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Sustainable Operations, Industry Performance, and Environmental Sustainability: A Case Study on U.S. Marine Fisheries and Pacific Bluefin Tuna

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Table of Contents

I. Introduction

When thinking of the numerous industries we have across the United States, the environmental impacts created from their unsustainable operations is not always at the forefront of our thoughts. The fact that negative impacts on our environment can also create problems for our economy is often overlooked as well. The damaging impact marine fisheries in the United States have on our environment, and the cost it creates for the fishing industry, is a good example of this cycle between sustainable (or unsustainable) operations and productivity.

In the United States, and all over the world, fisheries play major economic roles through the generation of revenue and employment opportunities. In 2014, the U.S. was the fourth largest tuna fishing nation in the world (Galland, et al. 2016). Beginning with 2006, the U.S. fishing industry generated over $103 billion in sales and created over 1.5 million jobs (National Marine Fisheries Service, 2007). This may seem small compared to the United States total nominal GDP of almost $14 trillion in 2006, however this industry is not insignificant (World Bank, 2019). The fishing industry is small compared to other U.S. industries, however it is a stable and growing industry compared to other markets. In 2006, the marine fishing industry contributed a mere .7% to the nation's GDP. In contrast, by 2016, the industry generated $212 billion in sales, nearly $25 billion of which were produced by California fisheries alone (National Marine Fisheries Service, 2018). By this time, the nation's GDP had grown to over $16 trillion and the fishing industry had grown to contribute to roughly 1.3% of the nation's GDP.

While bluefin tuna catch numbers are lower than other tuna species, such as the common Skipjack, the bluefin species is one of the most valuable tuna on the market. With less than 1% of the total tuna landings worldwide, bluefin tuna still manage to generate over $2 billion in sales for the global market (Galland, et al. 2016). From an economic stance, the fishing industry has been a growing market in the United States, as we have seen from the growth in the industry's GDP contribution. However, from an environmental point of view, fisheries are growing increasingly unsustainable, and their future success relies on how they proceed to operate in the coming years. In 2015, the U.S. National Oceanic and Atmospheric Administration (hereinafter, NOAA) published information regarding the population of bluefin tuna. The NOAA noted in their "Pacific Bluefin Tuna" fact sheet that the population of spawning bluefin tuna were only about 4% of their original levels and that the species were subject to overfishing (National Marine Fisheries Service, 2015). The report also states that should the species continue to be overfished, regulations would need to be implemented in order to protect the species from reaching levels they could not recover from (National Marine Fisheries Service, 2015). With bluefin tuna being one of the most valuable species, they are the most vulnerable to overfishing as fisheries are looking to make the most profits with the least effort possible. However, if fisheries continue to overfish the population, the species could reach an endangered level. It is important for fisheries to begin implementing sustainable fishing practices so as to not deplete the tuna species. This is important not only given the environmental services that tuna provide, but also for the fishing industry's economic stability in the long run.

In this paper we ask the following: Has the implementation of sustainable practices in U.S. marine fisheries contributed to the increase in an industry's economic performance between 1994 and 2014? We hypothesize that the utilization of sustainable practices, including legislation meant to protect tuna populations and marine ecosystems, contributed to increasing the marine fishing industry's economic performance. This paper analyzes how marine fisheries operate in the United States and the negative effects they impose on marine ecosystems, specifically among Pacific bluefin tuna fish populations. By gauging environmental parameters, including declining tuna fish populations and overfishing, in relation to the industry's economic performance, we argue that the implementation of sustainable practices that protect marine ecosystems and tuna populations could lead to an improvement in the industry's health.

The arguments made in this paper can be extended to consider how efforts made to address broader environmental sustainability objectives can be accompanied by economic efficiency and profitability. Our goal is to use the fishing industry as a case study to argue that protecting natural resources and the environment is important to an industry's economic health and in some cases is also necessary for the future profitability of an industry.

II. Literature Review

This literature review explores various leading issues regarding the operations of marine fisheries and their impacts on marine ecosystems and species, specifically Thunnus orientalis, or Pacific bluefin tuna. First, we summarize the history of bluefin tuna in the Pacific Ocean and determine that due to specific characteristics of the species, they are vulnerable to overfishing and current regulations do little to enforce sustainable practices. Secondly, we discuss the Magnuson-Stevens Conservation and Management Act in relation to marine fishery operations and environmental sustainability in marine ecosystems. Next, we discuss views around the "Tragedy of the Commons". In this discussion it is established that the existence of open access commons create an incentive for marine fisheries to operate unsustainably and for overexploitation of the resources available through them to occur. Next, we establish the economics behind the management of fisheries and use the Maximum Economic Yield curve in order to determine the level of effort at which fisheries need to operate in order to maximize their profits. Fifthly, we discuss the economic weaknesses of current sustainability incentives for marine fisheries and determine possible alternatives that would be cost efficient and incentivize environmental sustainability. Next, we find that the overexploitation of bluefin species, the occurrence of bycatch, and pollution by abandoned fishing gear are among the most damaging effects of unsustainable practices by marine fisheries. Lastly, we discuss how an increasing consumer demand for seafood along with the impacts of climate change have also led to progressive negative impacts on marine ecosystems. Overall, the sources discussed show a sense of urgency for marine fisheries to implement sustainable operations and for management to create fishery-driven incentives in order to protect the Pacific bluefin tuna species and their ecosystem.

II.A. The Story of Pacific Bluefin Tuna

In the Pew Environmental group's article, "The Story of Pacific Bluefin Tuna" the authors discuss the history of the Pacific bluefin tuna species and their importance within their ecosystem as well as to fishermen and coastal communities through the years. Bluefin tuna were not officially recognized as a distinct species until 1999 (The Pew Environmental Group, 2013). Because bluefin tuna are an extremely athletic species, they are top predators in the pacific ocean, can weigh up to 1000 pounds, and grow up to 10 feet in length (The Pew Environmental Group, 2013). Bluefin are a highly migratory species that matures slowly, leaving them especially vulnerable to overfishing as they are hunted year round in different areas of the Pacific and Atlantic ocean.

Bluefin tuna have been fished for nearly a thousand years as fishers hunt for the species prized and valuable deep-red meat. Beginning mostly in Japan, bluefin were caught mainly via harpoon and the hook and line methods. With an increase in demand over time, fishing methods became more efficient allowing for a greater number of catches in a smaller amount of time. During the mid-1990's an increase in demand for high quality tuna in Japan lead to the rise of floating tuna ranches off the coast of Mexico (The Pew Environmental Group, 2013). The creation of these tuna ranches allowed ranchers to fatten the tuna which created an even more desirable and valuable fish. However, most of the tuna on these ranches were juveniles, around 3 feet in length, and had not yet had the chance to reproduce (The Pew Environmental Group, 2013). Figure II.A.1 exhibits the only three spawning areas for bluefin tuna that are located in "the East China Sea, the Sea of Japan, and in the Pacific waters of Shikoku" along with the species migration patterns (The Pew Environmental Group, 2013). With all three spawning locations falling on the Northern Pacific shorelines, the success of bluefin populations in other areas of the Pacific ocean depend on their survival and migration across the ocean. However, Japan has historically accounted for the majority of bluefin tuna catches from the Northern Pacific ocean, with South Korea and China Taipei accounting for a majority of the remaining 10% of catch totals (The Pew Environmental Group, 2013). Figure II.A.2, provided by the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, illustrates the annual retained catches of Pacific bluefin tuna by country in the North Pacific Ocean from 1952 to 2018 (ISC for Tuna and Tuna-like species in the North Pacific Ocean, 2019). This graph shows Japan's reign on Pacific bluefin catches and specifically, in 2011, Japan, South Korea, and China caught 81% of the total bluefin population in the Pacific ocean, leaving the United States and Mexico to split the remaining 19% (The Pew Environmental Group, 2013). Because of this, there is a much smaller number of bluefin tuna that survive long enough to migrate across the Pacific ocean, which in turn hurts the American and Mexican tuna fishing industries.

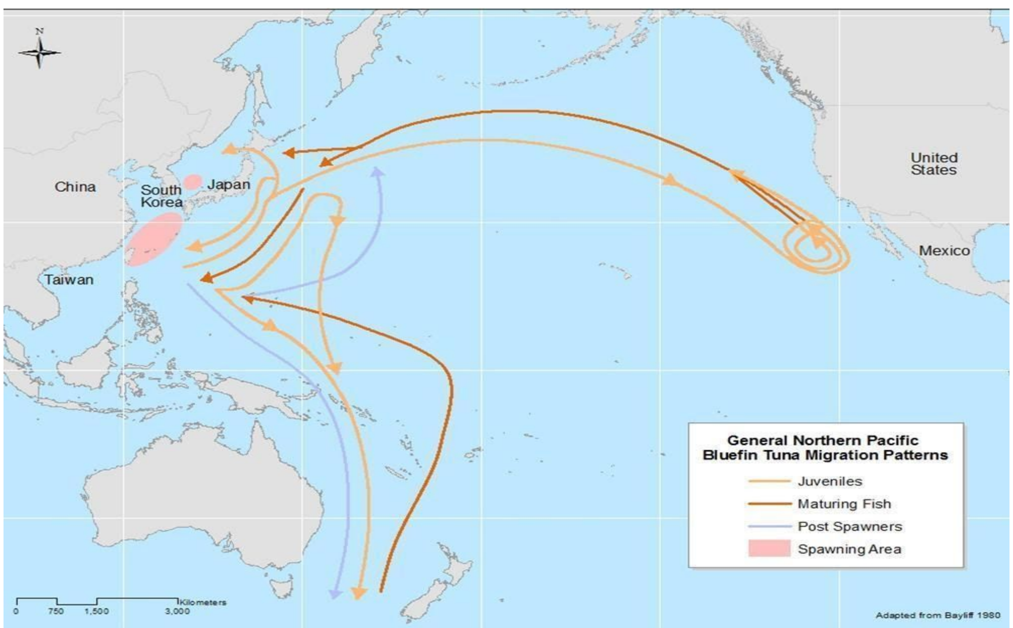


Figure II.A.1. Northern Pacific Bluefin Spawning Areas and Migration Patterns, by National Oceanic and Atmospheric Administration, 2018, retrieved from https://swfsc.noaa.gov/Pacificbluefintuna/ copyright 2018 by National Oceanic and Atmospheric Administration.

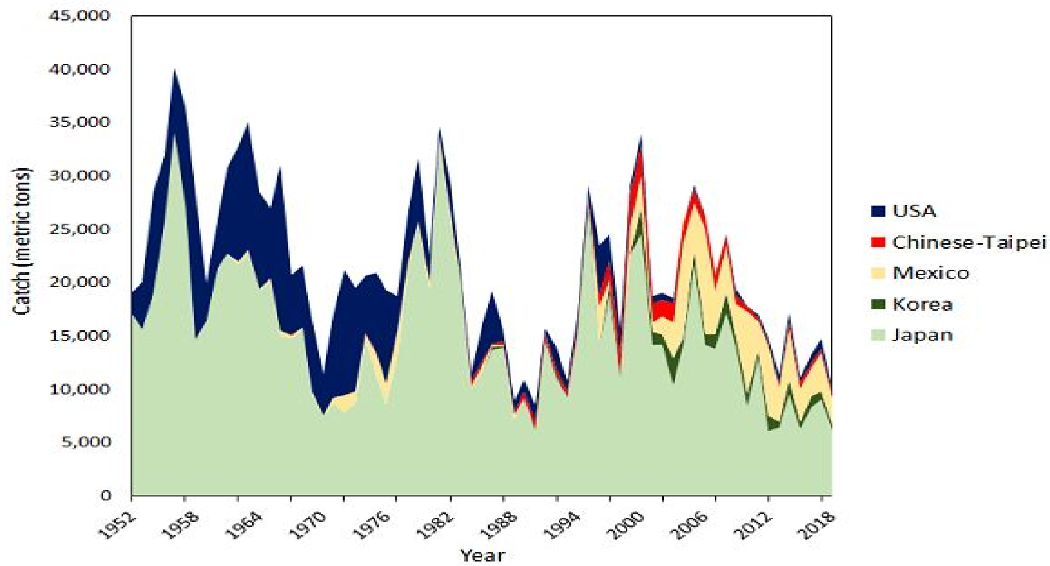


Figure II.A.2. Annual Retained Catches of Pacific Bluefin Tuna in the North Pacific Ocean, by ISC for Tuna and Tuna-like Species in the North Pacific Ocean, 2019, Retrieved from http://isc.fra.go.jp/fisheries_statistics/index.html Copyright 2019 by ISC for Tuna and Tuna-like Species.

In the Pacific Ocean, bluefin populations have been monitored by the Inter-American Tropical Tuna Commission (hereinafter, IATTC) since 1950 and the Western and Central Pacific Fisheries Commission (hereinafter, WCPFC) since 2004, both of which are responsible for the management of fisheries and review of species assessments (The Pew Environmental Group, 2013). However, in the case of bluefin tuna, both organizations have failed to adequately manage the bluefin population and the fisheries hunting for the species. It was not until 2012 that the IATTC issued a catch limit for bluefin tuna, however, the limit was not backed by scientific research and their enforcement measures were not significant enough to ensure fishers did not exceed the limit (The Pew Environmental Group, 2013). For the WCPFC, it was not until 2014 that they restricted the catch of bluefin juveniles by 50%, however, the problem of enforcement arises once again (World Wildlife fund, 2016). Because of inadequate enforcement for restrictions issued by the IATTC and WCPFC, they have thus far been unsuccessful in sustaining population levels. The Pacific bluefin population is currently at "less than 4% of historic levels and stock has steadily declined since 1995" (The Pew Environmental Group, 2013). In order for the story of Pacific bluefin tuna to continue, restrictions must be put into place and effectively enforced in order for the species to once again return to a healthy and sustainable population level.

To summarize, the story of Pacific bluefin tuna is a long one, dating back nearly a thousand years. However, the overexploitation of bluefin tuna, their vulnerability to overfishing due to spawning patterns and slow maturity growth, and their importance as being a top predator in the ocean have largely gone unnoticed. With Japan's advantage over bluefin populations due to spawning ground locations, the species is widely overexploited before they are able to migrate to the East Pacific Ocean where the U.S. and Mexico will continue fishing from the left over stock. This creates a rapidly declining population of bluefin tuna in the Pacific ocean and a growing need for effective regulations that protect the species. However, as we have seen from regulations implemented by the IATTC and WCPFC, they are difficult to enforce and do not create a significant amount of protection for Pacific bluefin populations. Continuing on, we will look at a few of the more significant policies and regulations throughout history that have played a role in fishery management and protecting bluefin populations.

II.B. The Magnuson-Stevens Conservation and Management Act

In the "Magnuson-Stevens Fishery Conservation and Management Act" (hereinafter, MSA) that was first established in 1976, the U.S. Department of Commerce declared the following findings among several other important factors. First, the Department of Commerce declared in the MSA that “the highly migratory species of the high seas,” among many other species in the Pacific Ocean, were “valuable and renewable natural resources” that contributed to the “food supply, economy, the health of the nation, and provided recreational opportunities” (National Marine Fisheries Service [NOAA], National Oceanic and Atmospheric Administration, & U.S. Department of Commerce, 2007). Secondly, the MSA declared that the stocks of certain fish had seen a decline over the years, some of which to the point where “their survival was threatened” (NOAA et al., 2007). The Department of Commerce continued by stating that these declines in stock were due to “increased fishing pressure, inadequate fishery resource conservation and management, and the loss of habitats” directly and indirectly related to fishery operations (NOAA et al., 2007). Lastly, the MSA states that the “greatest long-term threat to the viability of commercial and recreational fisheries is the continuing loss of marine and other aquatic habitats” and that habitats should see an increased consideration for the “conservation and management of fishery resources in the U.S. (NOAA et al., 2007).

The Department of Commerce declared the purpose of the MSA to include the following elements. To begin, the most important purpose of this act was to “take immediate action to conserve and manage the fishery resources off the coast of the United States” (NOAA et al., 2007). They would do this by “exercising sovereign rights for the purposes of exploring, exploiting, conserving, and managing all fish within the exclusive economic zone” that was established by the Presidential Proclamation 5030 of 1983 (NOAA et al., 2007). Secondly, this act set out to “support and encourage the implementation of international fishery agreements for the conservation and management of highly migratory species,” that would include Pacific bluefin tuna (NOAA et al., 2007).

Overall, the goals of the MSA were to reduce overfishing, rebuild depleted stocks, and to increase the long-term economic and social benefits associated with marine fisheries. Although first established in 1976, the MSA experienced two major revisions over the past forty-three years. The first revision occurred in 1996 with the passage of the "Sustainable Fisheries Act," while the second revision was introduced in 2007 under the "MSA Reauthorization Act" (National Oceanic and Atmospheric Administration, 2019). Under the first revision, the Sustainable fisheries Act worked to strengthen requirements that prevented overfishing and introduced fish habitats "as key components in fishery management" (National Oceanic and Atmospheric Administration, 2019). The MSA Reauthorization Act established annual catch limits and accountability measures, "promoted market based management strategies, strengthened the role of science" in education and decision making, and "enhanced international cooperation by addressing illegal, unregulated, and unreported fishing and bycatch" (National Oceanic and Atmospheric Administration, 2019).

II.C. The Tragedy of the Commons

Expressed as a percentage share of U.S. GDP, sales revenues from the U.S. fishing industry are relatively low, contributing to 1.3% of the total U.S. GDP in 2016, however, this is a rise in contribution from .7% in 2006 (National Marine Fisheries Service, 2018). While the U.S. marine fishing industry is small relative to the United States' overall GDP, the industry is still large enough to warrant further examination from economic and environmental viewpoints. Economically, the largest competition for a fishing company comes from the fact that their resource is found on common ground, or, as economists refer to this type of resource: "the open access commons." Marine fisheries must pull their resources from the ocean, in which all other marine fisheries must do as well. The resources in this open access are limited due to nature, and this fact drives fishing companies to catch all they can before their competition. In "The Economics for Fisheries Management," authors Grafton, Kirkely, Kompas, and Squires note that it is "in the interest of all those who fish to agree to restrict their catch to prevent overexploitation," however, it is a difficult task to keep fishers from over-exploiting resources that are so easily available (Grafton, et al., 2016). Oceans are an open access resource, therefore there is an absence of property rights over marine species, effective management of ocean species, and "cooperation among harvesters" (Grafton, et al., 2016). When fisheries exceed their fair share of catches it creates a cost that impacts other fishers as well as the ecosystem they are pulling from. Environmental economists know this to be the "tragedy of the commons."

In order to prevent overfishing and overexploitation of marine ecosystems, policies have been made in the past to "prevent the tragedy of the commons in fisheries" by limiting "access to fishing grounds, and to limit the Total Allowable Catch (TAC) by fishing fleets" (Grafton, et al., 2016). Such policies in the U.S., include the Magnuson-Stevens Fisheries Conservation and Management Act of 1976 and the National Environmental Policy Act of 1969, both of which aim to enable more sustainable operations from marine fisheries (National Oceanic and Atmospheric Administration, 2019).

As it has been stated above, the existence of open access commons causes industries, such as the marine fishing industry, to operate unsustainably and overexploit the resources available in these commons. However, due to the absence of property rights over open access resources, it is increasingly difficult to detect when overexploitation is occurring before the damage becomes detrimental to a species health. Policies have been created in the past in attempts to protect marine species, however, their effectiveness is oftentimes inefficient and lacks proper enforcement.

II.D. The Economics of Fisheries

The authors of “The Economics for Fisheries Management” argue that some policies regulating fisheries do not always work due to the fact that fishers respond to them by finding ways to catch more fish without breaking regulations. Grafton, Kirkely, Kompas, and Squires, provide an example whereby one regulation reduces the length of a fishing vessel, fishers will build boats wider instead in order to catch larger numbers of stock (Grafton, et al., 2006). Therefore, “regulations must explicitly consider the incentives of fishers” in order for them to be effective (Grafton, et al., 2006). In order for fisheries to operate sustainably, “they need long-term and secure rights” that account for the stock caught and sustainable management (Grafton, et al., 2006). This could involve providing fisheries with “decision-making responsibilities” that help align “incentives with sustainability goals” and improved fishery management (Grafton, et al., 2006).

When discussing the economics of fisheries, the maximum economic yield (hereinafter, MEY) is one of the most important factors to consider. The MEY shows the maximum difference between total revenues and the cost of fishing. The MEY help fisheries find the most efficient level of operation that also allows them to generate the highest possible economic surplus (Grafton, et al., 2006). This surplus is called the “resource rent” and can be taxed or used in order to be spent on goods and services that benefit the welfare of a country (Grafton, et al., 2006). It is in a fisheries best interest not to exceed the maximum economic yield of operations, solely because doing so would cause the extra inputs to become less and less efficient and therefore more costly. Grafton, et al, states that the MEY is determined by various factors such as the "management structure, stock level, and nature and extent of fishing effort" (Grafton, et al., 2006). In order for their economic yield to be maximized, fisheries must ensure that their inputs "minimize the cost of harvest" at the maximum yield (Grafton, et al., 2006). Therefore, fisheries must use their equipment and factors of production at the most efficient rates possible.

The surplus production model in figure II.D.I, provided by Grafton and associates (2006) shows the relationship between total revenue and effort. To begin, we assume, based on standard economic canons, that the industry demand, displays an inverse relationship between price and quantity and is well behaved. Thus, we do not have to worry about a drastic change in cost or revenue and can therefore use the model as a basic analysis of production in the fishing industry. Therefore, the yield curve in this production model, which also represents sustainable harvest levels, is a measure of the total revenue from each catch (Grafton, et al., 2006). The model shows that with each increase in effort after the maximum yield, there is a decrease in revenue.

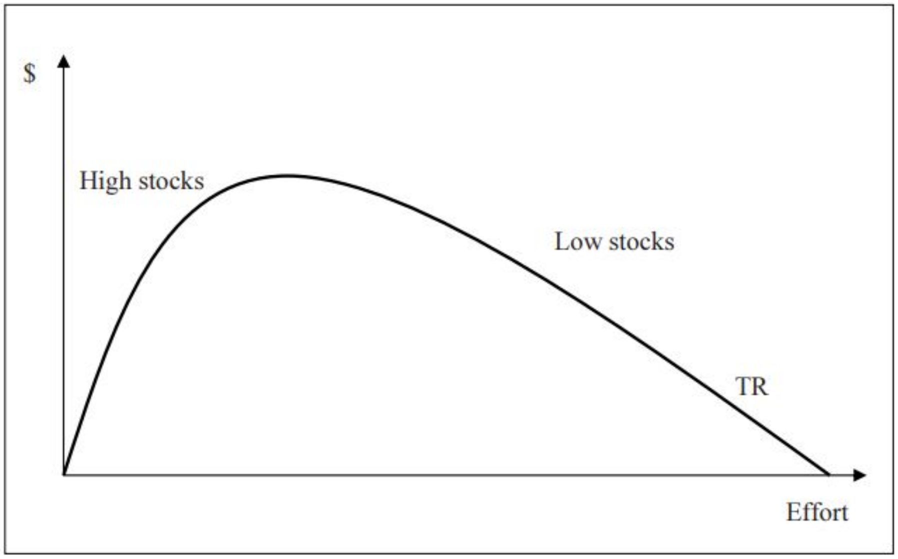


Figure II.D.1. Hypothetical Relationship between Total Revenue and Effort, by Grafton, Q., Kirkley, J., Kompas, T., Squires, D., 2006, Copyright 2006 by R. Quentin Grafton, James Kirkley, Tom Kompas and Dale Squires.

By introducing total costs into the picture, we can see in figure II.D.2, provided by Grafton, et al, what is known as the bionomic equilibrium. The bionomic equilibrium, at point B in figure II.D.2, expresses the point at which economic profit is equal to zero. Point B is representative of an economically sustainable harvest for a fishery. Any point on the yield curve that falls to the right of point B, represents an effort that is economically unsustainable and therefore the costs are exceeding profits made. Points that fall to the left of point B, and to the right of the maximum economic yield on the yield curve represent the tragedy of the commons. At the level of effort represented by E_o, profits are measured by the distance between A and C, and are positive. Thus, at this point the cost of fishing is relatively low. However, at low cost, there is an incentive for new fishing vessels to enter the market, increasing effort levels and lowering the profit margin per vessel until point B is reached.

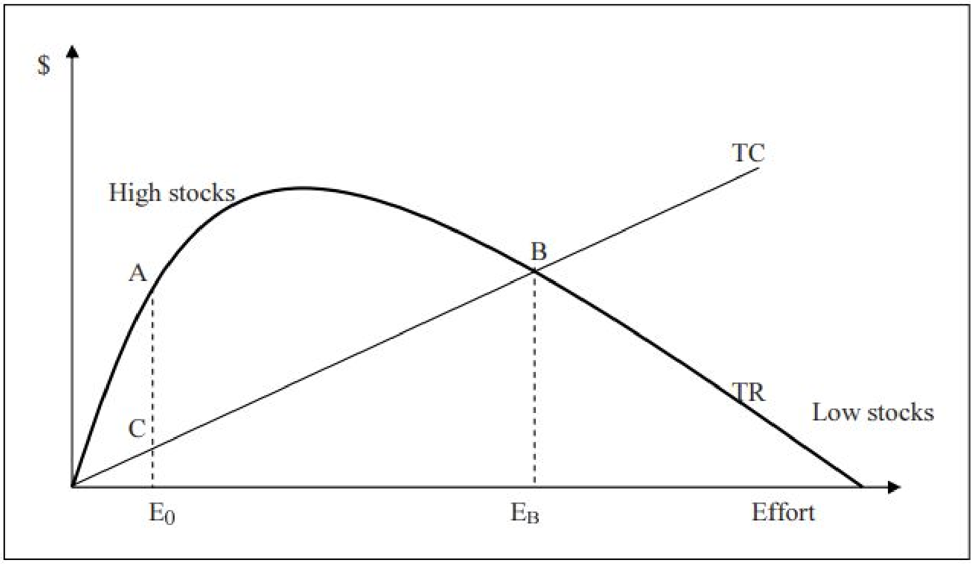


Figure II.D.2. Bionomic Equilibrium in Relation to Total Revenue, Effort, and Cost, by Grafton, Q., Kirkley, J., Kompas, T., Squires, D., 2006, Copyright 2006 by R. Quentin Grafton, James Kirkley, Tom Kompas and Dale Squires.

When all competing fisheries act in this manner, stock populations fall over time and the "per-unit cost of fishing rises until all economic profits are dissipated" (Grafton, et al., 2006). Grafton and his colleagues also make an important note that if any fisherman decides to limit the amount of stock they catch while the others do not, the lone fisherman will only be hurting his own profits. Therefore, there is no incentive for fishers to limit their catch to that below the point of equilibrium (Grafton, et al., 2006). Because of this, popular marine species such as the Pacific bluefin tuna are continually at risk of overexploitation and the need for restrictions that are effectively enforced are increasingly necessary as fishers seek to make profits.

In summary, the MEY is used to demonstrate the need for regulations to include incentives that cause fisheries to operate more sustainably. The MEY illustrates the level at which fisheries operate in order to receive maximum profits, which is determined by many industry specific factors such as management structure, stock level, and fishing effort. It is shown in the MEY that any level of effort after the maximum economic yield has been reached causes revenue to decrease and cost to rise. Figure II.D.2 illustrates the tragedy of the commons and shows that when costs are low, new competitors will enter the market until economic profits for each fishing vessel are driven to zero. Because current regulations are often ineffective and there is little incentive for fishers to limit their individual catches, marine species are continually overexploited and the need for sustainable incentives are ever growing.

II.E. Costs and Incentives for Sustainable Marine Fisheries

Thus far, we have discussed the economics of fisheries and the ways in which marine fisheries operate based on economic profits, costs, and incentives. As we saw in the previous section on the economics of fisheries, fisheries will not respond to new sustainable parameters unless they are economically profitable. This fact has led many scholars to argue that incentives focusing on the individual, community, and on territorial rights would better promote sustainable fisheries (Grafton, R. Q., et al., 2006).

Grafton and associates argue that a “greater emphasis should be placed on fisher motivation when managing marine resources” (Grafton, R. Q., et al., 2006). The authors analyze the existing “ecosystem approach” in order to determine its weaknesses and discuss other alternatives that may have greater success in the fishing industry. The authors note that the main goal of the ecosystem approach is to create healthy and resilient marine ecosystems, however, many of the primary enforcement measures used to do this, such as marine reserves and no-take areas, leave holes in the system (Grafton, R. Q., et al., 2006). Despite the benefits that do arise from the measures that are in place, they still do little to “overcome many key contributors of unsustainability, such as overcapacity" (Grafton, R. Q., et al., 2006). Along with this, the authors argue that current measures of enforcement do "nothing to provide incentives for fishers to take into account the full impact of their harvesting practices" on fisheries stocks (Grafton, R. Q., et al., 2006). Therefore, the authors argue that in order to address the issues that the ecosystem approach is unable to solve, new methods should be implemented that fill in the gaps left open by the current approach.

Grafton et al., states that fishers need "economic rights and accompanying responsibilities" that would create incentives for individuals and the collective to promote sustainable fishing practices (Grafton, R. Q., et al., 2006). This would involve providing fishers with more secure harvesting and territorial rights to fish stocks (Grafton, R. Q., et al., 2006). Giving fisheries property rights over fish would ensure that they receive the benefits of the accessible stock by limiting the number of fishers, while still preventing fisheries from holding ownership over the resource (Grafton, R. Q., et al., 2006). The authors note that this would not ensure complete sustainability by the fisheries, however, additional property rights would mean that fisheries are directly impacted by the cost of overexploitation (Grafton, R. Q., et al., 2006). With overexploitation becoming a direct cost for fisheries, there would be an increased interest in the long-term conservation of marine ecosystems (Grafton, R. Q., et al., 2006). Therefore, fisheries would seek to "protect the value of their assets and also encourage the greatest possible sustainable flow of benefits from fishing" (Grafton, R. Q., et al., 2006). This would involve individual as well as a collective action by all fisheries that have access to the resource. Grafton et al., note that individual efforts would "indirectly contribute to sustainable fisheries by improving economic performance and reducing the problems of overcapacity" (Grafton, R. Q., et al., 2006). At the same time, a collective effort would ensue by the "direct attempts to ensure sustainability by improving management decision making, the quality of scientific advice, and the monitoring of fisher behavior" (Grafton, R. Q., et al., 2006).

In summary, the authors of this paper argue that current measures of enforcement for sustainable operations do little to incentivize fishers to operate sustainably. This is largely due to the fact that fishers are profit driven, and most sustainability measures do not take into account the economic motivations of marine fisheries. Therefore, new measures must be implemented that create incentives connecting the economic benefits of marine fisheries with the social benefits of marine ecosystems. Grafton and associates argue that these measures should include giving fisheries more secure harvesting and territorial rights over fish stock in order to accomplish this goal. Otherwise, fisheries will continue to operate unsustainably until the natural resources being exploited become unrecoverable.

II.F. The Unsustainability of Marine Fishery Operations

It is no secret that the fishing industry's operational practices are often environmentally unsustainable. The overexploitation of marine species, habitat destruction, and the abundance of bycatch are only a few of the major problems that arise from the everyday operation of fisheries. The overexploitation of the bluefin species and the accumulation of bycatch are major concerns, especially as the population of bluefin tuna in the Pacific Ocean have fallen so dramatically over the past few decades. However, these are not only concerns for the population of bluefin alone, but for other species within their ecosystem as well. Bycatch occurs when species of fish are caught that are not being hunted for and are thus killed due to the fact that they have been mistakenly caught (Alverson, Et. al, 1994). Along with this, when predator species are overexploited, prey species become more abundant and a "trophic cascade" occurs in which all species are affected (World Wildlife Fund, 2007). There are many examples of trophic cascades occuring. One example transpired when sea urchin predators were removed resulting in the increase of sea urchin populations on coral reefs. This ultimately caused an increase in the erosion of coral reefs and thus a decrease in the populations of algal-grazing species (World Wildlife Fund, 2007). In 2013, the PEW Environmental Group found that "Pacific bluefin tuna populations have declined by over 96%" from their historical levels and 90% of the bluefin caught had not reached spawning age (The Pew Environmental Group, 2013). As we already know, bluefin tuna are a predatory species, and the overexploitation of bluefin and increases in bycatch by marine fisheries could lead to major changes in the marine ecosystem across all trophic levels.

Along with overexploitation, the damage of marine habitats are another concern arising from the unsustainable operations of marine fisheries. In the case of tuna fisheries, most of their fishing techniques are not as environmentally unfriendly as techniques adopted under many other types of fisheries. Therefore, the largest damage occurs from the pollution of fishing gear that gets lost or left behind. Fishing gear that begins to pollute the ocean can still come in contact with any live animals in the ecosystem. This is known as "ghost fishing," in which animals are ensnared or trapped by leftover fishing gear (National Oceanic and Atmospheric Administration, 2015). Ghost fishing has a large impact across all species living in the ocean and has become a wide scale problem. For example, in a study done by Uhrin, Matthew, and Douglas, it was found that over 85,000 lobster and crab ghost traps have been left in the Florida Keys Marine Sanctuary alone (Uhrin, Matthews, and Douglas, 2014). It has also been found that discarded fishing gear accounts for nearly 10% of all marine litter and is extremely hazardous to the millions of species that live in our oceans (National Oceanic and Atmospheric Administration, 2015). This is not only environmentally destructive, but also economically harmful to the fishing industry as studies have shown that around 90% of the species that get caught in abandoned fishing gear are of commercial value (National Oceanic and Atmospheric Administration, 2015).

In sum, the issue of species overexploitation along with the occurrence of bycatch due to pollution by marine fisheries are major concerns for the marine fishing industry. These two problems alone could lead to major changes in marine ecosystems and events such as these have already occurred in the past as seen by the removal of sea urchin predators. However, this is not only an environmental problem, but also an economic problem as the fishing industry is harming their own potential profits by operating unsustainably and damaging the ecosystem from which they obtain their resources.

II.G. Demand and Ecosystem Health in Relation to the Marine Fishing Industry

Fisheries are reliant on the ecosystem in order to provide consumers with the seafood products they demand. In a study conducted by Tidd, Blanchard, Kell, and Watson, it was found that the consumption of fish and seafood worldwide account for the largest single animal-based production sector, providing 4.3 billion people worldwide with 15-20% of their animal protein intake (Tidd, et al. 2018). In some countries this consumption is as high as 50% of the consumer's total animal intake (Tidd, et al. 2018). The demand for seafood is already large and it continues to increase every year by around 4% (Tidd, Et al. 2018). This demand increase is driven by several factors including population increases, technological innovations, the increased availability of disposable income, and other relative factors (Tidd, Et al. 2018). The demand for seafood creates an increasing pressure on marine fisheries to provide consumers with a growing number of stocks, and as we have seen according to the tragedy of the commons, individual fisheries will attempt to pull as much stock as possible before their competitors. However, "at least 30% of large commercial fish stocks are currently classified as overexploited" (Tidd, Et al. 2018). In order to keep up with such high growth in demand, fisheries must attempt not to overexploit fish populations to the point of irrecoverable levels or extinction. Should this happen the fishing industry would see a major decline in performance seeing as how substantial the demand for seafood is. However, it is equally important for consumers to limit their intake of seafood in order to decrease the overall demand for the good and release the pressure for fisheries to catch such large amounts of the stock.

The effects of climate change are another factor that impacts the health of marine ecosystems, and thus also impacts the performance of marine fisheries. The biggest effect of climate change is the rising levels of greenhouse gases and CO_2 emissions. The majority of these emissions into the atmosphere get absorbed by our earth's oceans. Because of this, the average temperature of the oceans have increased by around .2^{0}C per decade over the past thirty years (Bruno & Hoegh-Guldberg, 2010). These emissions have also caused an increase in ocean acidification with pH levels decreasing by approximately .2 pH units every decade. Though these may seem like small and insignificant amounts, the changes in pH levels and temperature are associated with a substantial decline in carbonate ions and have a serious impact on the health of species living in the ocean (Bruno & Hoegh-Guldberg, 2010). Even moderate changes in temperatures affect the metabolic rates of species which determine "life history traits, population growth, and ecosystem processes" (Bruno & Hoegh-Guldberg, 2010). When the range of which fish are able to acclimate to the changes, "mortality risk increases, fitness is reduced, and populations decline" (Bruno & Hoegh-Guldberg, 2010). Because of this habitat health declines and it is another source of cause for trophic cascades.

As seen above, marine ecosystems are negatively impacted by numerous different sources such as increases in consumer demand, overexploitation by fisheries, and climate change. Because of this it is increasingly imperative for fisheries to respond by becoming more sustainable and for consumers to limit their seafood intake in order to protect marine populations as much as possible. Doing so is vital to the success of marine species and therefore is also crucial for the success of the fishing industry.

III. Methods

We have thus far discussed the important facts, opinions, and research that have been provided by leading scholars in the field concerning sustainable marine fishery operations. Based on this research we have ultimately determined that there is an imperative need for fisheries to begin operating more sustainably in order to protect the species they are fishing. We also indicate that doing so is crucial to the industry's long run economic performance as well as to the environment's long term viability. We return to our question on whether the implementation of sustainable practices in U.S. marine fisheries have led to increases in the industry's economic health as well as the environmental health of the bluefin tuna species and their ecosystem. We hypothesized that the utilization of such practices has contributed to increasing the marine fishing industry's economic performance by way of protecting the environment and species they are benefiting from. We proceed to gauge a set of parameters in an effort to address our underlying assertion.

In an effort to address our hypothesis we will be analyzing data related to environmental and industry performance indicators during times associated with the enforcement of important regulations and policies between 1994 and 2014. The main regulations we will be considering include the Magnuson-Stevens Act of 1976, along with its 1996 and 2007 revisions, namely the Sustainable Fisheries Act and the MSA Reauthorization Act. Qualitative information on these regulations is found under the National Oceanic and Atmospheric Administration, where the act and its revisions have been posted in full by the organization (NOAA et al., 2007). The quantitative information behind the aforementioned legislative pieces is interpreted as follows. The environmental factors in our analysis include the total stock biomass and the spawning stock biomass of the Pacific bluefin tuna. This data is provided by the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (hereinafter, ISC) in their 2014 stock assessment of bluefin tuna in the Pacific Ocean (ISC for Tuna and Tuna-like species in the North Pacific Ocean, 2014). This information is gathered and disclosed annually. In order to analyze the effect these policies may have had on the industry's performance, we will examine data on the industry's ex-vessel revenues from commercial west coast fisheries and the number of purse seine vessels fishing for highly migratory species in the Pacific ocean. This data is provided by the Pacific Fishery Management Council under their current highly migratory species report: "Summaries of Commercial Fishery Catch, Revenue, and Effort" (Pacific Fishery Management Council, 2019). This information is updated semi-annually.

To analyze this data we will be performing an empirical analysis by conducting a descriptive correlational study to determine whether correlations have occurred between the health of the environment and the economic performance of the industry since the inception of said regulations. We intend to learn whether or not the implementation of these policies may have had a positive impact on the environment's health and the industry's performance.

IV. Data

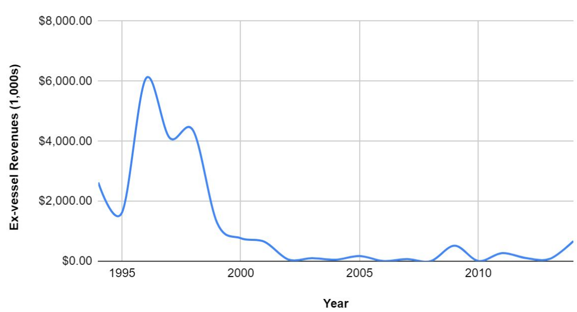
IV.A. Overview of Data

Table IV.1. has been derived from data provided by the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean and the Pacific Fishery Management Council from 1994 to 2014. The table displays data for ex-vessel revenues (postseason price per pound for the fisheries commercial catch) for Pacific bluefin tuna and total ex-vessel revenues for all highly migratory species (hereinafter, HMS) for west coast commercial fisheries that has been adjusted for inflation in 2018 dollars and is measured in 1000's. Table IV.1. also includes the number of purse seine vessels (vessels which deploy nets around schools of fish in order to catch their stock and is largely used when fishing for bluefin tuna) targeting HMS in west coast commercial fisheries, the estimated total biomass of bluefin tuna in the Pacific Ocean, and the estimated total spawning biomass of bluefin measured in kilograms.

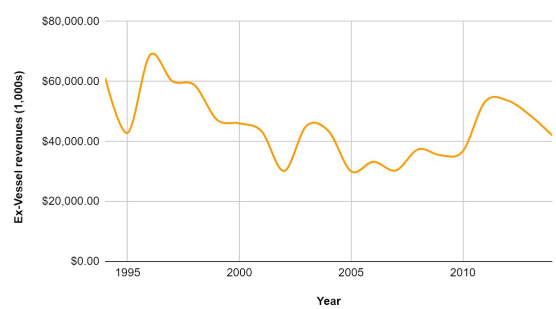
Year	Ex-vessel revenues for Bluefin (1000s)	Ex-vessel revenues for all HMS (1000s)	# of purse seine vessels for all HMS	Total biomass of bluefin tuna (kg)	Total spawning biomass of bluefin tuna (kg)
1994	$2,625.00		19	84249	47101
1995	$1,625.00	$42,874.00	18	97759	61686
1996	$6,085.00	$68,776.00	21	93811	61792
1997	$4,113.00	$60,140.00	24	95164	56769
1998	$4,347.00	$58,742.00	25	92261	56831
1999	$1,282.00	$47,240.00	12	89995	53870
2000	$765.00	$46,053.00	15	86247	52593
2001	$646.00	$43,387.00	12	75553	49569
2002	$57.00	$30,169.00	2	77575	47783
2003	$99.00	$45,173.00	3	74293	47785
2004	$49.00	$43,401.00	9	68736	41069
2005	$173.00	$30,057.00	8	63621	34266
2006	$5.00	$33,278.00	1	50596	28170
2007	$69.00	$30,354.00	4	43654	22440
2008	$4.00	$37,384.00	2	40843	16909
2009	$515.00	$35,394.00	7	34649	12814
2010	$7.00	$36,771.00		32083	11505
2011	$270.00	$53,316.00	2	32774	11860
2012	$106.00	$53,678.00	1	34931	13795
2013	$75.00	$48,778.00		36485	15703
2014	$668.00	$42,031.00	8	35817	16557

Table IV.1. Data on Pacific Bluefin Tuna and West Coast Commercial Fisheries. Data for pacific bluefin tuna biomass from ISC for Tuna and Tuna-like species in the North Pacific Ocean (2014), for revenues and vessel numbers from Pacific Fishery Management Council (2019).

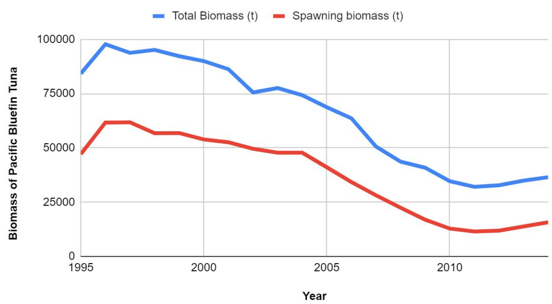
Below are graphs that have been derived from the information above in order to better display the trends for each set of data from year to year. We can see in graph IV.1. that ex-vessel revenues for west coast commercial fisheries obtained from Pacific bluefin tuna hit a high in 1996 at around $6 million before decreasing rather dramatically. After this fall, revenues remained below $1 million with a low of only $4,000. In graph IV.2., ex-vessel revenues gathered by west coast commercial fisheries for all HMS are shown and we can see these revenues also hit a high in 1996. However, the fall in revenue afterwards was not nearly as severe as seen in graph IV.1., and these revenues increased again in the later years after some fluctuations between 2000 and 2010. Interestingly, graph IV.3. shows that the total stock biomass for bluefin tuna in the Pacific Ocean is highest in 1996 and begins to decline in the following years. Graph IV.3. also shows that the population decreases rather steadily from 1996 and it is not until around 2011 that the population sees an increase in numbers. Continuing with this trend, graph IV.4. shows that the number of vessels fishing for HMS in west coast commercial fisheries began to increase around 1995 which can most likely be explained by the revenues the industry was seeing at the time. Increasing revenues are an incentive for competitors to enter the market and we can see this happen as the number of vessels are increasing at the same time revenues were at their highest. The number of vessels continued to increase for four years until 1998 in which the number of vessels dropped by 13 vessels from 1998 to 1999. This makes sense seeing as revenues for not only bluefin tuna, but for all HMS, had seen a quick downturn in 1996 and the profitability for competitors would have decreased with the falling revenues.



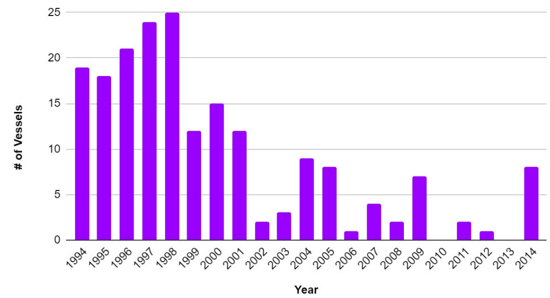
Graph IV.1. West Coast Commercial Fishery Ex-Vessel Revenues for Pacific Bluefin Tuna, by Pacific Fishery Management Council, 2019, retrieved from https://www.pcouncil.org/highly-migratory-species/stock-assessment-and-fishery-evaluation-safe-documents/current-hms-safe-document/pacfin-data/ Copyright 2019 by Pacific Fishery Management Council.



Graph IV.2. West Coast Commercial Fishery Ex-Vessel Revenues for all HMS, by Pacific Fishery Management Council, 2019, retrieved from https://www.pcouncil.org/highly-migratory-species/stock-assessment-and-fishery-evaluation-safe-documents/current-hms-safe-document/pacfin-data/ Copyright 2019 by Pacific Fishery Management Council.



Graph IV.3. Estimates of Total and Spawning Biomass in kg for Pacific Bluefin Tuna Stock, by ISC for Tuna and Tuna-like Species in the North Pacific Ocean, 2014, retrieved from http://isc.fra.go.jp/reports/stock_assessments.html Copyright 2014 by ISC for Tuna and Tuna-like Species in the North Pacific Ocean.



Graph IV.4. Vessel Numbers in West Coast Commercial Fisheries for all HMS, by ISC for Tuna and Tuna-like species in the North Pacific Ocean, 2014, retrieved from http://isc.fra.go.jp/reports/stock_assessments.html Copyright 2014 by ISC for Tuna and Tuna-like Species in the North Pacific Ocean.

IV.B. Descriptive Statistics

Graph IV.5. features a summary of our descriptive statistics for our data on west coast marine fisheries industry performance and Pacific bluefin tuna population data. In graph IV.5., “E-VR Bluefin” represents the data for the ex-vessel revenues of bluefin tuna in west coast marine fisheries, and “E-VR HMS” represents the data for ex-vessel revenues for all HMS and both are measured in the 1000’s. The variable deemed “#vessels HMS” represents data for the number of purse seine vessels attributed to fishing for all HMS in west coast marine fisheries. Lastly, “Total Biomass” and “Spawning biomass” represents the data for the total biomass of bluefin tuna and the total spawning biomass of bluefin tuna in the Pacific Ocean measured in kilograms.

From this data we can see the standard deviations for each variable. For the ex-vessel revenues for Pacific bluefin tuna there is a maximum value of $6.08 million and a minimum value of only $4000. The average for this variable is $1.12 million and has a standard deviation of $1.72 million showing a rather large deviation from the mean for most variables. For the second variable, ex-vessel revenues for all HMS, there is a minimum value of around $3 billion and a maximum value of around $6.8 billion. The standard deviation for this data set is around $1 billion showing another large deviation from the mean between values. Thirdly, the number of purse seine vessels has a minimum value of 1 vessel and a maximum value of 25 vessels. This variable has a standard deviation of 8 vessels once again showing a wide range from the mean. Next, looking at the total biomass of Pacific bluefin tuna, we see a minimum value of 32,082kg and a maximum value of 97,759kg with a large standard deviation of 24,705kg. Lastly, the total spawning biomass of Pacific bluefin tuna has a minimum value of 11,505kg and a maximum value of 61,792kgs. This variable has another large variation from the mean of 18,722kg.

Due to the nature of these variables, the large standard deviations given the observations under each variable shows that the values significantly change over the time period we are looking at. This is not interpreted necessarily as a negative factor, however, since each of the variables mainly see a decline in values over time, these standard deviations suggest that these are significant decreases which we know to be harmful to the industry (as revenues are declining) and for the health of the bluefin species (as their populations are decreasing).

Graph IV.5. Descriptive Stats for West Coast Marine Fisheries Industry Performance and Bluefin Tuna Population Performance Data

	E-VR Bluefin	E-VR HMS	#vessels HMS	Total biomass	Spawning biomass
Mean	$1,123	$44,350	10	63,862	36,232
Median	$270	$43,394	8	68,736	41,069
SD	$1,723	$10,691	8	24,705	18,722
Min	$4	$30,057	1	32,083	11,505
Max	$6,085	$68,776	25	97,759	61,792
1st Q.	$69	$36,427	3	36,485	16,557
3rd Q.	$1,282	$49,913	17	86,247	52,593
Count	21.00	20	19	21	21

IV.C. Correlation Analysis

Using this data we have conducted a correlation and displayed the results below in graph IV.6. in order to determine whether or not any of the variables are positively correlated and are therefore impacted by each other. When analyzing correlations we must understand what the data means. In a correlation, a coefficient of +1 represents the strongest possible positive correlation. This indicates that the variables being analyzed are strongly related and there is most likely a connection between the two variables. A coefficient of 0 denotes that there is no relationship between the two variables and one does most likely not impact the other. A coefficient of -1 represents the strongest possible negative correlation and signifies that the two variables most likely have an indirect relationship with one another. However, we must also note that just because two variables are positively or negatively correlated, does not mean that one variable is the direct cause of the outcomes for another variable.

Graph IV.6. Correlation Results for West Coast Marine Fisheries Industry Performance and Bluefin Tuna Population Performance Data

	E-VR Bluefin	E-VR HMS	#vessels HMS	Total biomass	Spawning biomass
E-VR Bluefin	1				
E-VR HMS	0.77	1			
#vessels HMS	0.86	0.63	1		
Total biomass	0.65	0.39	0.78	1	
Spawning biomass	0.63	0.38	0.75	0.99	1

As we can see in graph IV.6., the total biomass of bluefin tuna in the Pacific Ocean has a positive correlation of .99 to the total spawning biomass of bluefin tuna in the Pacific Ocean. This is nearly a perfect correlation and we can assume that there is an incredibly strong direct relationship between the two variables. This makes sense as we can determine that the total biomass of Pacific bluefin tuna would be directly impacted by the number of total spawning Pacific bluefin tuna that would allow their population to grow, decline, or remain steady.

Continuing on, we can see that there is a strong positive relationship between the number of purse seine vessels in the Pacific Ocean to the total biomass and the total spawning biomass of bluefin tuna. This positive correlation is valued at +.78 and +.75 respectively and shows that as the population of spawning and total biomasses of Pacific bluefin tuna have decreased over time, the number of purse seine vessels have also generally decreased. This is most likely due to the fact that as the population is declining, there is less stock available for fisheries to catch and therefore less room for a large number of competitors in the market.

Next, looking at the ex-vessel revenues for all HMS in relation to the number of purse seine vessels we can see that there is a positive correlation of +.63. This is not as strong as the other relationships we have already looked at, however, this may be due to the fact that this is only including one type of fishing vessel, among many, hunting for HMS in the Pacific Ocean. Should we have included all types of vessels attributed to HMS in the Pacific, this correlation may have been stronger. However, we are focusing on purse seine vessels for the reason that they are the most used vessel in hunting for Pacific bluefin tuna. Still, the existence of a positive correlation between these two variables show that as the number of purse seine vessels decline, ex-vessel revenues for all HMS decline to some degree as well. This shows that Pacific bluefin tuna are a significant resource to the industry.

Next we come to the relationship between ex-vessel revenues attributed to Pacific bluefin tuna and the number of purse seine vessels. The correlation coefficient between these two variables is a strong positive +.86. As we mentioned before, the purse seine vessel is the most common type of vessel used in fishing for Pacific bluefin tuna. Therefore, we would expect this correlation to be rather strong as the two variables are dependent on each other. Thus, as the ex-vessel revenues for Pacific bluefin tuna decreased, the number of vessels also decreased.

When looking at the relationship between ex-vessel revenues for all HMS and the total biomass of Pacific bluefin tuna, there is a positive correlation of +.39. For ex-vessel revenues in relation to the total spawning biomass of Pacific bluefin tuna, there is a positive correlation of +.38. When looking at the data we see that the highest ex-vessel revenues for all HMS occurred when the total biomass of bluefin tuna stock was also at their highest. The same can also be said for ex-vessel revenues in relation to the total spawning biomass of Pacific bluefin tuna. We might want to assume that this trend would continue rather steadily, and as the population of bluefin tuna declined, the ex-vessel revenues for all HMS would also steadily decline. On the contrary, we can see from the correlation coefficient the decline between the two variables are positively correlated, however the relationship is not strong. Therefore, the ex-vessel revenues for all HMS are most likely impacted by other factors that could include the population numbers for the other HMS that we are not looking at in this paper. It is still important to see however, that the population of bluefin tuna is positively correlated and does have some impact on the revenues for all HMS, thus once again showing the importance of the bluefin tuna species to the marine fishing industry. We see this significance again in the relationship between ex-vessel revenues for bluefin tuna and ex-vessel revenues for all HMS as these two variables have a strong positive correlation coefficient of +.77. We can therefore assume that as the revenues attributed to bluefin tuna increase, the revenues for all HMS also increase.

Lastly, looking at the relationship between ex-vessel revenues for Pacific bluefin tuna and the total biomass of bluefin in the Pacific Ocean, we can see that there is a positive correlation of +.65. In regards to the total biomass of spawning bluefin tuna there is a correlation of +.63 in relation to the ex-vessel revenues for Pacific bluefin tuna. While the correlation is not as strong as some of the other relationships we have seen thus far, we can still assume that the decline in the population of bluefin tuna has a direct impact on the revenues attributed to the species.

In analyzing this data, we have discussed the fall across all variables in 1996 and have considered that the fall in ex-vessel revenues, the number of purse seine vessels for all HMS, and the population declines of bluefin tuna are all correlated and are impacted by each other. As we saw in our correlation data, the total biomass and the total spawning biomass of bluefin tuna in the Pacific Ocean are almost perfectly correlated and are therefore heavily reliant on each other. We also saw that the number of purse seine vessels attributed to all HMS were strongly correlated to the total and spawning biomass of bluefin tuna. Thus, we made the assumption that as the population of bluefin tuna declined, the number of vessels also declined as there was less room for competitors in the market for the bluefin species. We also saw that the number of purse seine vessels for all HMS in the Pacific was strongly correlated to the ex-vessel revenues for Pacific bluefin tuna showing that much of their revenues were attributed to Bluefin tuna. Looking at the relationship between ex-vessel revenues for all HMS and bluefin populations, we determined that while the correlation between the two variables was not strong, the present positive correlation expressed the importance of the bluefin species to the industry. Next, we saw that the correlation between ex-vessel revenues for all HMS and ex-vessel revenues for Pacific bluefin tuna was very strong and therefore, reinforced the significance of the bluefin species. Lastly, we noticed that while the relationship between the total and spawning biomass of bluefin tuna to the ex-vessel revenues for Pacific bluefin was not as strong as the relationship between other variables, the correlation still proved that the decline in the bluefin population had a significant impact on the ex-vessel revenues for Pacific bluefin tuna.

V. Summary and Interpretation of Results

Thus far we have used Pacific bluefin tuna population levels as an indicator of the species health and have determined that there is a positive correlation between bluefin tuna biomass and the marine fishing industry's economic performance. Continuing, we discuss whether or not the implementation of regulations such as the MSA may have had an impact on the environment's health as well as the industry's performance.

The first year we consider is 1996, which is when the first revision of the MSA was established and is the first significant year regarding regulations that falls into our timeline of data. As we have already discussed, 1996 was the most successful year in our timeline for both the industry and the bluefin tuna species. However, the years following 1996 were not as hopeful for either subject. Only five years after 1996, Ex-vessel revenues for Pacific bluefin tuna attributed to West Coast Commercial fisheries had fallen by 89.4%. Over the same period, the total biomass of Pacific bluefin tuna had fallen by 19.5%. Comparing these numbers we cannot make any assumptions that the implementation of this regulation had a positive impact on the industry's economic performance or on the health of bluefin tuna.

The next year we examine is 2007, which is when the MSA reauthorization act was established. Once again, we continue to see a decrease in Pacific bluefin tuna populations with a 19.9% decrease in total stock biomass in a five year period after 2007. However, during this time period the industry does experience a 34.9% increase in ex-vessel revenues attributed to bluefin tuna. Yet, according to the data and statistics found and analyzed we cannot assume that the increase in industry performance was solely due to the establishment of this reauthorization act, however, it is not excluded from being an aid.

In addressing our hypothesis, we are not in a position to categorically accept the claim that the implementation of regulations and policies in U.S. marine fisheries led directly to an increase in the health of the industry. However, we have determined that the health of the marine fishing industry is strongly correlated to the health of the bluefin population. Therefore, when marine fisheries begin to implement sustainable practices in their daily operations there would be an increase in the industry's health in the long-run.

VI. Limitations, Policy Implications, and Potential Avenues for Future Research

While we do know that there is a correlation between the population of Bluefin tuna and the marine fishing industry's economic performance, we cannot exclude the fact that there are multiple other factors involved in determining the health of both components. For example, global warming, pollution, ocean acidification, and many other elements affect the health of the bluefin species along with the unsustainable operations of marine fisheries. However, all these things affect the industry's performance as well as other components such as consumer demand, employment, and the economy's performance as a whole.

Other limitations within this research paper include the complications of data inconsistency and unavailability. For example, some of the data we use in this paper include values for all HMS, while others only include Pacific bluefin tuna. There was also some data that was missing from our data ranges that may have created inaccurate correlations. However, these data holes were limited, and therefore most likely did not have a large effect on our outcomes.

Lastly, we must also acknowledge the fact that we are not able to determine whether or not fisheries have actually implemented the regulations established into their everyday operations. As we have discussed before, many fisheries will undergo unsustainable and damaging shortcuts and overexploit resources in order to gain maximum profits before competitors can take advantage of them. Thus, there is room for further research by investigating how the marine fishing industry has gone about implementing these regulations into their daily routine or how often individuals attempt to disregard the regulations before them in aim of making a larger profit. Doing this would allow us to better tell whether or not such sustainable operations have an impact on the industry's economic health.

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