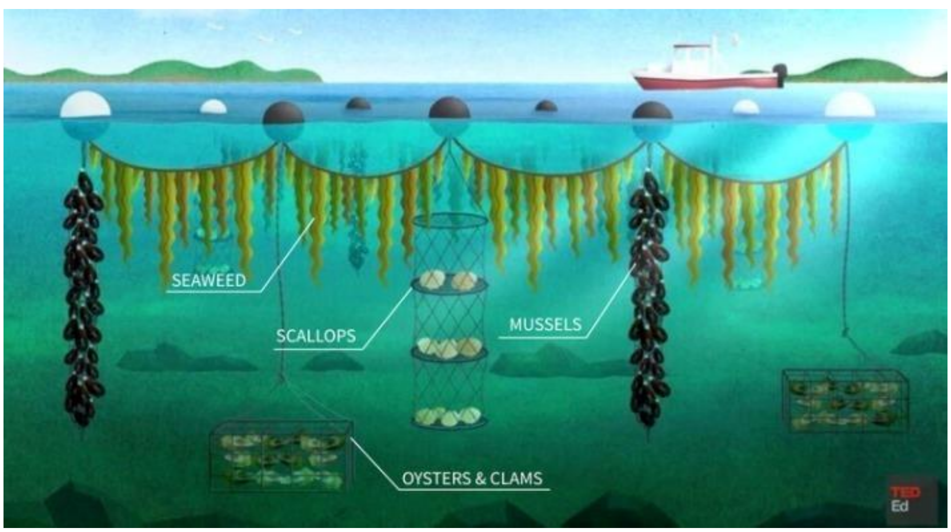

Figure 7: A schematic of the vertical ocean farms designed by GreenWave (GreenWave, 2022).

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