Investigating the Relationship Between *S. purpuratus* Density and *M. pyrifera* Biomass

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Abstract

The relationship between *S. purpuratus* and *M. pyrifera* in the Southern California Pacific coastal regions was analyzed to determine whether they had a significant impact on each other and the biodiversity of the species which rely on the kelp forest habitat. Papers included in this systematic literature review reported decreased kelp biomass when the urchin density was high, as well as the presence of urchin predators, *S. pulcher* and *P. interruptus,* at a lower concentration. These findings signify that the percent of *M. pyrifera* biomass is dependent on the amount of grazing and therefore population of *S. purpuratus* within the region which is directly regulated by the number of *S. pulcher* and *P. interruptus.*

Keywords: *S. purpuratus, M. pyrifera,* biodiversity, density, biomass, habitat

Introduction

Sea urchin barrens are regions dominated by herbivorous sea urchins on rocky reefs lacking algal vegetation (Filbee-Dexter & Scheibling, 2014); these areas are the result of kelp forests that have been devastated by the overgrazing of sea urchins and consequently the loss of aquatic organisms that rely on the source of macroalgae, or kelp, as a providence of nutrients and energy (Kriegisch et al., 2016). One study indicates that the replacement of kelp forests to urchin barrens can result in a 36% reduction of total species richness in association with the kelp beds in the Southern California Channel Islands (Graham, 2004). Once a region becomes an established urchin barren, it is difficult for that area to return to a stable kelp forest as the reverse shift occurs only if sea urchin density is reduced below the return threshold, signifying that there needs to be enough urchin predators present within the habitat to control the density of prey to allow Macrocystis *pyrifera* (giant kelp) to regrow and establish itself as a healthy forest again (Ling et al., 2015). The abundance of kelp forests along Southern California coasts is often regulated by *Strongylocentrotus purpuratus* (purple sea urchin) density in surrounding terrain. This relationship varies based on the abundance of predators, such as *Panulirus interruptus* (spiny lobster) and *Semicossyphus pulcher* (sheephead fish) (Nichols, 2009).

Sea urchins emerge from their hidden crevices and feed on the kelp stipes and blades when there is an insufficient amount of drift algae for consumption (Nichols et al., 2015). This is important because the abundance of kelp, which is a primary producer, is vital to the biodiversity of the marine species. Such animals depend on the kelp's providence as a cover from wave exposure, habitat protection, and a source of food for grazers and epibiont organisms that feed off the kelp biofilm (Marzinelli et al., 2011). In Southern California alone, over two hundred species of invertebrates, fish, algae, and mammals are commonly observed within the giant kelp forest ecosystems, supporting industries such as fisheries, tourism, and aquaculture (Graham et al., 2004).

Fig 1 This is the coast of Santa Monica, CA in which field researchers inspect sea urchin population and kelp density in an urchin barren among the shallow waters. This allows scientists to examine the relationship between the presence of sea urchins and the abundance of kelp beds. Taken by Tom Boyd (The Bay Foundation, 2013).

Where the concentration of *S. purpuratus* predators is lower, urchins thrive and there is an increased demand for food, resulting in a greater multitude of urchin barrens which replace lush kelp beds as the urchins food source, *M. pyrifera*, is consumed. *P. interruptus* is a nocturnal predator and *S. pulcher* is a diurnal predator in California (Nichols et al., 2015). With predators that hunt both in the day and night, communities of *S. purpuratus* are restricted to when they can emerge from the reef cracks and crevices to feed. While staying hidden, the urchins rely on drift algae as their source of food, but when there is not enough, the urchins emerge and consume the macroalgae. Predator-prey interactions affect the ecological structure of marine ecosystems, for if the abundance of predators is altered, the concentration of grazers would be impacted and inevitably alter biomass of kelp (Guenther et al., 2012). When there is an insufficient biomass of primary producers, the rest of the food chain is affected due to the lack of a source of food and energy for the herbivores, ultimately impacting the apex predators. The sea otter and *P. interruptus* are known as keystone species within their aquatic ecosystem and thus, their presence in the ecosystem is vital to its structure, composition, and function which is disproportionately large relative to their abundance (Nuñez & Dimarco, 2012). If such a keystone species were to disappear from the community, the diversity within the population would dramatically decline as the food web collapses. In this situation, species such as sea urchins become overabundant, leading to a decline in its food source, which is *M. pyrifera*.

Keystone Species and Hosts

M. pyrifera is considered a keystone host under the categorization of plants or other producers which establish a source of food and shelter for the keystone species and relative organisms dependent on the resources within the ecosystem. As a nutrient-rich source of food, *M. pyrifera* is relied on by the coexisting species to provide necessary supplements so that the flow of energy up each trophic level of the food chain is proportional to what is essential for successful survival and reproduction of all the organisms no matter their role in the food chain. Beyond providing food, shelter, and other resources, keystone hosts act as a determinant of biodiversity. In its absence, severe species loss can permanently impair the structure and function of the ecosystem, and so, *M. pyrifera* averts the destruction of a biological faction by controlling the imbalance in abundance of a certain plant or animal (Richard et al., 2017). Consequently, when there is a disruption in the balance of species, groups such as primary consumers, in this case, *S. purpuratus,* would grow exponentially in number to where their predators could not control their size and therefore, *S. purpuratus* would over consume *M. pyrifera*, their main food source.

Functional redundancy is defined as multiple species being able to perform similar roles within communities and ecosystems, essentially contributing in equivalent ways and can therefore be substitutable with little impact on the ecosystem (Rosenfeld, 2002, Lawton & Brown, 1993). Keystone species exhibit quite low functional redundancy and therefore cannot be simply replaced if eliminated from its food web. When there is a unique factor removed from its ecosystem, surrounding conditions must adapt and conform to the new environment, or otherwise collapse as observed in the devastating transformation of kelp forests to urchin barrens. In other terms, no alternative species can fill its ecological niche and with such a gap in the trophic cascade, the bottom-up effects would be catastrophic without the foundational primary producer to establish stability to the ecological structure. While *P. interruptus* and *S.*

pulcher have a larger functional redundancy as only secondary consumers, meaning they could be more easily replaced with a similar species, the assumption that there would be little ecological impact on the ecosystem is inaccurate as redundant species are considered necessary to ensure ecosystem resilience to perturbation. In biological terms, perturbation is an alteration of the function of a biological system by external or internal means. Functional redundancy parallels several fundamental issues in ecology including organization of species into trophic levels, competition, ecological niches, and limiting similarity, which is the highest level of niche overlap between two given species that will allow continued coexistence.

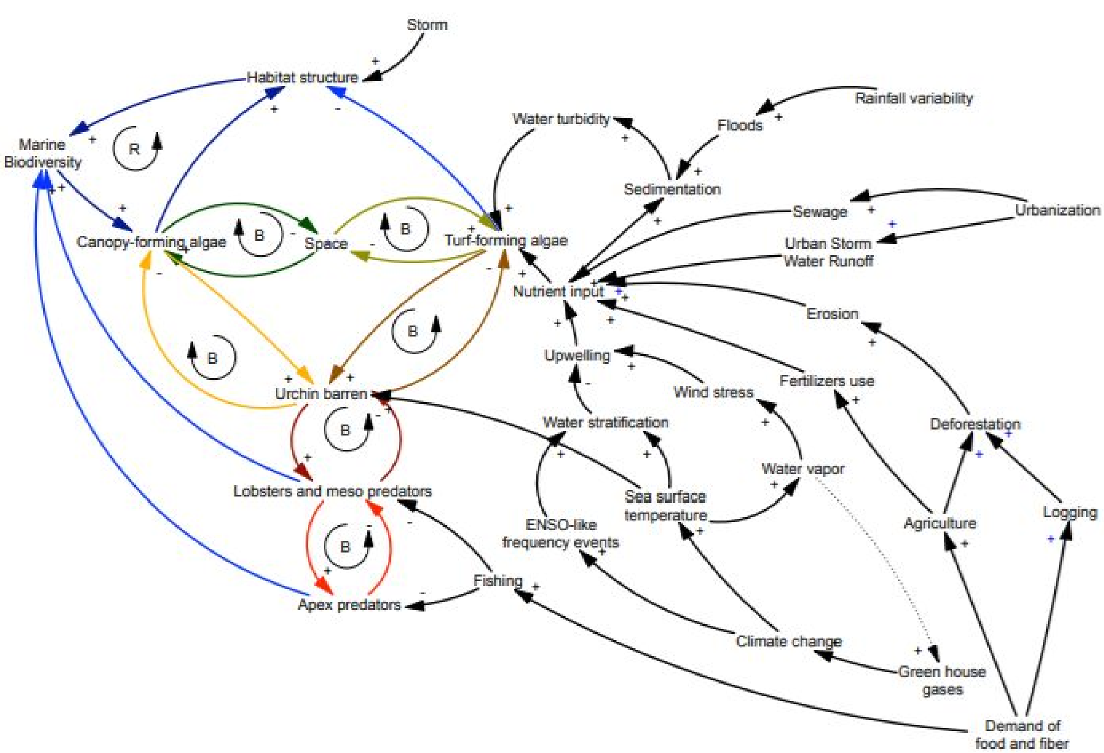

Fig. 3 This loop diagram shows the environmental relationships within kelp forest transitions. The feedback from the shifting factors within the system reflects the influx marine biodiversity, kelp abundance, urchin density and so forth (Rocha, 2010).

Fisheries and Predator-Prey Interactions

By taking an "Ecosystem-Based Management" approach, fishermen act as predators of sea urchins, effectively controlling their population as they catch the organisms for commercial use. The average landings for *S. pulcher* from 2000-2011 in California were 97,000 pounds per year and for the *P. interruptus*, a total of 695,000 pounds were collected for the 2010-2011 fishing seasons (California Department of Fish and Wildlife, 2011). By fishing the predators of *S. purpuratus*, fishermen essentially become the top level of the trophic cascade as they alter the population of species at lower trophic levels (Lafferty, 2004).

When focusing on the predator-prey interactions, size plays a major role in the success of hunting urchins, which is profoundly different in areas that are overfished, in terms of *S. pulcher* and *P. interruptus*, compared to protected locations, where the predator populations are not regulated by fisheries. Through the comparison of marine reserves and fished areas, it is observed that fisheries cause a decline in predatory-fish body size, highlighting the importance of size-structured interactions (Hamilton et al., 2014). By managing the populations of these two species, there is a greater chance of also controlling the amount of overgrazing of *M. pyrifera* by *S. purpuratus* as there would be a balanced population between the three factors. Prior to increasing fishery harvest at San Nicolas Island, *S. pulcher* annually consumed around 20–33% of the *S. purpuratus* population; experimental removal of sheephead from an isolated reef in the same study resulted in a 26% annual increase in urchin densities, indicating strong trophic interactions (Tegner & Dayton, 2000).

While examining the role played by both the prey and predator, the present vegetation must also be considered. Studies reveal that a higher density of vegetation, in this case, *M. pyrifera,* provides prey species with security from exposure to their predators in the habitat (Heck & Crowder, 1991). Frequency and duration of predator pursuits decreased as the biomass of *M. pyrifera* rose.

Fig. 4 This image shows the kelp bed and the diverse species populations it supports. These kelp beds are off the Channel Islands coast, showing how the health of the ecosystem is dependent upon the health of the primary producer: kelp forests. Taken by Brett Seymour (National Park Service, 2017).

Current Measures

As the shifting from stable and healthy kelp forests to devastated urchin barrens has increased over the past few decades, researchers and conservationists have worked together in the attempt to prevent any further damage to the ecosystem as it affects more than just the kelp, urchins, sheephead, and spiny lobster. Since *M. pyrifera* provides shelter and nutrients to such a biodiverse community of over seven hundred aquatic organisms, it is vital that the macroalgae is protected to maintain a balance not only in its own habitat, but also the other ecosystems that rely of the stability of the oceans in order for the global cycles to connect and establish the environment we live in today. In the Palos Verdes region alone, The Bay Foundation has restored 46 cares of kelp forest in two covers and four open shore reefs with over 7500 hours of underwater recovery efforts. Due to these conservation efforts, the density of *S. purpuratus* has reduced from an average of 30 to about 2 individuals per square meter, resulting in increases of kelp, invertebrates and overall fish diversity and biomass (The Bay Foundation, 2013).

Purpose

The purpose of this study is to investigate the ecological correlation between the shifting sea *S. purpuratus* density and *M. pyrifera* biomass along the Southern California Pacific coast. When the primary producer is removed from the food chain, it will result in a bottom-up trophic cascade, meaning there will be shifts in the balance of and relationships between the existing species that are involved with and affected by the primary producer. There is also a concern of top-down trophic cascade effects, in which the apex predator, often categorized as the keystone species for their specific region or ecosystem, is removed, causing a change in the balance and abundance of its prey and the producers. This paper attempts to find data and alternative methods to support the growth and stabilization of *M. pyrifera* regarding its region to restore the balance within the Southern California aquatic ecosystems.

Research Question

What is the relationship between *S. purpuratus* density and *M. pyrifera* biomass in the ecosystems along the Southern California Pacific coast?

Alternative Hypothesis

A greater density of *S. purpuratus* will lower the *M. pyrifera* biomass which causes a shift in the trophic cascade and food web along the Southern California Pacific coast.

Null Hypothesis

There is no significant impact of *S. purpuratus* density on *M. pyrifera* biomass concerning its food web along the Southern California Pacific coast.

Methods

Data Sources

The current study design involved the use of systematic literature review from peer-reviewed papers in this field. Data on the effects of *S. purpuratus* populations on *M. pyrifera* biomass was collected from several papers with pre-existing experiments. Using the already published data from papers, relationships between the biomass of *S. purpuratus* and *M. pyrifera* and their environmental impact were investigated. Data from several papers were pooled together and analyzed through the use of statistical analysis, calculating standard deviation and standard error.

Information obtained from peer-reviewed articles was retrieved from various online databases including JSTOR, ScienceDirect, PlosOne, EBSCOHost, Google Scholar, ResearchGate, PNAS, etc. The quantitative data obtainable within the peer-reviewed articles was used throughout the research project to support any claims throughout the investigation of the relationship between *S. purpuratus* density and *M. pyrifera* abundance.

The Bay Foundation provided past reports of Southern California coasts' aquatic conditions, as well as The San Diego Sea Urchin Project, which is a program within The San Diego Watermen's Association. Biological reports from the Fish and Wildlife Service, a part of the U.S. Department of Interior, supplied statistical reports and reviews that aided in the data collection.

Key terms used to find relevant literature through journals or electronic databases included kelp abundance, urchin density, species richness, trophic shifts, urchin barrens, primary producers, kelp recovery, and biodiversity reduction, urchin predators, keystone species, bottom-up trophic cascade, Southern California coasts, and fisheries. These search words helped keep a narrowed focus on the questions addressed in this research paper. Using the reference pages of each paper, other credible and related articles were found, establishing a plethora of information and statistics pertaining to the topic. A network of credible authors and researchers was also formed through the utilization of referenced papers similar to the issues addressed in each initial paper.

Systematic literature review was used for there was an accessible amount of peer-reviewed scientific papers available with already conducted experiments and studies. This information provided a sufficient amount of data that could be combined and statistically analyzed to examine the relations between organisms within the kelp forest ecosystem to add new information to the academic conversation in this field.

Data Collection

Data collection through electronic databases took place at Thousand Oaks High School, Moorpark College Library, Thousand Oaks Public Library and other local resources. There were no labs or field research conducted for this project, only theoretical research involving systematic literature review of peer-reviewed articles. The initial goal was to accumulate around sixty peer-reviewed papers along with collective information from various journals and environmental project reports. The systematic literature review was conducted on data ranging from ten to twenty academic papers. The data sourced from pre-existing experiments and studies conducted by researchers focused on the Southern California Pacific coastal regions regarding the health and balance of the *M. pyrifera* food chain. Such data measured the rate of *S. purpuratus* consumption of *M. pyrifera*, predator consumption of *S. purpuratus*, which in this paper focuses on *S. pulcher* and *P. interruptus, M. pyrifera* regrowth, urchin barren expansion, keystone species loss, species richness reduction, and shifting patterns in the ecosystem. Maps, graphs, diagrams, and tables of data from the academic papers were utilized to help in the explanation of information used to present a clear and cohesive analyzation. The results varied in species, locations, durations, time/season, and treatments. Human interference was also considered when comparing data and forming conclusions. Statistical analysis, calculating standard deviation and standard error, was utilized through pre-existing tables and graphs to examine the significance of the relationship between *S. purpuratus* density and the biomass of *M. pyrifera* forests based on the synthesized data from the numerous peer-reviewed articles.

The gap addressed in this paper was the finalized analyzation of synthesized data from numerous pre-existing experiments within peer-reviewed papers to determine the direct relationship between *S. purpuratus and M. pyrifera,* as well as the indirect relationship pertaining to the predators of urchin*s P. interruptus,* and *S. pulcher.*

There was a focus on a data collection from peer-reviewed articles that ranged from 2004 to 2018, with a few review articles dating as far back as 1996 for shifts in the stability and abundance of *M. pyrifera* forests began in the mid to late nineties. Numerous review articles from the past decades provide data showing general shifts in trends pertaining to the abundance of *M. pyrifera, S. purpuratus, S. pulcher,* and *P. interruptus.* This specified time period allowed the information to remain significant with respect to current ecological issues in the marine community, as well as addressing historical events that correlate to the present topic. By having a large enough time frame to include data, past experiments could be utilized as a comparison to the more recent experiments in order to establish a solid foundation of different locations, treatments, species, seasons, temperatures, and relationships among organisms. These comparisons were used to correlate the significance of data and whether to be mentioned or cited in the research project.

Parameters

In reference to Fig. 5, the no fishing region is a reserve where preventative measures have been put in place to try to preserve the ecosystem and keep it mostly untouched by man. It is, however, available for research purposes that aim to use their results for improving current conditions or proposing and implementing regulations to aid with future changes or damage to the environment. Restrictions set to maintain the reserve include the kelp is not harvested, the urchins are not captured, nor are the sheephead and lobster caught for any commercial fishing. Hence, by keeping the region undisturbed by human interference, the interactions between organisms is controlled by the ways of nature and not by man. In comparison, the region that does allow for fishing, shows the sheephead and lobster targeted for commercial use. However, evidence of whether the kelp is utilized for harvesting or other human uses is not available within the given information from the studies. With the allowance of human activity, results will reveal the impact which mankind has on otherwise thriving ecosystems.

Results

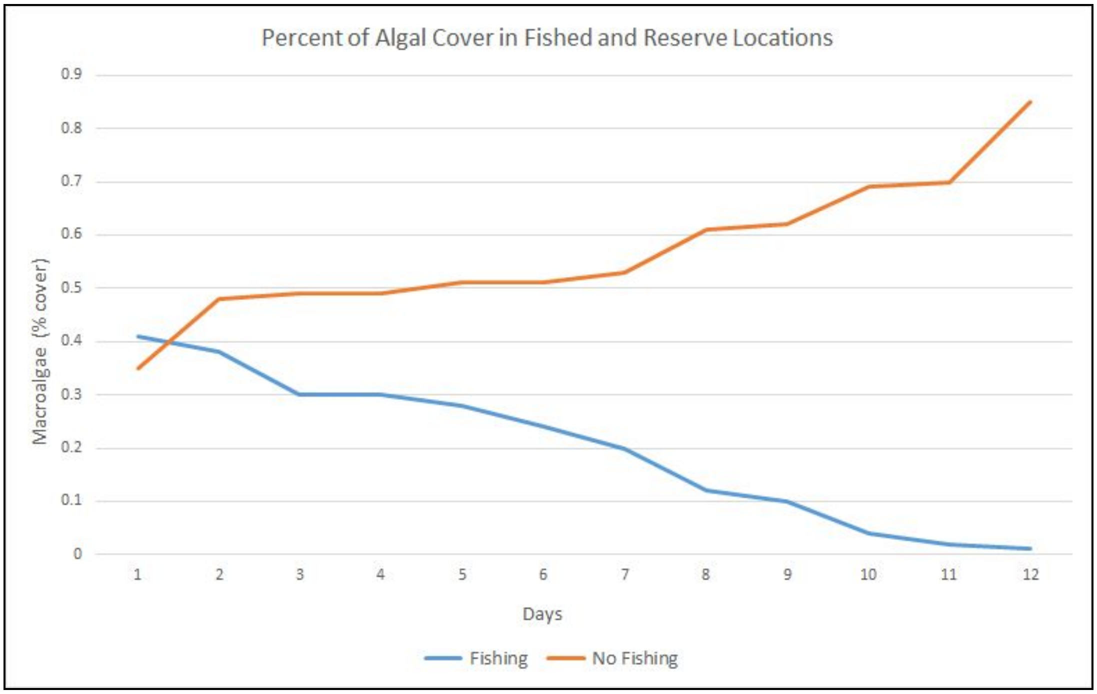

Fig. 5 This graph shows the relationship of percentage of macroalgal cover in both fished and reserve regions. In the fishing location, the macroalgae decreases in percent cover over the course of twelve days for the synthesized experiments in multiple locations within the Southern California Pacific region, while the percentage of macroalgae increases in a restrictive, no fishing location (Shears & Babcock 2003, Lafferty, 2004).

Based on the data, there is an overall decreasing trend of *M. pyrifera* in the open fishing region, while macroalgae located in the no fishing region, or marine reserve, increases in growth over the span of the specified twelve-day period. Results indicate the percentage of macroalgal cover is greatest at 85% in the region of no fishing on the final day of the experiment. Inversely, the macroalgae is at its lowest point in the fishing region on day twelve with only 1% of coverage. The data was extracted from two studies, one was conducted on the waters surrounding the Anacapa Island, Santa Barbara (Shears & Babcock, 2003) and the other took place in the coastal regions of the Channel Islands (Lafferty, 2004). The amount of *M. pyrifera* that can thrive within a certain region is dependent upon whether it is located in a reserve or open fishing area.

Table 1 This data table shows the sheep head biomass and urchin density; as *S. pulcher* increases in biomass, the density of *S. purpuratus* declines (Hamilton & Caselle, 2014, Nichols et al., 2015). With an R^2 value of 0.8804 there is an evident correlation between the dependent variable, sheephead biomass and independent variable, urchin density.

Sheephead Biomass (T Ha^{-1})	Urchin Density (No. 60 m^{-2})
0.025	805
0.046	710
0.09	490
0.1	576
0.15	380
0.35	241
0.41	302
0.45	267
0.48	243

0.5	205
0.52	256

The data was collected from and combined among multiple studies, Hamilton & Caselle, 2014, Nichols et al., 2015 and as the urchin density peaked to 805 No. $60m^{-2}$ the sheephead biomass was at its lowest point of only 0.025 T Ha^{-1}. At the highest count of 0.52 T Ha^{-1} of sheephead biomass, the urchin density declined to a mere 256 No. 60 m^{-2}.

Table 2 This data table shows an increase in *P. interruptus* catch and release numbers as the density of *S. purpuratus* decreases (Lafferty 2004, Guenther et al., 2012). The R^2 value of 0.6727 reveals the percentage of variance between the dependent variable, lobster catch and independent variable, urchin density. In the studies used to synthesize the data, the species were collected and analyzed in the coastal regions of kelp forest habitats primarily around the Channel Islands area.

Lobster Catch (No. km^{-2})	Urchin Density (No. m^{-2})
25	45
55	45
52	39
140	20
120	12
135	11

150	7.5
118	18
150	5.1
152	7.2
275	5
283	7.5
250	0.5
298	3.5
310	1.5

The data was collected from and combined among multiple studies, Lafferty 2004, Guenther et al., 2012 and the lobster catch was observed to be at its highest point of 310 No. km^{-2} while urchin density was at a low of 1.5 No. m^{-2}. In a similar way, the smallest value of 25 No. km^{-2} of lobster catch resulted in an urchin density of 45 No. m^{-2}.

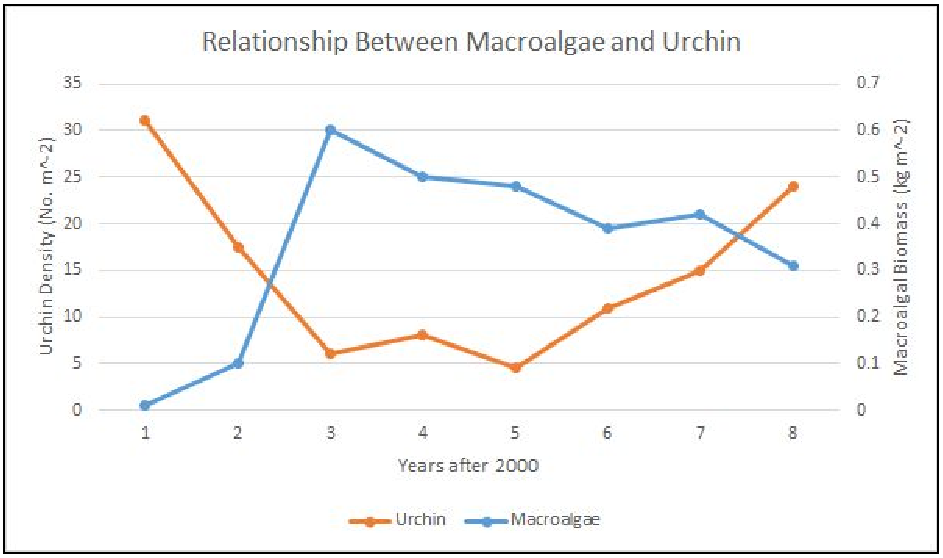

Fig. 6 This graph reveals an inverse relationship between macroalgal biomass and urchin density over an eight-year period of study. The organisms were analyzed around the Naples Reef in Santa Barbara (Guenther et al., 2012, Reed et al., 2011, Hamilton & Caselle, 2015, Edwards et al., 2014).

As the biomass of *M. pyrifera* increases from year one at 0.01 kg m^{-2} to year three at 0.6 kg m^{-2}, the density of *S. purpuratus* decreased from year one at 32.5 No. m^{-2} to 5.8 No. m^{-2} in year three. The trend continues as the urchin density further decreases with the macroalgae increasing until year five. In that year, the density of *S. purpuratus* then increased from 4.85 No. m^{-2} in year five to year eight with a value of 24.2 No. m^{-2}. As the relationship between the two organisms is confirmed, the biomass of *M. pyrifera* then decreases from 0.48 kg m^{-2} in year five to 0.31 kg m^{-2} in year eight.

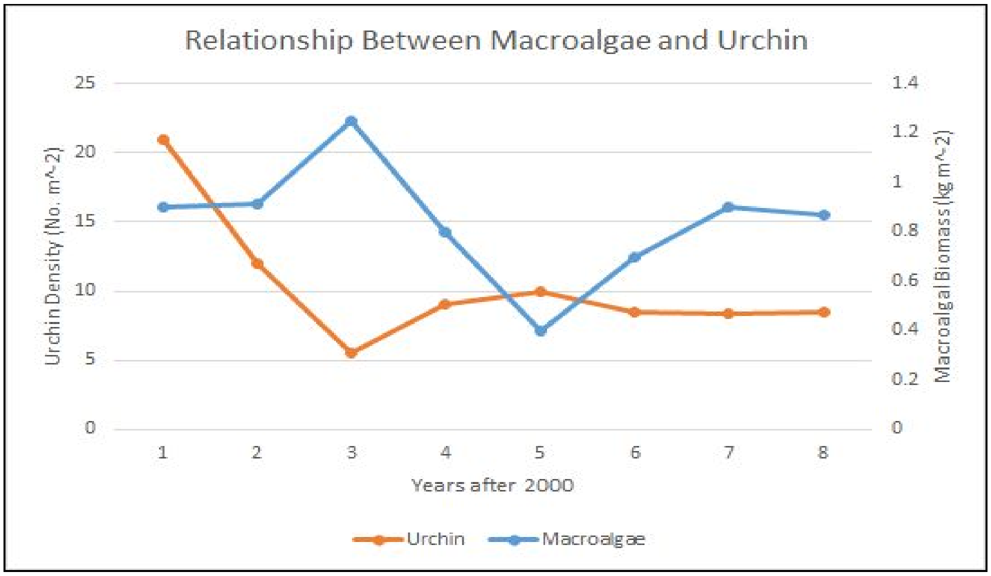

Fig. 7 This graph also shows an inverse relationship between macroalgal biomass and urchin density over an eight-year period of study. The organisms were analyzed around the Mohawk Reef in Santa Barbara (Guenther et al., 2012, Reed et al., 2011, Hamilton & Caselle, 2015, Edwards et al., 2014).

As the density of *S. purpuratus* decreases from 21 No. m^{-2} to 5.5 No. m^{-2} over the course of three years after 2000, the biomass of *M. pyrifera* increases from 0.9 kg m^{-2} to 1.25 kg m^{-2}. At the end of the eight year study, the macroalgae reduced only about 3.33% in biomass with the final data recorded as 0.87 kg m^{-2} while the sea urchin density declined about 59.5% with the final data recorded to be 8.5 No. m^{-2} .

Discussion

The graphs and tables represent the complex relationships between the balance of the abundance of *P. interruptus, S. pulcher, M. pyrifera,* and *S. purpuratus* along the Southern California Pacific coastal regions. When analyzing results, the tables and graphs recognize the varying relationships as they influx based on different concentrations between the three main factors: predator, prey, and primary producer. There is a clear direct relationship between the biomass of *M. pyrifera* and the number of urchin predators, either *S. pulcher* or *P. interruptus* for as the number of urchin predators increase, limiting the urchin population itself, the kelp beds can increase their growth without being grazed upon at such high rates. The data reveals an indirect relationship between *M. pyrifera* and *S. purpuratus* for when the density of urchins increase, they consume more kelp and therefore decrease the kelp's biomass.

With data in Fig. 5 focused on the differences of the percentage of macroalgal cover in either an open fishing location or a marine reserve region, the impact of human activity and interference can be accurately assessed. It is clear that the biomass of *M. pyrifera* that maintains healthy growth within a certain region is dependent upon whether the predator of *S. purpuratus* is controlled or not, ultimately regulating the density of algae grazing invertebrates. Based on the results of the graph, an increase is evident in the percentage of macroalgal cover in the no fishing, or marine reserve region, indicating that a greater abundance of *S. purpuratus* predators, *S. pulcher* and *P. interruptus*, allows a higher percent of *M. pyrifera*. Thus, the relationship between trophic cascades is revealed as the primary consumer is at a minimal density when the secondary consumer is at its optimal or even maximum density.

The pattern of the data points in Table 1 reveals an indirect relationship between the density of *S. purpuratus* and biomass of *S. pulcher* within the specified Channels Islands regions. When comparing the population of urchins with respect to the number of urchin predators to the biomass of macroalgae located in the same region, it is evident that there is a direct correlation to the number of secondary consumers, urchin predators, and the biomass of the primary producer, kelp. Likewise, based on the results of Table 2, the trend which the data follows, indicates that the density of *S. purpuratus* is dependent on the number of *P. interruptus* captured and released within the region where the study was conducted. Therefore, the predator of urchins directly influences the population of this primary consumer, which in turn controls the concentration of macroalgae in that area. As the predators decrease in number, colonies *S. purpuratus* have the freedom to graze upon the available *M. pyrifera*, often leading to a shift from healthy kelp forests to devastated urchin barrens.

With these findings, it can be concluded that there must be regulations on the population of *S. pulcher* and *P. interruptus* to maintain a balance between predator, prey, and producer in which the prey is *S. purpuratus* whose primary diet is *M. pyrifera*, the producer. The marine reserve data compared to that of the open fishing region indicates that human interference through commercial fishing and harvesting has a large impact on the stability of the kelp food web as factors such as fish and lobster are removed from the environment, a shift in trophic levels occurs and the collapse of the food chain is eminent.

Limitations

When analyzing data from multiple studies, there are a number of factors that could disrupt the results include variances in oceanic conditions such as water and atmospheric temperature, time and season the study was conducted, location of where the samples were collected and examined, and salinity of the surrounding waters. Human interference includes fisheries, shipping yards, sport fishing, and plant or animal harvesting for other needs. With the presence of these human activities, certain species cannot survive in the altered conditions and therefore vacate their habitats, causing an imbalance of organisms within a specific region or ecosystem.

Since the data, from the chosen peer reviewed articles, were collected in varying locations within the Southern California Pacific coastal regions, it cannot be precisely determined the amount of pollution affecting the natural habitats of the focused-on species for this study. Invasive species also plays a role in unaccounted for impacts on the results of data which was utilized for the synthesize tables and graphs presented earlier in the paper. As the concept for this project originally stemmed from the 2007 tsunami in Japan, which brought over a wave of invasive species, affecting and eliminating native populations of certain species including macroalgal communities, secondary consumer fish, etc., nonnative organisms were a potential factor in false results or unrecognized shifting elements which could skew the data.

The variables, units, concentrations, species and methods towards performing experiments and collecting data also differed between studies. Different measurements were accounted for through unit conversion calculations and was conducted for Table 1 and 2 of synthesized data. Another factor was either the size of the region focused on for the experiment or the number of organisms studied. Some researchers only looked at around ten individuals of *S. purpuratus,* while other experiments examined over two hundred specimens. In a similar way, the macroalgae was both measured by percentage of cover over a habitat and the biomass within a specified sector. These different conditions are vital towards accurate results as many variances could cause false correlations between experiments and conclusions.

Conclusions

The systematic literature review provides supporting evidence that with a higher concentration of sea urchins in a focused area, the biomass of kelp declines, leading to the spread of urchin barrens throughout the Southern California Pacific coast. A great reduction in biodiversity is also prevalent as the kelp populations die out and being a keystone host and primary producer, they provide food and shelter to a wide range of species within its ecological system. Ultimately, the results reveal that there is a direct correlation between *M. pyrifera* and *S. purpuratus* which both contribute to the species richness within a region and the stability of a balanced ecosystem.

Further Work

Further research should be conducted in other locations to compare the conditions of Southern California Pacific coastal regions to that of varying climates, terrains, species, ocean current patterns, food webs, and more. A handful of studies have taken place around the Aleutian Islands in Alaska, as there is a wide range of species populations which are dependent on the safe and nutrient-rich habitat provided by macroalgae of various types. With Australia's coastlines occupied by coral reefs and kelp forests, many studies have also been focused there, where the temperatures of the water on average are warmer, creating a different environment for species to survive in. Other marine zones include the coasts of the Northwest Atlantic, South America, and South Africa as they parallel in conditions of urchin-kelp relationships and apparent shifting from kelp beds to urchin barrens. By comparing these alternate locations, the trends established in the data I have already synthesized from marine researchers' papers can be analyzed alongside the data from similar regions in different parts of the world and determine if those patterns are observed globally. Such information would allow researchers to formulate potential steps to take to help prevent further destruction of kelp forests, which would also result in a loss of species richness within its habitat as the source of food dissipates.

In future investigation, invasive species also must be taken into account as they cause an upset in local habitats when those non-native species are introduced and have no natural competition and can thus eat anything within their diet. Competition among species for all trophic levels including producers, consumers, and predators is a determining factor towards the stability and integrity of community structure within the habitat.

Conservational efforts implemented in threatened regions of kelp beds such as regulation of commercial fishing and harvesting could help preserve and restore those communities back to their original health and stability, providing once again nutrients and habitat for dependent species. By also establishing preventative measures and management in vulnerable sections of kelp forests, the future species richness and biodiversity in the surrounding areas will be protected from potential loss or reduction. With this in place, the ecological balance between producer, consumer, prey, and predator within the food web can be maintained.

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