


S.958: Coral Reef Sustainability Through Innovation Act of 2017



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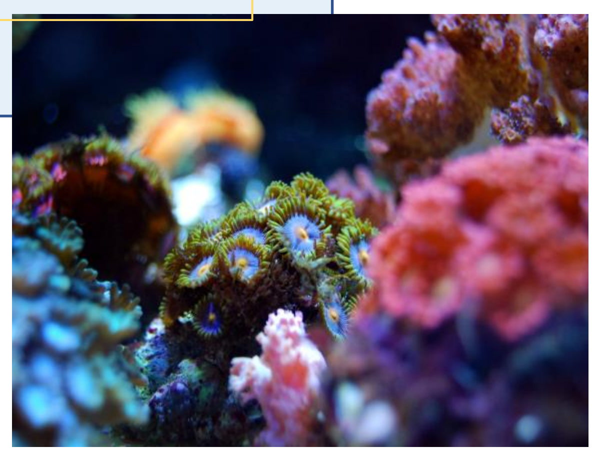

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Executive Summary

Corals reefs are a productive ecosystem that provide important ecological services to other marine organisms and humans alike. They provide food and shelter for marine organisms, and coastal protection, tourism and fishing for humans. Less than one percent of the ocean houses all of the coral reefs in the world, but 25% of biodiversity. Unfortunately corals are experiencing life-threatening stress due to anthropogenic causes, which can be divided into two main categories. The global threat at hand is climate change, specifically ocean acidification and warming, caused by an increase in greenhouse gas emissions; and local threats which include sedimentation, contamination, sea level rise and poor fishery practices and management. When corals experience this level of stress, they expel the algae that live symbiotically within them, causing them to lose their color, which can lead to their death.[1]

Due to the multi-faceted challenges that every reef faces, government action is necessary to coordinate a remediative solution, as no single action will suffice. To confront this systemic issue, an integrated approach that brings together coastal communities, fishers, divers, scientists, the tropical tourist industry, chemical manufacturers, fossil fuel companies, and upstream polluters is needed. In the past, such coordinated efforts have been led by the public sector, such as in the case of the experimental restoration of the Islas Marietas reef in Central Mexico (Tortolero-Langarica et al., 2014). The 2015 expansion of the Papahanaumokuakea Marine National Monument in the subtropical waters to the northwest of the Hawaiian archipelago indicates that certain segments of the government recognize the value of reefs and the need to protect them.[1]

The *Coral Reef Sustainability Through Innovation Act of 2017* (S. 958) was recently introduced to the Senate by a Democratic senator from Hawaii, Mazie Hirono.[1] It is a much-needed comprehensive update to the *Coral Reef Conservation Act of 2000*, reflecting the new data and the intensification of the situation in the intervening years. The Act prioritizes programs that address the following: [1]

1. Scientific research and monitoring of coral reef degradation
2. Monitoring or management of financial hardship
3. Projects that address economic harm and job loss caused by coral degradation and ecosystem benefits
4. Development of projects to aid rural communities and business
5. Development of projects providing management options for impacted tourism industries.

The bill draws on the prize-giving process of the earlier Stevenson-Wydler Technology Innovation Act of 1980, which awarded prizes for technological advances in the United States[1]. From examining the Stevenson-Wydler Act, we can extrapolate the specific mechanisms surrounding the raising and funding of the various prizes given out in the Coral Reef Sustainability Through Innovation Act.[1]

[1] For references, please see the full Coral Reef Sustainability Through Innovation Act of 2017 Final Report

Background

Corals are animals from the phylum Cnidaria that exist as individual polyps and form colonies of thousands. There are two types of corals, the reef-building hermatypic hard corals and the non reef-building ahermatypic soft corals (Sheppard et al., 2009). Photosynthetic, reef-building, hard corals have a calcium carbonate backbone, and are mostly found in shallow warm waters, less than 90 meters deep, with an optimal temperature range from 21-29°C (Barnes,1987). Hermatypic hard corals, unlike the ahermatypic soft corals, form a symbiotic mutually beneficial relationship with an algae called zooxanthellae (Sheppard et al., 2009). The mutualistic relationship is based on the zooxanthellae providing up to 90% of the nutrients that the coral needs to survive by engaging in photosynthesis, and the coral provides a safe habitat to the algae (Barnes, 1987).

Figure 1: Coral Polyp in mutualistic symbiosis with zooxanthellae (Smithsonian)

On the other hand, the ahermatypic soft corals, like the fan coral, have a flexible skeleton made of a gorgonin protein and spicules which are clumps of calcium carbonate (Barnes, 1987). These types of corals are capable of living within a wider range of temperatures and depths, including both cold, deep waters as well as warm, shallow waters. In addition, soft corals can exist as part of the hard reef ecosystem. Soft corals also do not form a mutually beneficial relationship with zooxanthellae, (Sheppard et al., 2009) instead their nutrients are obtained through their tentacles, which contain stinging cells called nematocysts that are utilized to trap prey (Barnes, 1987).

Despite the fact that coral reefs cover less than 1% of the world ocean bottom, they support about one quarter of all marine life that depend on coral reefs for food, shelter or species interaction (Anthony, 2016). It is estimated that the global value of ecosystem services is $145 trillion a year when the total biome area is taken into account. Within the $145 trillion, a hectare of degraded coral reef contributes $36,794 per year while a healthy and thriving coral reef contributes up to $2,129,122 per hectare per year (Costanza, 2014). This estimation takes into account the benefits of coral reefs such as human well-being, public goods, and ecosystem services that support a balanced marine ecosystem.

Benefits of Coral Reefs

The diversity of coral reef species and their habitats make them one of the world's most productive ecosystems, essential for a healthy ocean, human economies, and sustainable livelihoods. Coral reefs conglomerate the greatest of biodiversity in the ocean, meaning that there is high variability among the marine organisms that inhabit this complex ecosystem. Coral reefs provide goods and services that contribute to human well-being, that is estimated as $30 billion dollars in net benefits a year (Cesar., et al 2003). With over 500 million people who are dependent on coral reefs around the world, the cost of coral destruction is immense (Branchini et al., 2015).

Tourism and fisheries in particular are two sectors that are heavily dependent on the health of coral reefs. Reefs have sustained coastal communities by providing income and a protein source. Globally, 6 million metric tons of fish catches per year are harvested from fisheries associated with coral reefs - accounting for one quarter of the total catch in developing countries (Evans et al., 2002). Overall, a healthy thriving reef can potentially provide $5.7 billion dollars from fisheries alone (Chen., et al 2015). In the U.S. alone, commercial fisheries dependent on coral reefs are valued at over $100 million dollars annually, plus an additional $100 million dollars from recreational fisheries (NOAA, 2017a).

Coral reefs' beauty has inspired an entire tourism industry and lifestyle, which is part of the main economy of many developing coastal countries. Snorkeling and diving are among the most popular tropical tourist activities, generating a net profit of around $9.6 billion dollars each year (Cesar et al 2003). Just in the Caribbean Region alone, the tourism industry is worth $89 million dollars. It generates around $1.5 billion dollars per year in the Great Barrier Reefs, and $1.6 billion dollars annually in Florida (Chen., et al 2015).

Other important ecosystem services coral reefs provide do not necessarily generate direct capital such as coastal protection, which has been grossly undervalued. Reefs act as a natural barrier and coastal buffer from weather events in coastal zones, reducing swells and wave energy and protecting coastal infrastructure, activities and human lives (Pascal et al., 2016). A reef can reduce up to 97% of the average wave energy and 84% of the wave height, preventing flood and damages that will cost money to the coastal communities and government. Additionally, 64% of coral reefs are located around highly populated coastal areas in developing countries, which are scarce of resources to recover from increasing severe weather events as a result of climate change (Pascal et al., 2016). The expected increase in severe weather events will elevate the costs of artificial dikes to $12-71 billion dollars per year by 2100. The act of conserving and restoring coral reefs for coastal protection purposes would significantly decrease the amount of associated costs from other flood prevention methods such as the artificial dikes, which are less cost effective than conservation and restoration of coral reefs for coastal protection (Ferrario et al., 2014).

Environmental Problems Facing Coral Reefs

Even though coral reefs are essential ecosystems for at least one third of marine species as well as human economies and livelihoods, they face threats leading them towards extinction. Deep cold water corals mostly face threats related to sea mining, pollution and bottom trawling. Hard photosynthetic reef building corals face the aforementioned threats and others such as degrading fishing practices, rising ocean temperatures, rising sea level, ocean acidification and sedimentation. These problems not only cause environmental degradation and loss in biodiversity, but also cause financial hardship and economic losses in coastal communities and industries that are dependent on them.

Currently, the most prominent threat to coral reefs is climate change which is very difficult to assess as it causes the warming of the oceans, acidification, sea level rise and change in weather patterns; all of which have detrimental effects on coral reefs. Climate change is rapidly occurring because of the burning of fossil fuels for energy and other industrialized processes which has increased greenhouse gas emissions. This has caused an increase in the greenhouse effect responsible for global warming. Greenhouse gases like carbon dioxide (CO_2) trap heat in the atmosphere and radiate it back to the earth's surface. Climate change will also result in an increase in sea level, which limits the sunlight available to zooxanthellae, the algae that live within corals and produce nutrients through photosynthesis.

Ocean Acidification

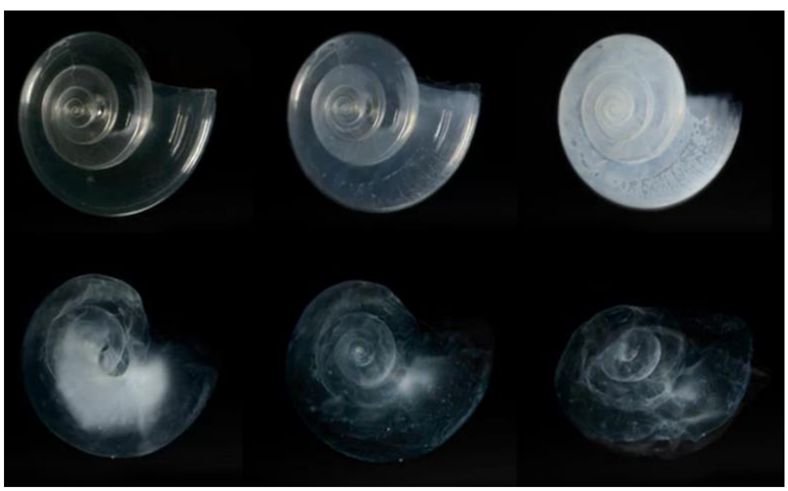

Figure 2: Calcium Carbonate Skeleton Dissolving Over Time (NOAA)

The ocean acts as a CO_2 sink, reducing the concentration of this molecule in the atmosphere. An excess dissolution of CO_2 causes a respective decline in the pH level of the ocean thus leading to ocean acidification. When fossil fuels are burned, they release carbon dioxide into the air. When dissolved in the ocean, carbon dioxide reacts with the water releasing hydrogen ions, this reaction is responsible for decreasing the pH and thus making the water more acidic (Albright et al., 2018). Laboratory studies predict that acidification will have a detrimental effect on the marine ecosystem, especially in biotic calcification and reef diversity if the pH reaches below 7.8. The acidic waters create a dissolving effect in coral skeleton, thus reducing biomass of the colonies and calcification (Fabricius et al., 2011). The hydrogen ions bond with carbonate, which prevents calcium ions from bonding with carbonate to form calcium carbonate. Hard corals depend on the formation of calcium carbonate to secrete and grow their skeletons, therefore lower concentrations of calcium carbonate molecules in the water will inhibit corals' efficiency to repopulate and increase biomass (Albright et al., 2018).

Ocean Warming

Global climate change causes the rise in ocean levels and sea surface temperature. An increase in sea level will result in an increase in the distance between the symbiotic algae, zooxanthellae, and the sea surface. These photosynthesizing algae will then receive less sunlight, which will result in less production of nutrients for the coral polyp. Due to the loss of these nutrients usually produced by the algae, the corals will have a hard time surviving.

An increase in temperature has caused a variety of problems related to ocean health that include change in weather patterns and currents, an increase in frequency and severity of storms, an increase in sea level rise and the most direct effect in corals: bleaching. Coral bleaching occurs when the zooxanthellae that live inside the polyp tissue become distressed due to an outside force, such as ocean warming, and leave the polyp. By leaving, the coral loses 90% of its nutrient source that the algae provides with photosynthesis. Bleaching will occur when temperatures rise above the standard 25-29 degree Celsius range for an extended period of time (Gross, 2006). Bleaching does not necessarily mean death for the coral because the zooxanthellae can return to their host if conditions return to normal. However, if the conditions persist within a certain amount of time, then the coral will die of nutrient depletion.

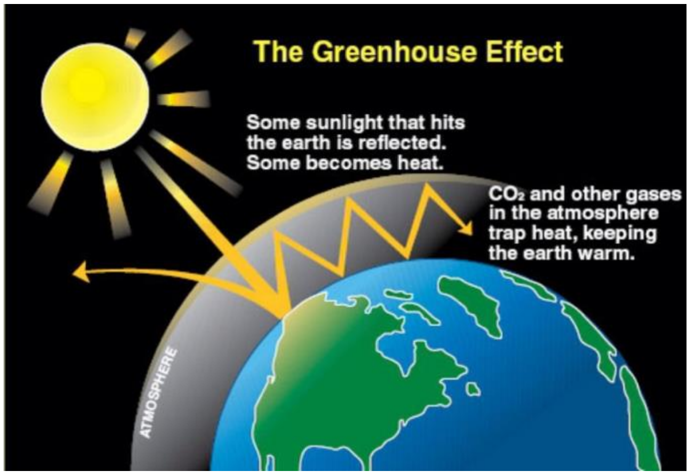

Figure 3:Greenhouse Effect (Medium)

Another cause of increasing ocean temperature, inducing bleaching, is the periodical El Niño Southern Oscillation or ENSO. El Niño occurs when the waters of the Equatorial Pacific become warmer and the eastern winds get weaker, reducing the mixture of cold and warm water, moving warm water currents east towards the coast of Peru (NOAA, 2017d). El Niño occurs naturally, but it has been intensifying with global warming, causing episodes of widespread bleaching across the Pacific. The last El Niño episode in 2015-2016 caused the third largest mass bleaching event in history - impacting approximately 70% of tropical coral reefs (Hughes et al., 2017; NOAA, 2017b).

Sedimentation & Contamination

Other anthropogenic stressors that influence the health and biomass of coral reefs are land-based sedimentation and contamination. Construction, agriculture and deforestation create sediments and excess nutrients that without proper land base management are carried into the ocean via rivers and other water sources, through a process called runoff. Runoff causes three primordial problems: (1) excess nutrients in the water, (2). increased amount of suspended particles in the water column and, (3) particle settlement on top of corals that can bury them (Fabricius, 2005). Pesticides and fertilizers used in agriculture and construction are nutrient-rich and used by external algae that settles on top of the coral. This algae uses up oxygen and prevents light from reaching the corals (Piniak, 2004). The increase in phytoplankton and suspended particles carried from rivers directly decrease the sunlight that reaches the coral, thus decreasing photosynthesis rates (Fabricius, 2005). The same happens when particles settle on top of the corals; the sediments bury the coral and prevent light from reaching the zooxanthellae, ceasing photosynthesis, eventually killing the coral from nutrient starvation (Piniak, 2004).

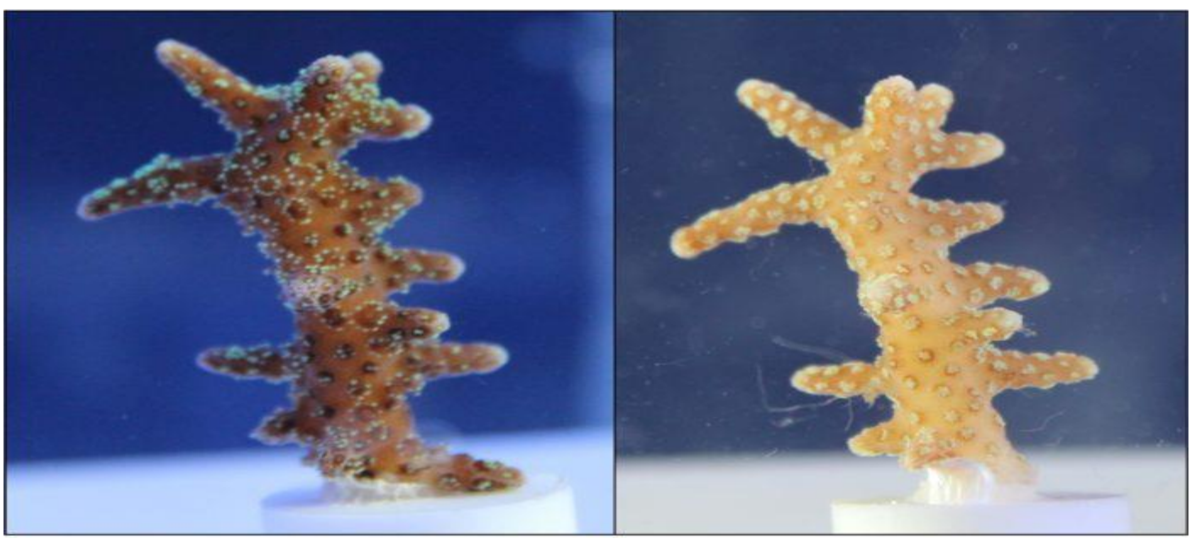

Figure 4:Oxybenzone effecting coral (Craig Downs)

Other chemicals carried by runoff can be toxic to corals and can cause direct negative impacts on their immune system, leaving corals more susceptible to disease caused by naturally occurring viruses and bacteria. Additionally, other chemicals like oxybenzone and octinoxate used in sunscreens are toxic to corals, increasing the rate of diseases even in minimal concentration and can lead to an increase in probability of bleaching. An experiment by Danovaro et al., (2008), showed that a minimal concentration of 10 μL/L of sunscreen can cause bleaching after only 96 hours in addition to other detrimental effects to coral health.

Land based pollution accounts for 80% of solid waste in the oceans. This has become a global problem and the United Nations reports that if this continues into 2050, there will be more plastic than fish in the sea (United Nations, 2018). Lamb et al., (2018) conducted an experiment on the impact of macroplastic in coral specimens. The experiment found that the chances of disease in coral before coming in contact with plastic is about 4%, but after coming in contact with plastic, the chances increased to 89%. Interaction with plastics can carry coral-harming diseases and plastics themselves can inhibit corals' ability to feed thus increasing stress. This can contribute to a compromised immune system in coral, making them more susceptible to illness. Additionally, research has shown that coral polyps are ingesting microplastics due to their similar size to sand and planktonic organisms, which they normally feed on (Hall et al., 2015). Plastics are difficult or impossible to digest when eaten, meaning that corals will not filter feed enough to sustain themselves after the microplastic is ingested (2015).

Lastly, another source of pollution that accounts for part of the other 20% of solid plastic waste pollution in the ocean is vessel equipment including fishing gear, nets and lines (United Nation, 2018). Nets, in particular, also affect reefs when lost or discarded. These nets are commonly referred to as ghost nets. These nets travel in the water column until they get tangled or settle on reefs, disrupting the light, and potentially dragging and breaking coral structures (Bruckner et al., 2005).

Fishery Management

Poor fisheries management, which consist of overfishing and poor fishing practices in both industrial and small-scale artisanal fisheries, have become a problem for an array of ecosystems and species. The commercial demand has increased the fishing efforts, and technology has allowed fishing in deeper zones far from the coast. Industrial fishing includes bottom trawlers that drag everything in the way of the net, this includes target species like shrimp and non-target bycatch fish, invertebrates, corals, sponges, and other sessile and tiny specimens. The indiscriminate killing of non-target species results in a shift of balance in the coral ecosystem and loss of biodiversity (Clark et al., 2010).

Other coral reef small-scale fisheries target herbivore species, like parrotfish. The parrotfish trim coral polyps, clearing it from algae settlements and preventing an overgrowth of the same, thus maintaining a balance of macroalgae and coral growth. When herbivore populations decline, the algae that is positioned on top of the corals grows freely, covering the polyps and thus asphyxiating the colonies (Bozec et al., 2016).

Additionally, other poor fishing practices include cyanide and dynamite fishing. Both are destructive practices that kill everything in their path. Cyanide is used to lull fish for the aquarium trade, poisoning coral polyps, and leading to bleaching (Jones et al., 1999). Blast or dynamite fishing can kill schools of fish, causing them to float to the surface, and become more easily collected. The explosion breaks up the calcium carbonate backbone, destroying the reef.

Figure 5: Parrotfish eating algae off coral (Ken Marks)

On the other hand, the blast can damage and kill other non-target species that are undesired by fishers. This will eventually reduce biodiversity and throw off the balance required for proper ecosystem function (Mcmanus et al., 1997). Both practices are prohibited in almost every country but are still an issue in some parts of Asia and Africa.

Other

Disruptive fisheries, pollution, and warming ocean temperatures affect some species while benefiting others. Massive algal blooms caused by nutrient runoff and warm waters are known to asphyxiate entire reefs (Diaz-Pulido et al., 2007). Loss of herbivores like sea urchins and parrotfish allows algae to settle in corals with no predators to clean it. Overgrowth of species such as the crown of thorns starfish (*Acanthaster* spp.), which preys on coral polyps, is now the second top cause of coral mortality in the Great Barrier Reef (Hoey et al., 2016).

Different impacts mentioned above have supported the outbreaks of the crown of thorns starfish. The first hypothesis to explain the outbreaks was the "predator removal hypothesis," which supports the idea that the outbreaks were a result of a shift in ecosystem balance, due to fisheries of the predominant crown of thorns predators like the giant triton (*Charonia tritonis)* (Cowan, Pratchett, Messmer, & Ling, 2017). On the other hand, other studies support that increased food availability due to nutrient-rich waters from agricultural runoff and warm temperatures increases survival and development rate of the larvae (Uthicke et al., 2015).

Legislative Analysis

As a way to combat the problems facing coral reefs mentioned above, a Democratic senator from Hawaii, Mazie Hirono, proposed new legislation to the Senate for future review. The legislation at hand is S.958: The Coral Reef Sustainability through Innovation Act of 2017 (hereafter referred to as “the bill”). The main purpose of the bill is to fuel further innovation and research surrounding the prevention of coral reef degradation and financial hardship to coastal communities dependent upon corals. This legislation is an amendment to the Coral Reef Conservation Act of 2000, which was created to halt the coral degradation occurring across the world. The Coral Reef Sustainability Through Innovation Act seeks to achieve its primary goals through facilitating prizes and incentives for innovative solutions and research on coral reefs and coastal communities through competitions. Government agencies would be the main actors in creating the different prize competitions. The monetary prizes are awarded according to five main priorities: (Mazie Hirono, 2017)

- Priority 1: Sustainability and growth of coral reef research
- Priority 2: Scientific management of coral reefs
- Priority 3: Economic management of coral reefs in communities
- Priority 4: Creation of communal advancement
- Priority 5: Aid tourist communities

The bill draws on the prize-giving process of the earlier Stevenson-Wydler Technology Innovation Act of 1980, which awarded prizes for technological advances in the United States. From examining the Stevenson-Wydler Act, we can extrapolate the specific mechanisms surrounding the raising and funding of the various prizes given out in the Coral Reef Sustainability Through Innovation Act. Funds are allocated on a competition-by-competition basis, in which these funds are disbursed from monies coming from either the government or the private sector. There is a maximum amount of prizes and disbursements that can be distributed over each prize competition (Stevenson-Wydler Technology Innovation Act of 1980, 1980).

There are many benefits to the bill and the prize model it seeks to follow. The concept of an innovative competition and prize allows for an increased amount of novel ideas that may have not been originally thought of without the incentive of the competition spurring innovative thoughts and behaviors. Another benefit of this model is runner ups, who have still come up with innovative ideas, can further develop their ideas and be able to raise more awareness and thus subsequent research for the coral reef topics at hand.

Solutions to Problems Facing Coral Reefs

The Coral Reef Sustainability Through Innovation Act of 2017 focuses on local solutions to the challenges facing corals. As ocean warming and acidification accelerate in the coming decades, local solutions to reduce coral degradation, increase monitoring, and forge economic opportunities for coral dependent communities are critical. The prize categories created by the bill will promote innovative solutions to the challenges facing corals. The following section will address three solutions that fall within the priority prizes designated by the bill.

Solution 1: Scientific Research and Monitoring of Coral Reef Degradation

In order to mitigate coral degradation, the Coral Reef Sustainability through Innovation Act of 2017 will address scientific research that focuses on increasing the resilience of corals. Four possible programs that could be beneficial and are eligible for the prizes in the act are: (1) asexual propagation in coral nurseries; (2) sexual reproduction in labs; (3) the pairing of coral with hardier algae; and (4) the reduction of contaminants and sediment runoff.

Assisted reproduction through sexual and asexual reproduction is an important solution that uses technology and different scientific methods to further assist in coral's natural adaptation. Efforts that utilize a coral's asexual reproduction for restoration are reliant on fragmentation to increase the number of corals and the rate at which they grow. When corals are fragmented below a certain size, they shift their resources towards accelerating their growth rate as a competitive strategy to gain access to more resources and space for security (Forsman et. al 2015). Fragmenting corals then forces corals to grow at an accelerated rate for eventual outplanting in areas chosen for restoration. Non-governmental organizations (NGOs) such as *Coral Restoration Foundation,* based in the Florida Keys, are working toward replenishing degraded reefs. The *Coral Restoration Foundation* fragments branches of healthy *Acropora* spp. colonies that have survived difficult climates and bleaching events, and place them in underwater *in situ* nurseries. These nurseries are sheltered, shallow-water locales where humans are able to propagate and grow new corals. After they grow to a sufficient size, they are grafted back into degraded reefs (Forsman et. al 2015).

Corals also reproduce sexually; this method of reproduction is the basis for their genetic diversity, and scientists are using it to their advantage. Researchers at the Smithsonian Tropical Research Center and the Mote Marine lab are using genetic engineering and crossbreeding to enhance coral diversity and resilience to climate change (van Oppen et. al, 2015). Parkinson et al., (2018) shows that there are species of corals that already have natural resistance to changes in the environment. The genetic resilience of these corals can be utilized through breeding for these traits within species and cross-breeding between species (van Oppen et. al, 2015). However, this research is still being done in the lab, and there is uncertainty in how these corals will succeed in nature, as the resistance to environmental change in modified corals is not yet well established. The research expects the genetic diversity to increase resilience and survival even after a bleaching event (Parkinson et. al, 2018).

Other methods that are still being researched include increasing coral resilience by pairing coral polyps with temperature-resistant zooxanthellae or hardier algae. Silverstein et al. (2017) reported that different types of zooxanthellae can resist more thermal stress than others. Scientists from the Rosenstiel School of Marine Science of the University of Miami are embarking in trials where they are pairing coral polyps with this type of symbiote, which may mean a new hope in the restoration of reefs. Scientists are optimistic that this will allow corals to withstand warmer temperatures and avoid future bleaching (Glynn, 2017).

Another way to increase coral resilience is by reducing other external stressors including land based runoff from rivers, which carries sediments and contaminants. Oleson et al. (2016) conducted a program in Hawaii that addressed sedimentation from agricultural lands via erosion from dirt roads. They engaged different models to target sedimentation "hot spots" in the roads that contribute the most to the erosion. Their goal was to show that a land scale policy that can address the problem at a low cost is achievable, ultimately benefiting both the agricultural community and the corals.

Metrics & Challenges

One of the metrics for measuring the success of assisted adaptation is the percent settlement per year of corals after the adapted corals are planted on surfaces in the ocean (Lirman et al., 2016). Measuring percent settlement involves measuring the number of newly settled larvae every two months (Martinez et al., 2013). If the amount of living corals present in the area of the assisted reef is higher after each two-month interval than in a control area, the settlement could be considered successful. However, the scale and feasibility of assisted adaptation is a challenge when it comes to reducing coral degradation. In nurseries, the total cost of producing about 66,000 juvenile corals is around $624,000 USD for a single species (Nakamura et al., 2011). Because there are about 800 species of hard corals in the world and mortality rates are high in juvenile corals, assisted adaptation in nurseries would be too expensive to carry out for every single species (Evans et al., 2002).

Solution 2: Addressing Financial Hardship and Economic Harm in Coastal Communities

Coral reefs support huge amounts of biodiversity and benefit many millions of people as a source of food and income (Cinner et al., 2018). Solutions that alleviate the financial hardships in coral dependent communities include the establishment and successful management of marine protected areas (MPAs), and the wider adoption of sustainable fishing practices.

MPAs can reduce long-term economic hardship that communities face related to coral degradation. MPAs allow coral based ecosystems to recharge - providing a safeguard for the economic benefit and ecosystems services they produce. MPAs in the United States fall under the following categories: 1. No use zone, which prohibits every activity including tourism in their boundaries; 2. No take zones, which prohibit extraction activities like fishing; 3. Buffer zones, which are transitional areas between no take zones and multi-use zones; and, 4. Multi-use zones, which allow all tourism, aquaculture, and fishing activities.

The United States has over 1,700 MPAs, only 7% of which are “no take” zones and, of these 1,700 MPAs, 76% are controlled by state and territorial governments (Gass et al., n.d.) . While there are locally managed MPAs, these do not amount to a large percentage of managed area, as the federal government still manages 60% of the total MPA area. Within the United States, only 14% of MPAs are home to tropical coral reefs.

The proper management of MPAs not only benefits affected coral reefs through proper conservation of ecosystems, but also creates a safer environment for fish to grow and reproduce. The establishment of no-take zones in critical habitats used for spawning and reproduction allows for marine organisms to replenish, both in number and in size (Soler et. al, 2015). The fish within the no take zone will ultimately overpopulate the protected area, resulting in a migration of fish to waters outside the MPA boundaries, referred to as the "spillover effect," (Colléter et al., 2014). The spillover occurs because the marine boundaries do not apply to marine wildlife, thus increased biomass will spill into adjacent waters, thereby improving catch efficiency and catch size of fisheries outside the boundaries of the protected areas (Lorenzo, Claudet, and Guidetti, 2016). Additionally, the establishment of protected areas with consensus of the stakeholders and communities have the potential to increase ecotourism, which will provide income for multiple industry sectors (e.g. hotel, restaurant, recreational fishing, diving, etc.) (Rees et al., 2012). Thus MPAs can have a beneficial effect on both food security and sustainable livelihoods of these local communities (Weigel et al., 2014).

To address the conservation of reefs and alleviate financial hardship, sustainability is a must. If fisheries and MPAs are properly managed, one square kilometer of a healthy reef system can provide up to 15 tonnes of seafood per year (Rising, & Heal, 2014). Unsustainable fishing methods that must be addressed include, but are not limited to, the improper overuse of nets and trawlers, as well as the harvesting of undersized, immature and pre-reproductive specimens. Helping communities upgrade to sustainable fishing methods is difficult work, but it is achievable once fishers understand the benefits.

The use of hook-and-line and circle hooks along with banning destructive fishing methods such as trawling are sustainable options. Hook-and-line fishing employs short fishing lines and lures. It allows for fishers to target species, thus reducing bycatch without causing significant harm to them, and minimal physical contact to coral reefs (Sustainable Fisheries Group, Blue Halo Initiative, & Waitt Institute, 2017). Using circular hooks as opposed to J-shaped hooks reduce mortality rates in juvenile fish as it lowers the probability of the hook penetrating the vital organs of the fish and allows for easier bycatch release (2017). Hook-and-line fishing empowers fishers to properly preserve high-value fish when they are caught, thus increasing the use of a temperature control chain. The global demand for sustainable fish is increasing, which suggests this practice is viable in the long run (Potts et al., 2016). Ultimately, sustainable fishing methods will provide a more lucrative and sustainable livelihood for coastal communities, and better outcomes for the ecosystems they manage (Sustainable Fisheries Group, Blue Halo Initiative, & Waitt Institute, 2017). These solutions improve the marine biomass and economic productivity of the local communities that depend on the coral reefs.

Metrics & Challenges

When MPAs are established, fish, corals, and other reef-dwelling species are able to flourish and reproduce. As these populations increase, fish and invertebrates will travel outside of the marine protected area, "spilling over" into unprotected areas, thus increasing individual catch size and biomass long-term (Da Silva et al., 2015). This impact of the spillover effect is measured in terms of fish catch, fish size, quality of catch and species caught. The spillover effect will ensure that fishers benefit economically from the area while still establishing ecosystem security (Cinner et al., 2018). While catch size and quality will improve in the long run, the spillover effect takes time as fish populations recharge. In one study, a MPA took six years before flourishing organisms were found outside of its boundaries (Da Silva et al., 2015). While it takes time for fisheries to recharge in marine protected areas, the premium pricing of sustainably harvested wild fish may offset the reduction in fish catch in the long term. The rapidly increasing global market share for sustainable fish (up from .5% in 2005 to 14% of market share today) is valued at $11.5 billion dollars annually. These market forces indicate the long-term feasibility of mixed use MPAs.

Case Study of Marine Protected Area

Marine Protected Areas (MPAs) can provide critical protections for coral reefs, but to ultimately succeed they must benefit local communities as well. It is generally maintained that since MPAs increase the number and diversity of fish they must benefit neighboring fisheries and provide income to local communities. Yet any theoretical position must be bolstered by actual data. It is therefore encouraging to see that MPAs can indeed fulfill their potential, as is the case in the Republic of Palau. Granted, Palau has unique advantages. It is blessed with an engaged community, a supportive government, and a history of traditional management. Many places are not so lucky. Palau provides an example to which other MPAs can aspire, and shows what is indeed possible (Friedlander,2017).

The Palau Protected Areas Network (PAN) was established in 2003 and it includes 35 MPAs which vary in habitat type, age, size, shape, and allowed usage. Some of these variables, it has been shown, have a greater effect on an MPAs effectiveness than others. The establishment of a no-take policy is of massive importance, as MPAs with a no-take status had twice the average biomass of resource fish (commercially viable fish, or fish that play a major role in subsistence) than unprotected areas had. It should be noted that the biomass of non-resource fish was comparable between the two, proving that the presence or absence of fishing was the key variable, as opposed to the influence of other human activities. Of particular note was the fivefold difference in biomass between no-take MPAs and unprotected areas when it came to piscivorous fish, including sharks, jacks, and groupers. Size and age were, respectively, the next most significant factors, given a no-take status. Larger MPAs protect more habitat and thus are more likely to have complete, fully functioning ecosystems within their borders. Moreover, a reduced perimeter-to-area ratio means they are less affected by what goes on outside the MPA. The age of the MPA since its establishment is also a factor in effectiveness because while direct effects may occur within five years of an MPA’s establishment, indirect effects can take 13 years or more to manifest, and many large predators need upwards of 10 years of protection in order to fully recover (Friedlander,2017).

An increase in large predators means not only that they are available to spawn and perpetuate their numbers, but that they can migrate to neighboring unprotected areas where they will be available to fishers, to whom they are extremely valuable. The presence of these large fish provides other benefits to Palau. People are willing to pay to see such species: dive tourism to see sharks adds $1.9 million to the republic’s economy. The death and sale of these animals would, by comparison, bring in only $10,800. The same basic rule holds true for other species. The charismatic bumphead parrotfish and Napoleon wrasse, for instance, are worth 100 to 1,000 times more alive than dead (Friedlander,2017).

MPAs’ monetary benefits generate crucial support in Palau’s local communities. This support is further enhanced by the fact that traditional knowledge is respected and integrated in the MPAs’ implementation. Ultimately, it is this community support that ensures the success of Palau’s MPAs -- and the MPAs support Palau’s communities in turn (Friedlander,2017).

Solution 3: Tourism management & Premium Pricing

Coral reef based communities depend heavily on the tourism and fishing industries. For example, of the $36 billion dollars generated from coral reef tourism globally per year, $3 billion dollars of tourism revenue is from the Florida Keys alone. Degraded reefs will attract fewer tourists, resulting in a decline in the tourism industry (Spalding et al., 2017). Some tourists, however, are willing to pay a premium to dive a pristine reef or see rare animals such as turtles or sharks. Broadly, this is known as payment for ecosystem services (PES) and is defined as a voluntary financial transaction in which a buyer, in paying extra to see an intact ecosystem, helps to ensure the long-term conservation of that ecosystem (Bladon et al., 2014).

Tourists' willingness-to-pay to see high quality coral reefs can reduce fishing pressure by providing an alternative, yet lucrative, source of income for coral dependent communities (Grafeld et al., 2016). Some of these funds would then be funneled back into these coastal communities and conservation efforts focused on the restoration of degraded reefs. In addition, tourists inspired by their encounters with endangered coral species could help establish conservation programs and Non-governmental Organizations(NGOs) through diving in nurseries and cleaning the coral, which could become a productive form of voluntourism (Pendleton et al., 2016).

The diving industry depends significantly on healthy reefs, and willingness-to-pay programs play an important role in supporting local economies and conservation (Grafeld et al., 2016). Governments and NGOs utilize these funding sources by financially compensating fishers for limits on fish catch and fishery closures. This provides positive financial incentives to fishermen and encourages compliance with MPAs, which protect the marine environment, while also ensuring sustainable fishing methods.

This pricing strategy encourages conservation, while still allowing for tourism. Payment for ecosystem services is an economic tool that can help address the economic stress local communities face due to coral reef degradation.

Metrics & Challenges

The benefits of premium pricing can be measured by the number of tourists who pay higher prices to visit reefs with increased fish biomass and/or a greater number of charismatic species (sharks, turtles, groupers, etc.). This can be measured by tracking the number of dives at "pristine" reefs that occur, as well as by recording the net income generated from such dives. The amount of money generated for local conservation efforts per diver is an important metric to show the additional benefit of these premium dives. Larger scale challenges include ensuring that the net income generated from such dives is able to appropriately compensate communities, meeting or exceeding the income generated from harvesting charismatic species. Additionally, dive operators should ensure that tourists are respectful of the integrity of the prized reefs they are visiting.

Coral Monitoring

There are two primary ways to monitor corals: through direct observation and satellite imaging. In-depth direct observation is the most accurate method of monitoring coral reefs and their associated ecosystems but is challenging on a global scale. Satellite imaging provides immediate, macro-level assessments of coral cover and bleaching risk based on sea surface temperatures. Recent advancements have rapidly increased satellite capabilities. In September of 2017, NOAA expanded its satellite monitoring system from 24 "virtual" stations to 190 (NOAA, 2017c). This system aims to anticipate bleaching events up to two weeks in advance. The increase in satellite monitoring is particularly useful for remote areas of the Pacific Ocean, as direct observation is expensive and difficult on an ongoing basis. Direct observation is carried out through scientists swimming transects, or areas of land, placing remote monitors of water quality such as a rotary sediment trap (Storlazzi et al., 2011), and monitoring of ocean acidification through conductivity-temperature-depth (CTD) probes. Multiple sites or transects are assessed and scientists extrapolate this site-specific data to make inferences regarding the health of larger reef areas.

Resilience indicators, such as coral growth rates, percent recruitment of larvae into polyps, ocean temperature changes, acidification changes, herbivore mass, and the concentration measurements of sediment and pollution from direct sampling, help researchers and communities create risk profiles for corals. As ocean warming and ocean acidification increase, these risk profiles become essential to understand how corals will respond. A metadata analysis of factors considered by McClanahan et al. (2012) identified the most crucial resilience indicators for corals and coral reef management; they ranked the following six indicators as follows:

1. Resistant coral species
2. Resistant *Zooxanthellae*
3. Pollution
4. Sedimentation
5. Coral Diversity
6. Herbivore mass

Analysis of Costs and Benefits

Generally speaking, the benefits of these approaches include increasing the resilience of corals, mitigating their degradation, and improving the long-term economic stability of reef dependent communities. Specifically, hook and line fishing is more selective and allows fishers to properly preserve high value fish when they are caught; MPAs enhance habitat recovery, biodiversity, and catch quality; and voluntourism provides benefits to reefs at a remarkably low upfront cost. Yet each of these approaches has drawbacks as well, making thoughtful implementation critical. For instance, hook and line fishing results in a higher quality catch, but usually decreases the catch's overall volume (Frey et al., 2014). The establishment of MPAs does not always take local stakeholders into account, and fishers sometimes oppose their creation because traditional fishing grounds are reduced. Exclusion from the decision-making process prevents local investment and hampers the recovery of the ecosystem (Rees et al., 2012). Lastly, criticism of voluntourism has focused on its potential to lead to new forms of colonialism and dependency (Hartman et al., 2014). An increase in external aid may benefit the individual reefs, but environments can suffer overall: tourism generates waste and enhances the risk of creating an ecosystem that is reliant on faraway, external influences in order to maintain itself (2014).

Controversies of Problems

Warming Waters

As previously described, increasing ocean temperatures is the key driver of coral stress and death in the last thirty years. While it is clear that increasing ocean temperatures cause bleaching, there is a disagreement whether certain coral species will be able to adapt to this stressor. Research from the University of Texas at Austin found that one species of coral on the Great Barrier Reef adapted successfully to various temperatures (Matz et al., 2018). Most corals, however, have not been able to adapt to rising ocean temperatures, and the correlation between higher ocean temperatures and coral bleaching events have been proven (Heron et al., 2016). The research made by Heron et al., (2016) demonstrates that overall there is a low probability of corals to adapt at the fast rate that the ocean temperature is expected to increase.

Ocean Acidification

There is also disagreement in regards to the detrimental effects on coral health due to ocean acidification. While it has been established that ocean acidification reduces the efficiency of skeleton secretion for corals due to the lack for calcium carbonate molecules in the water, it is unclear how well corals will be able to adapt to these changes and how the species diversity may influence their resilience to change. This has been shown in a variety of studies that evaluated the effect of acidification in particular species. Scientists from the University of Ryukyus in Japan found that there was no significant effect on the coral species, *Acropora digitifera's* skeleton growth over a five weeks study period during which these corals were placed in a more acidic environment (Takahashi et al., 2013). On the other hand, Hoegh-Guldberg et al., (2007) indicated that there is a clear reduction in skeleton density in species found in the Great Barrier Reef. Even though there is no certainty that it was a direct effect of acidification, it is consistent with the changes in water pH (Hoegh-Guldberg et al., 2007).

Sedimentation and Contamination

Runoff from construction, deforestation, and agriculture brings sediment and contaminants to the ocean, which adversely affects corals. A study from the University of North Carolina Chapel Hill found that local stressors, like sediment and contamination, had undetectable impacts at a geographic scale (Bruno et al., 2016). However, another study by Canadian scientists at McMaster University and the University of Newfoundland states that sedimentation causes decreased growth rates and mortality in corals (Risk et al., 2011). In addition, the consequences of runoff reduce resilience in reefs, making them more vulnerable to the changes in temperature and ocean chemistry caused by climate change (Carilli et al., 2009). NOAA states that runoff can add pesticides to the water, which interferes with coral reproduction, as well as deposit sediments on the surface of corals, causing them to suffocate as their symbiotic algae cannot photosynthesize as sunlight availability decreases (US Department of Commerce, 2018).

Fishery Management

Poor fishery practices, such as blast or cyanide fishing, certain bottom trawling and long line fishing, can cause physical and chemical damage to corals. Blast fishing can turn an entire reef to rubble while cyanide fishing poisons and kills corals and other organisms in the ecosystem. The controversy over fishery management is primarily over the degree to which fishing should be reduced. Poor fishing practices are very effective at maiming fish so that they can be easily caught. The problem is that these practices poses a threat to corals by poisoning them or breaking up their structure, eventually killing them. The initial volumes of fish catch may be larger than with more sustainable methods like hook and line, for example in 1997, 20,000 tons of reef fish were caught from cyanide fishing alone in Hong Kong, however, the short and long-term sustainability of that fishery is close to zero (Barber et al., 1998). Sustainable fishing practices do not result in large volumes, but will increase the quality of the catch and allow the fish stocks to recharge - protecting these valuable resources for future generations (Darling et al., 2017).

Controversies of Solutions

Assisted Adaption

Assisted adaptation methods enable marine scientists to grow corals using both asexual and sexual reproduction methods. Assisted sexual adaptation includes selective breeding and genetic modification to increase resilient coral characteristics. Supporters of these assisted adaptations claim that the methods for transplanting corals are working well, and that they are effective in making corals more resilient to climate change (Albright, 2018). However, critics claim that these methods have not been replicated on a large enough scale, are costly, and distract from the main task of reducing carbon dioxide emissions (Riley, 2016a). Another assisted adaptation method is pairing corals with more resilient algae that will be more resistant to thermal stress and thus help corals survive warming oceans (Riley, 2016b), but it also creates the concern that enhanced organisms may outcompete native populations and reduce biodiversity overall (Albright, 2018). These concerns are valid, but more research is needed to prove long term efficacy of these methods. Corals are under imminent threats, and the consequences of doing nothing are far more severe, this is why the bill prioritizes scientific research in order to reverse coral degradation.

Sedimentation and Contamination

As discussed, sedimentation and contamination are other important stressors to corals. Avoiding coastal degradation and minimizing the construction of large developments near the coast will reduce sedimentation, however this is unrealistic, and management methods to prevent the sedimentation need to be evaluated (Reef Resilience Network, 2018). Local and regional land-use management, ecosystem restoration such as afforestation of natural filtration systems like marshes, is more important for the protection of coral reefs to reduce overall erosion, sedimentation and river runoff (Maina et al., 2013).

Marine Protected Areas and Sustainable Fishing

As described, a solution that benefits coral health and addresses financial hardship of the communities that depend on them is the implementation of MPAs and the use of more sustainable fishing methods. Fisheries are mostly based in areas with high biomass and biodiversity, which are the same areas selected by scientists and conservationists to create MPAs. In the long run, a well-established MPA with community and user support will benefit the fishing sector and the overall health of the ocean; but success of MPAs are hard to measure, as the success in benefiting the fishing industry may take years or decades to be seen. The controversy over area closures can create a social problem, and reducing traditional fishing grounds may result in imminent harm to the sector. In addition, some researchers argue that this pushes conglomerate fishing vessels into other areas, thus moving, not remedying, the problem (Rees et al., 2012).

As stated, sustainable fishing may reduce the volume of catch, but will increase the quality. In the long run catching fewer fish will replenish the stock, but if it is severely depleted it may take time for it to restock, resulting in possible economic losses. The dispute in regard to sustainable fishing methods is whether or not the catch volume of fish is economically feasible to cover the operational costs plus profits for the industry. This is why it is important to work with communities and industries that rely on fisheries to achieve sustainability by looking for economic alternatives and sustainable markets that create an incentive for responsible fishing (Hilborn, 2007).

Conclusion

Coral reefs provide tremendous ecological and economic benefits around the world. The reef loss observed in the last few decades points to a troubling future for corals and the organisms that rely on and live within coral structures. As human population, environmental demands, and global warming accelerate, action at the national level is critical to increase coral resilience to help safeguard against climate change. The Coral Reef Sustainability Through Innovation Act of 2017 will allow the United States government to create prizes for innovative approaches that help reduce the degradation of coral reefs and resulting economic hardship. To properly address reef degradation and financial hardship, the bill prioritizes scientific research to improve solution methods and increase resilience. Promising research includes exploring ways of selectively breeding corals to be temperature resilient, planting coral fragments to increase coral cover, and pairing coral polyps with resilient algae to prevent coral bleaching. The establishment of Marine Protected Areas, with consensus among stakeholders and proper management, will protect reefs and increase fishing quality, benefiting coastal communities that depend on them. In addition, implementing sustainable fishing methods, looking for economic alternatives and incentives will assure sustainability of the fish stocks ensuring the future of the sector.

Even though there are still controversies and challenges around how anthropogenic stressors are degrading corals, and uncertainty in how the proposed solutions are going to mitigate the problem, present and future scientific studies will prove and solve this uncertainties in order to revert coral health. The Bill creates a framework of opportunities to engage in innovative solutions that will overall contribute to corals health, thus will improve the benefits they provide to coastal communities, economies and livelihoods.

Glossary

Ahermatypic: of corals that are not reef-building
Anthropogenic: (chiefly of environmental pollution and pollutants) originating in human activity
Artisanal fisheries: small-scale, low-technology, low-capital, fishing practices undertaken by individual fishing households
Asexual reproduction: a type of reproduction that results in genetically identical offspring from only one parent.
Biodiversity: the variety of living things in a specific ecosystem, habitat, or the world. According to the United Nations Environment Programme (UNEP), biodiversity typically measures variation at the genetic,species,and ecosystem level.
Biomass: total weight the fish would have if it were taken out of the water
Biotic: relating to or consisting of living things, especially in their ecological relations
Bottom trawling: a destructive industrial fishing method where a large net with weights is dragged along the seafloor
Calcification: the process by which corals produce calcium carbonate (CaCO3) and build reefs
Coral: an immobile marine invertebrate animal that secretes a calcium carbonate structure. Many rely on a mutualistic symbiosis with algae (zooxanthellae) for most of their food
Coral bleaching: the process of color loss in coral due to the expelling of symbiotic algae, zooxanthellae
Coral reef: a diverse underwater marine ecosystem built on a large colony of living corals and their calcium carbonate deposits
Coral Polyp: tiny, soft-bodied organisms related to sea anemones and jellyfish, that make up a reef
Coral skeleton: Coral polyps secrete calcium carbonate, forming a skeleton around the polyp. New coral polyps form on top of skeletons of deceased coral skeletons
Ecosystem: the organization of and relationships between living organisms and their physical features
El Niño Southern Oscillation (ENSO)**:** a cause of increasing ocean temperature and coral bleaching in which the waters of the Equatorial Pacific become warmer and the eastern winds get weaker, reducing the mixture of cold and warm water, moving warm water currents east towards the coast of Peru. El Niño occurs naturally, but it has been intensifying with global warming, causing episodes of widespread bleaching across the Pacific.
Fish stock: subpopulations of a certain species of fish
Fragmentation: a form of asexual reproduction in which a piece of coral breaks off and becomes a genetically identical individual, causing a shift in resources towards accelerating growth rate as a competitive strategy to gain access to more resources and space for security
Ghost nets: fishing nets lost in the oceans accidentally or on purpose.
Greenhouse Effect: Greenhouse gasses like carbon dioxide (CO_2) trap heat in the atmosphere and radiate it back to the earth's surface, causing ocean warming
Hermatypic: Reef building hard corals that contain zooxanthellae
Hook-and-line fishing: fishing methods that employ short fishing lines with hooks that tend to be more selective and lower bycatch
Macroplastic: Relatively large particles of plastic found in the marine environment typically more than about 5 mm

Marine Protected Areas (MPAs): a regulatory tool for protected a part of the ocean, together with their overlying waters flora and fauna and other features
Microplastic: small pieces of plastic, < 5mm in diameter, widespread form of contamination found in marine ecosystems
Ocean acidification: When dissolved in the ocean, carbon dioxide reacts with the water releasing hydrogen ions, this reaction is responsible for decreasing the pH and thus making the water more acidic
Ocean warming: the increase in global ocean temperature caused by the ocean's absorption of atmospheric heat
Octinoxate: Octinoxate is a chemical found in sunscreen today, known to harm corals
Outplanting: the process of transplanting organisms from a nursery or lab to outside in the environment
Oxybenzone: Also known as benzonephenone-3, it is one of the most common chemical filters found in commercial chemical sunscreens, known to harm corals
Parrotfish: a group of marine fish herbivores that graze the reef, using their beaks to scrape plants and algae from the reef surface
Pesticides: a substance used for destroying pests and unwanted organisms that are harmful to cultivated plants or to animals; traditionally used in agriculture
pH: a measure of acidity and alkalinity on a scale of 1 to 14. More acidic solutions have a lower pH; ocean acidification occurs when the pH of the ocean is lowered
Phytoplankton: primary producers, fed on by corals and other organisms
Resilience: the ability of an ecosystem to effectively manage stress factors
Runoff: the draining of surface water and substances carried in it into a body of water
Sea mining: the extraction of minerals from the ocean floor
Sedimentation: the process of sediments from land depositing into water bodies, often exacerbated by runoff; causes decreased growth rates and mortality in corals
Sessile: (of an organism, e.g., a barnacle) fixed in one place; immobile
Spillover effect: The fish within the no take zone of an MPA will ultimately overpopulate the protected area, resulting in a migration of fish to waters outside the MPA boundaries, referred to as the "spillover effect." This occurs because the marine boundaries do not apply to marine wildlife, thus increased biomass will spill into adjacent waters, thereby improving catch efficiency and catch size of fisheries outside the boundaries of the protected areas
Sponges: the simplest multicellular living organisms that inhabit the same niche as corals
Sexual reproduction: a type of reproduction that results in genetically different offspring from the fusion of gametes of two parents
Swells: wave movement
Symbiosis: a close and long-term biological relationship between two organisms, for example the relationship between zooxanthellae and coral polyps
Willingness-to-pay: the maximum price a consumer will agree to buy one unit of a good or service
Zooxanthellae: photosynthetic algae that live in coral tissues mutualistically

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