Evaluating the Trophic Level Effects of Sea Star Wasting Disease in California

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ABSTRACT

Interspecific competition is a mutual interaction between two or more species in the trophic food web. The tidepools of the Pacific Northwest coast are an ideal study site for interspecific competition, specifically the sea star, as they promote prey and competitive behavior in the tidepools. In 2013, a sea star wasting disease (SSWD) epidemic hit the Pacific Northwest, which decimated many sea star species populations. In my project, I want to know what trophic level effects occurred in the California tidepools during the SSWD epidemic. I collected occurrence data (present or absent) from the GBIF (Global Biodiversity Information Facility) public database. The species of interest I gathered were the Purple sea star (*Pisaster ochraceus)*, Northern striped dogwinkle (*Nucella ostrina)*, California mussel (*Mytilus californianus),* and Sunflower sea star (*Pycnopodia helianthoides).* My results showed that the purple sea star and species of interest had a relationship between their occurrences and the SSWD period ($p<0.05$). Further analysis shows that all species' occurrences except the Sunflower sea star had differences during the SSWD periods. Although I found relationships and differences in occurrences during the SSWD period, there was insufficient data to conclude trophic level effects. A more robust statistical model with more substantial explanatory variables may help find future projects' trophic level effects.

KEYWORDS

interspecies, predator-prey, intraspecies, Sea Star Wasting Disease, occurrence

INTRODUCTION

Interspecific competition is a mutual interaction between two or more species in a trophic food web. An essential type of interspecific interaction is the interactions between a keystone species and the rest of an ecosystem. Keystone predators help maintain the balance of the ecosystem by controlling the herbivore populations that may overgraze plant species (Paine 1969). The purple sea star (*Pisaster ochraceus)* is a keystone predator in rocky intertidal zones on the west coast of North America (Paine 1969). *P.ochraceus* maintains its prey population, the California mussel (*Mytilus californianus),* through predation and promotes competition in the tide pool ecosystem. By consuming *M.californianus* as the competitive dominant space occupier, the purple sea star prevents a single species from monopolizing available space and increases overall community diversity (Navarrete & Menge 1996, Gosnell and Gaines 2012). *P.ochraceus* also maintains prey populations in tidepools by consuming prey and altering prey behaviors in their role as keystone intimidators. A keystone intimidator is a non-consumptive interaction; non-consumptive interactions may occur mainly in the absence of consumptive interactions in communities where prey possess costly anti-predator adaptations that substantially reduce their risk of consumption prey performance (Sih et al., 2010, Gosnell and Gaines 2012). Thus, the presence of a keystone predator changes the prey's foraging behavior and consumes enough prey to keep their abundance in equilibrium.

The tidepools of the Pacific Northwest coast are an ideal study site for interspecific competition, specifically the sea star, as they promote prey and competitive behavior in the tidepools. For example, sea stars may act simultaneously as keystone consumers and keystone intimidators through their effects on mussels and whelks, respectively (Peckarsky et al. 2008a, Gosnell and Gaines 2012). When the purple sea star is removed from the rocky intertidal zone, the primary prey, the mussels *Mytilus californianus* and *Mytilus trossulus*, outcompete other primary substrate species such as barnacles and algae. (Kay et al., 2019)

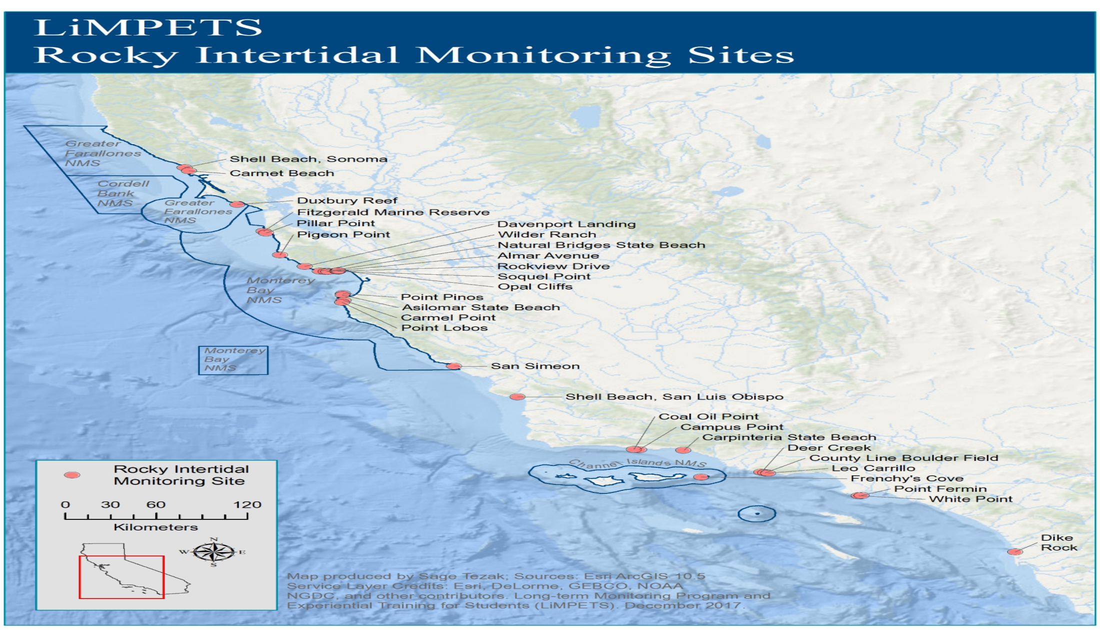
In 2013, a sea star wasting disease (SSWD) epidemic hit the Pacific Northwest, which decimated many sea star species populations. Many sea star species populations in the Pacific northwest declined with the recent outbreak. The decline of these sea star species may change the dynamics of keystone species, differences in prey behavior, and interspecific competition. While all disease-induced population declines can impact communities, diseases of keystone species, in particular, could have disproportionate effects on their communities because of the dominant effects of the host on community structure (Kay et al.,2019). With the severity of the SSWD epidemic, many sea star species were affected disproportionately, ranging from nearly decimated to extinct. Species response has generally been negative at both the individual (symptomatic individuals at a given site) and sometimes population level (all individuals of a particular species being impacted in a given region); however, there is much variability in the response of each species across space (Kay et al., 2019; Schultz, 2018; Hewson et al., 2018; Moritsch and Raimondi, 2018; Montecino-Latorre et al., 2016; and also Multi-Agency Rocky Intertidal Network).

In my project, I want to know what trophic level effects occurred in California tidepools during the SSWD epidemic. I plan to focus on the purple sea star (*P.ochraceus)* and its occurrence data throughout the epidemic. I will explore whether there are any relationships with its interspecies competitor, the Northern striped dogwinkle (*N.ostrina),* its prey, the California mussel (*M.californianus)*, and intraspecies competitor, the Sunflower sea star (*Pycnopodia helianthoides)*. I hypothesize that there is a relationship between the species and occurrence throughout the SSWD periods. Although finding a connection between species and occurrence is essential, it does not address if all species were affected equally by the SSWD epidemic. To address this, I also want to know the differences in occurrences between each species and SSWD periods. I hypothesize that not all occurrence means were equally distributed for the species of interest during the SSWD period.

METHODS

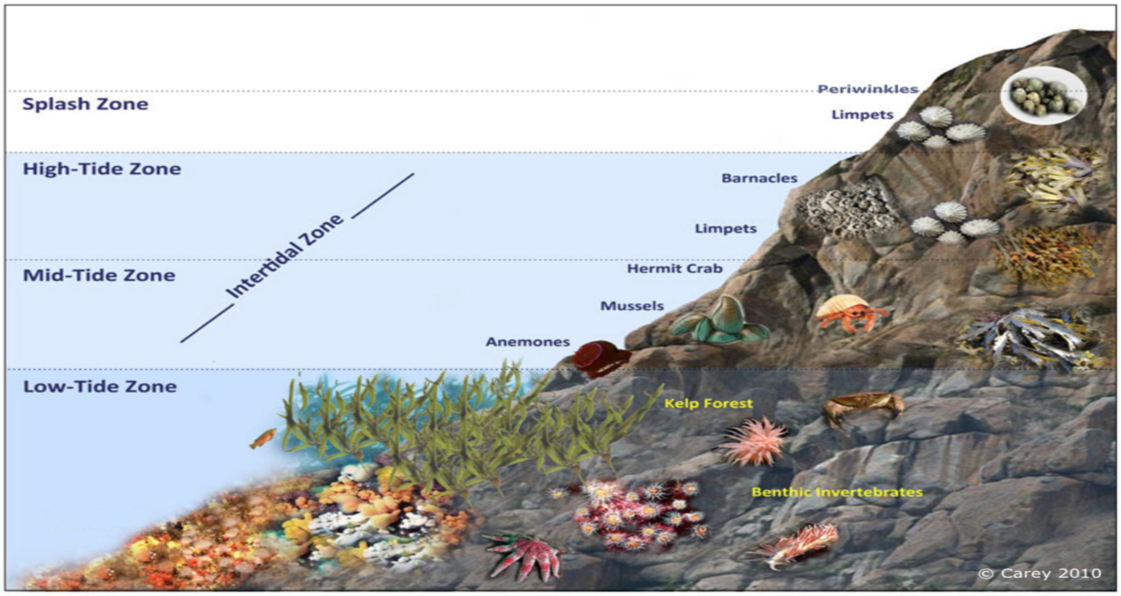
Study site:

My study site focused primarily on tidepools in California for my study. Rocky intertidal shores frequently occur along the entire length of the California coastline. In some regions, long stretches of rocky habitat dominate the shoreline, while in others (southern California, in particular), small rocky outcroppings are separated by long expanses of sandy beaches. Approximately 800 miles of rocky habitat occur along the California coast, comprising about 35% of the entire shoreline of California's outer coast. Rocky intertidal ecosystems of the Pacific coast support a high diversity of invertebrate and algal species and have served as a model ecosystem for experimental marine ecology (Mooney et al., 2016). Figure 1a shows how far the rocky intertidal occupies the California coastline. The four areas of the tidepool are supratidal, high, middle, and low zones. The difference in water level categorizes each zone due to the daily high and low tides throughout the day. Figure 2a exhibits the breakdown of each zona and where organisms would inhabit.



Source: Greater Farallones National Marine Sanctuary

Figure 1a: Rocky Intertidal sites in California



Source: [Science Learning Hub]

Figure 2a: Tidepool Zonation

Data collection:

I collected data from the GBIF (Global Biodiversity Information Facility) public database for my thesis. The species of interest I gathered were the Purple sea star (*Pisaster ochraceus)*, Northern striped dogwinkle (*Nucella ostrina)*, California mussel (*Mytilus californianus),* and Sunflower sea star (*Pycnopodia helianthoides).* I ran a chi-square test of independence and ANOVA for my data analysis. The variables for my Chi-square test are Species, Occurrence, Year, longitude, latitude, and state. For my ANOVA, the variables I obtained were Species, Occurrence count by year, year (2008-2021), and SSWD periods as pre-SSWD (2008-2012), During (2013-2017), and post-SSWD (2018-2021). I then made three datasets per SSWD period per species for each statistical analysis test.

Data Analysis:

I paired and categorized the species together in their respective SSWD periods for my chi-square test, and the purple sea star was the control. The null hypothesis was no relationship between the species and occurrence in each SSWD period. The alternative hypothesis was there is a relationship. The categorical variables were the species, and the nominal variable was the occurrence converted to a frequency count.

To measure the occurrence difference in each SSWD period for each species, I ran an ANOVA test. The independent variable is species and SSWD periods, and the quantitative dependent variable was the occurrence count by year. The null hypothesis was there was no difference in the SSWD period given the species' occurrence. The alternative hypothesis was that at least one SSWD period is significantly different from the over mean of occurrences. All tests and figures were done on RStudio and R commander (RStudio Version 1.4.1106 and R Commander Version 2.7-2).

RESULTS

Interspecies relationship in SSWD:

I found a relationship between the Purple sea star and the Northern striped dogwinkle and their occurrence in all SSWD periods. In figure 1, both species had increased in occurrence in all periods. Purple sea stars increased dramatically during the SSWD epidemic, and the Northern striped dogwinkle showed a small incremental increase in occurrence (Figure 1).

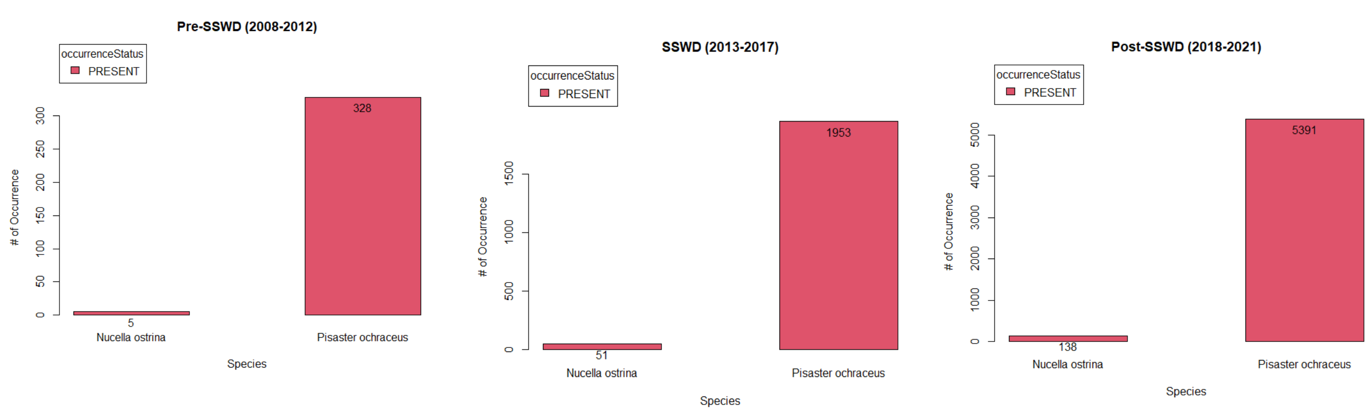


Figure 1: Purple sea star(*Pisaster ochraceus)* and Northern striped dogwinkle (*Nucella ostrina)* occurrence differences. Both species had an increase in occurrence throughout the SSWD period.

Table 1. Summary of Chi-square test Pre-SSWD

Frequency table	Species	
Occurrence status	*Nucella ostrina*	*Pisaster ochraceus*
Present	5	328
χ2 = 313.3	df = 1	p <2.2e^-16

Table 2. Summary of Chi-square test During-SSWD

Frequency table	Species	
Occurrence status	*Nucella ostrina*	*Pisaster ochraceus*
Present	51	1953
χ2 = 1805.2	df = 1	p <2.2e^-16

Table 3. Summary of Chi-square test Post-SSWD

Frequency table	Species	
Occurrence status	*Nucella ostrina*	*Pisaster ochraceus*
Present	138	5391
χ2 = 4990.8	df = 1	p <2.2e^-16

Predator-Prey relationship during SSWD:

I found a relationship between the purple sea star and California mussel and their occurrence in all SSWD periods ($p < 0.05$, Tables 4,5,6). There were some significant differences in the occurrence of the California mussel compared to the purple sea star (Figure 2).

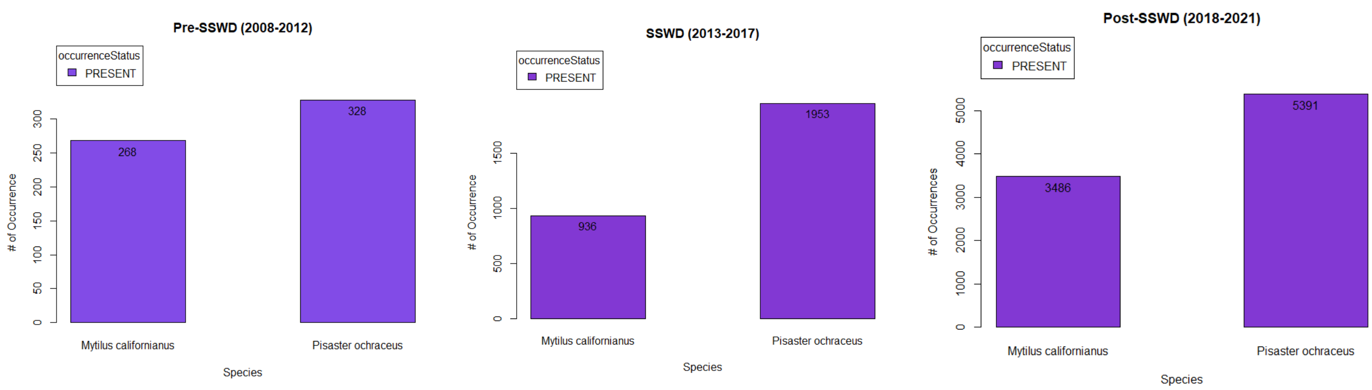


Figure 2: Purple sea star (*Pisaster ochraceus)* and California mussel (*Mytilus californianus)* occurrence difference. Both species have increased occurrence throughout the SSWD period.

Table 4. Summary of Chi-square test Pre-SSWD

Frequency table	Species	
Occurrence status	*Mytilus californianus*	*Pisaster ochraceus*
Present	268	328
$\chi 2 = 6.04$	df = 1	p = 0.014

Table 5. Summary of Chi-square test During-SSWD

Frequency table	Species	
Occurrence status	*Mytilus californianus*	*Pisaster ochraceus*
Present	936	1953
χ2 = 358.01	df = 1	p <2.2e^-16

Table 6. Summary of Chi-square test Post-SSWD

Frequency table	Species	
Occurrence status	*Mytilus californianus*	*Pisaster ochraceus*
Present	3486	5391
χ2 = 408.81	df = 1	p <2.2e^-16

Intraspecies relationship in SSWD:

I found a relationship between the purple sea star and sunflower sea star and their occurrence in all SSWD periods ($p < 0.05$, Table 7,8,9). Purple sea stars had increased while sunflower seas saw a decline (Figure 3).

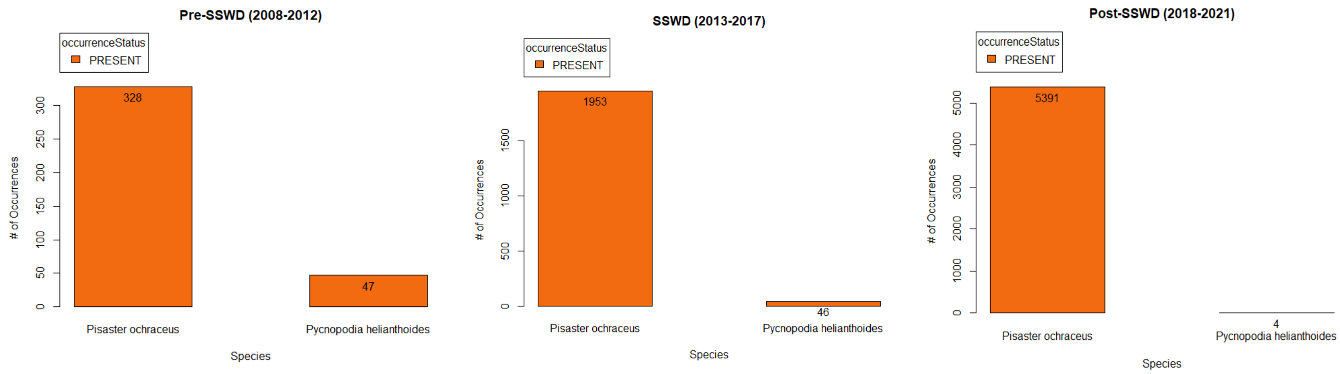


Figure 3: Occurrence differences are purple sea star(*Pisaster ochraceus)* and Sunflower sea star (*Pycnopodia helianthoides)*. The purple sea star increased throughout the SSWD period, while the Sunflower sea star had a dramatic drop in occurrence in the intertidal zone.

Table 7. Summary of Chi-square test Pre-SSWD

Frequency table	Species	
Occurrence status	*Pycnopodia helianthoides*	*Pisaster ochraceus*
Present	47	328
χ2 = 210.56	df = 1	p <2.2e^16

Table 8. Summary of Chi-square test During-SSWD

Frequency table	Species	
Occurrence status	*Pycnopodia helianthoides*	*Pisaster ochraceus*
Present	46	1953
χ2 = 1819.2	df = 1	p <2.2e^-16

Table 9. Summary of Chi-square test Post-SSWD

Frequency table	Species	
Occurrence status	*Pycnopodia helianthoides*	*Pisaster ochraceus*
Present	4	5391
χ2 = 5379	df = 1	p <2.2e^-16

Occurrences differences between species and SSWD period:

Purple sea star (*P.ochraceus):*

I found evidence that rejects the null hypothesis: there were occurrence differences for the purple sea star in the SSWD period ($p < 0.05$, Table 11). The purple sea star considered recovery in all periods (Figure 11). In the SSWD period, the occurrence was higher than in pre-SSWD. Post-SSWD shows a significant recovery in occurrence. After finding significance in my ANOVA, I ran a post hoc test, and I found that the Pre-During SSWD period was not significantly different($p = 0.08$). At the same time, Pre-Post and Post-During were significantly different ($p<0.05$, Figure 11.1, Table 11.1).

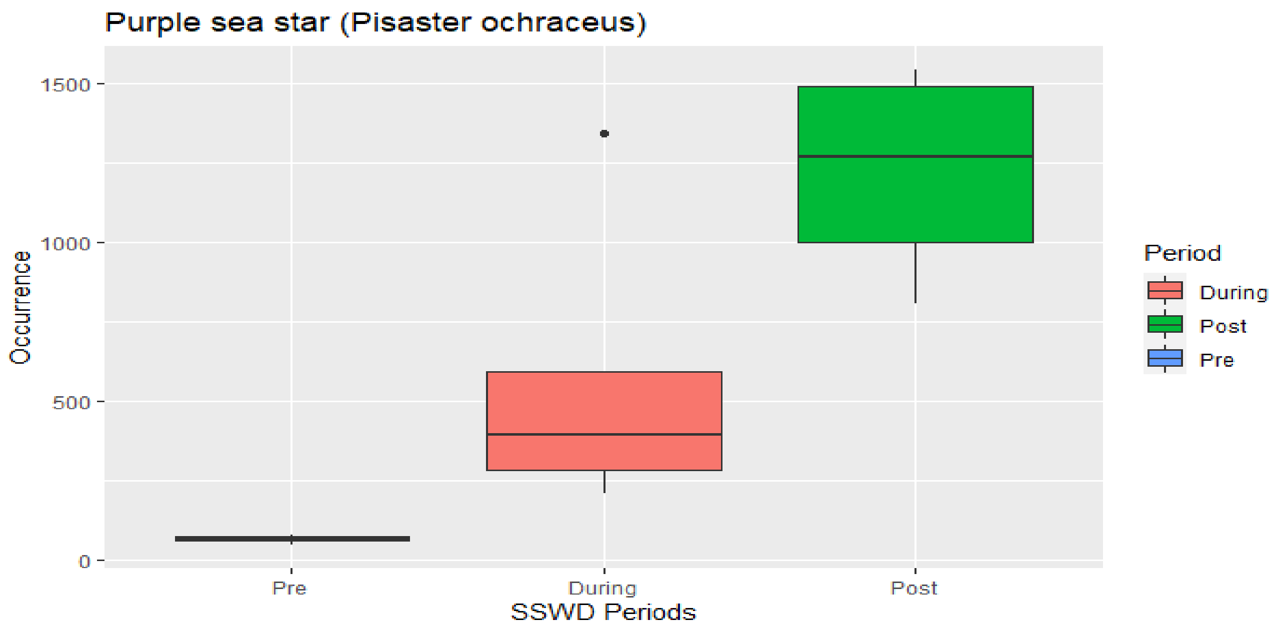


Figure 11. Purple sea star occurrence differences over SSWD periods. The purple sea star had increased in occurrence through the SSWD period. Post-SSWD shows recovery in the intertidal zone.

Table 11. Purple sea star (*P.ochraceus)* ANOVA results

	Df	Sum sq	Mean sq	F-value	Pr(>F)
Period	2	2963444	1481722	13.54	0.00108

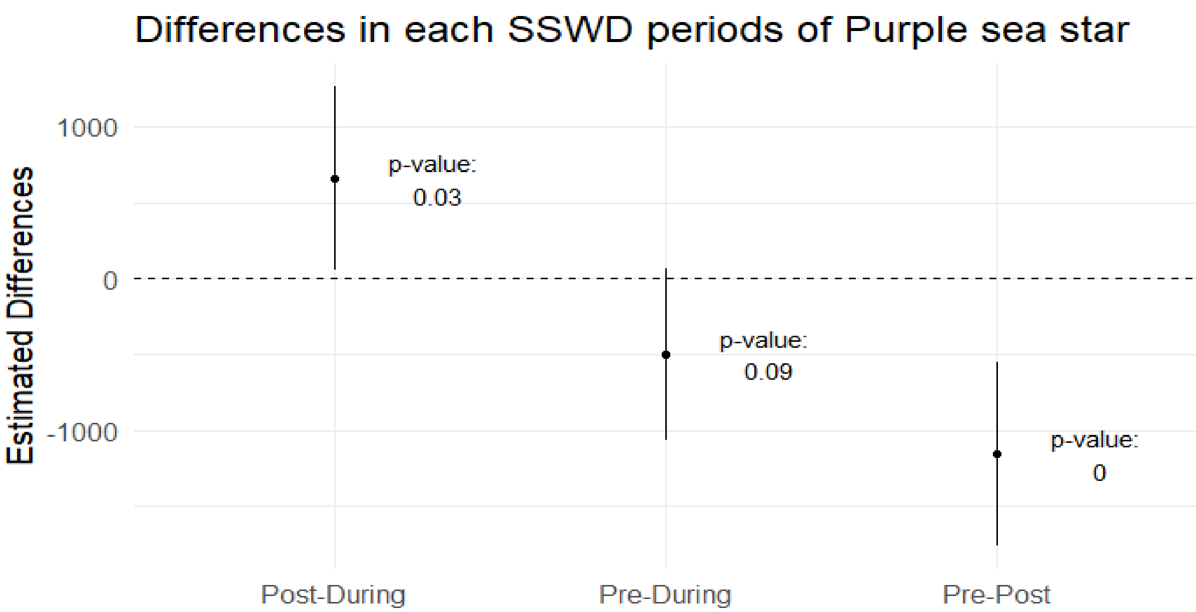


Figure 11.1 Purple sea star (*P.ochraceus)* comparative differences between each SSWD period. Significant differences if p <0.05

Table 11.1 Purple sea star Tukey HSD results. Significant differences in occurrences between each period if p <0.05

Term	contrast	Null value	estimate	conf.low	conf.high	adj-p.value
Period	Post-During	0	656.65	57.40	1255.90	0.032
Period	Pre-During	0	-498.00	-1062.97	66.96	0.085
Period	Pre-Post	0	-1154.65	-1753.89	-555.40	0.00078

Northern striped dogwinkle (*N.ostrina)*:

I found evidence that rejects the null hypothesis: there were occurrence differences for the Northern striped dogwinkle in the SSWD period ($p < 0.05$, Table 12). The northern striped dogwinkle had increased in occurrence throughout the SSWD period (Figure 12). I ran a post hoc test, and I found that Pre-During and Post-DUring SSWD periods were not significantly different($p = 0.14$). In contrast, Pre-Post SSWD periods were significantly different ($p<0.05$, Figure 12.1, Table 12.1).

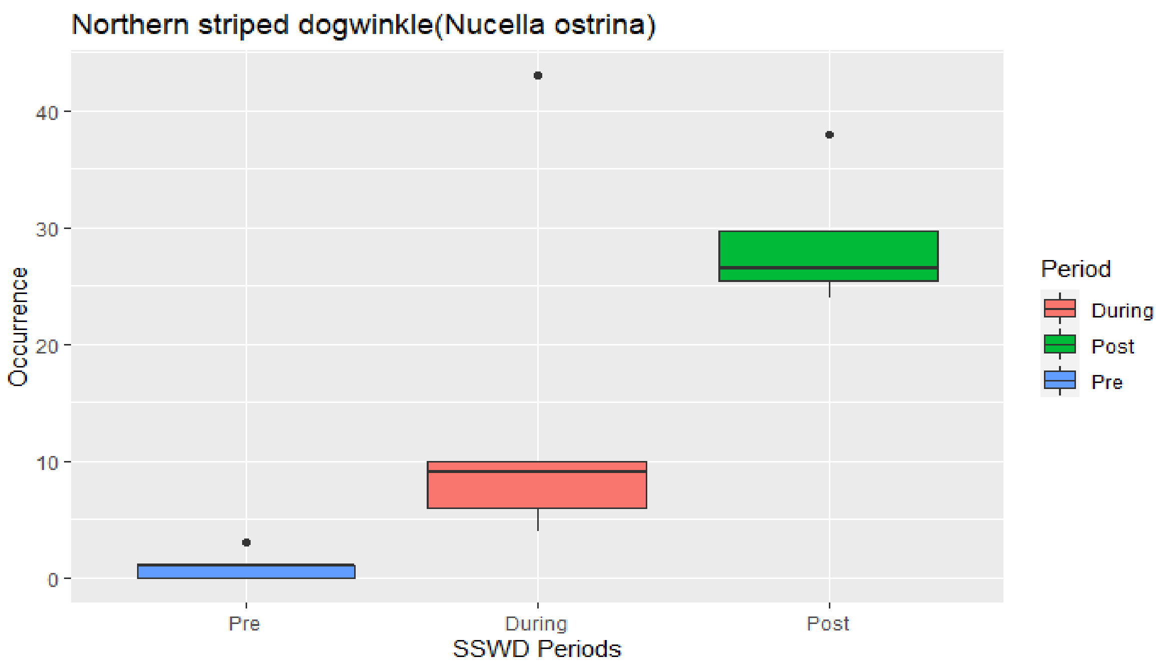


Figure 12. Northern striped dogwinkle (*N.ostrina)* occurrence differences over SSWD periods. Northern striped dogwinkle had incremental changes in occurrences through the SSWD period. More occurrences were more significant than the mean for some years, as shown by the outliers in this boxplot.

Table 12. Northern striped dogwinkle (*N.ostrina)* ANOVA results

	Df	Sum sq	Mean sq	F-value	Pr(>F)
Period	2	1715	857.5	8.06	0.0070

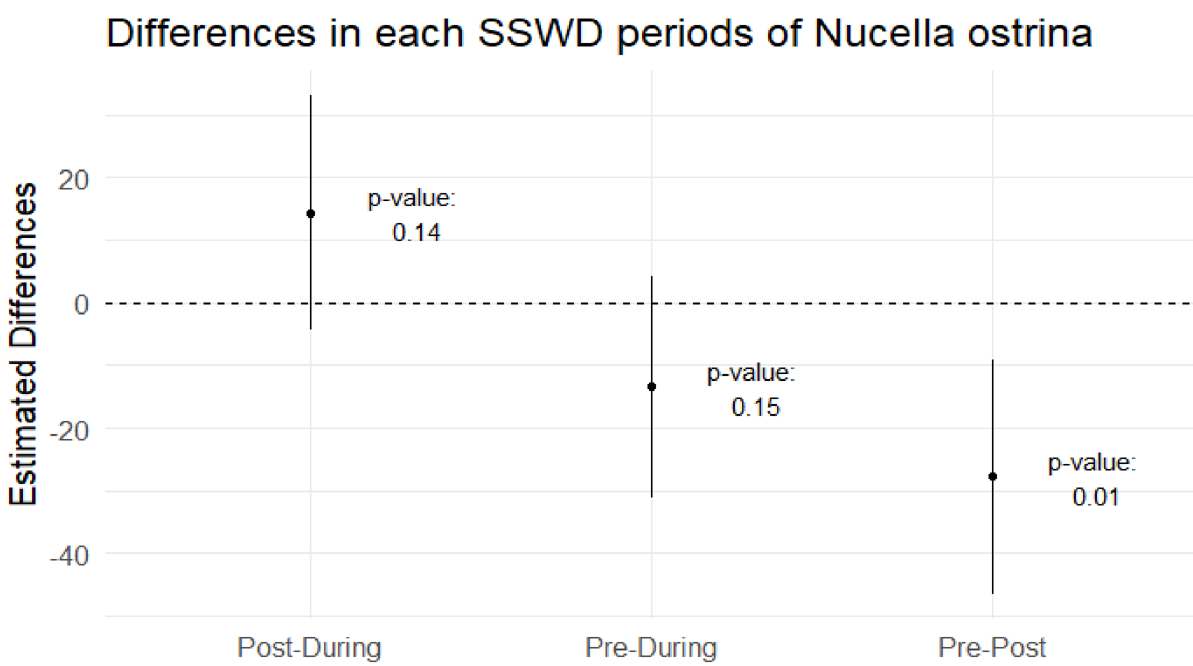


Figure 12.1 Northern striped dogwinkle (*N.ostrina)* comparative differences between each SSWD period. Significant differences if p <0.05. Pre-SSWD and Post-SSWD were significantly different in occurrences mean when paired.

Table 12.1 Northern striped dogwinkle (*N.ostrina)* Tukey HSD results. Significant differences in occurrences between each period if p <0.05

Term	contrast	Null value	estimate	conf. low	conf. high	adj-p.value
Period	Post-During	0	14.35	-4.33	33.03	0.14
Period	Pre-During	0	-13.40	-31.02	4.22	0.14
Period	Pre-Post	0	-27.75	-46.43	-9.06	0.0053

California Mussel (*M. californianus)*:

I found evidence that rejects the null hypothesis: there were occurrence differences for the California mussel in the SSWD period ($p < 0.05$, Table 13). The California mussel saw significant increases in occurrences through the SSWD periods (Figure 13). After my post hoc test, the Pre-Post and Post-During SSWD periods were significantly different($p < 0.05$). In contrast, the Post-During SSWD period was not significantly different ($p=0.21$, Figure 13.1, Table 13.1).

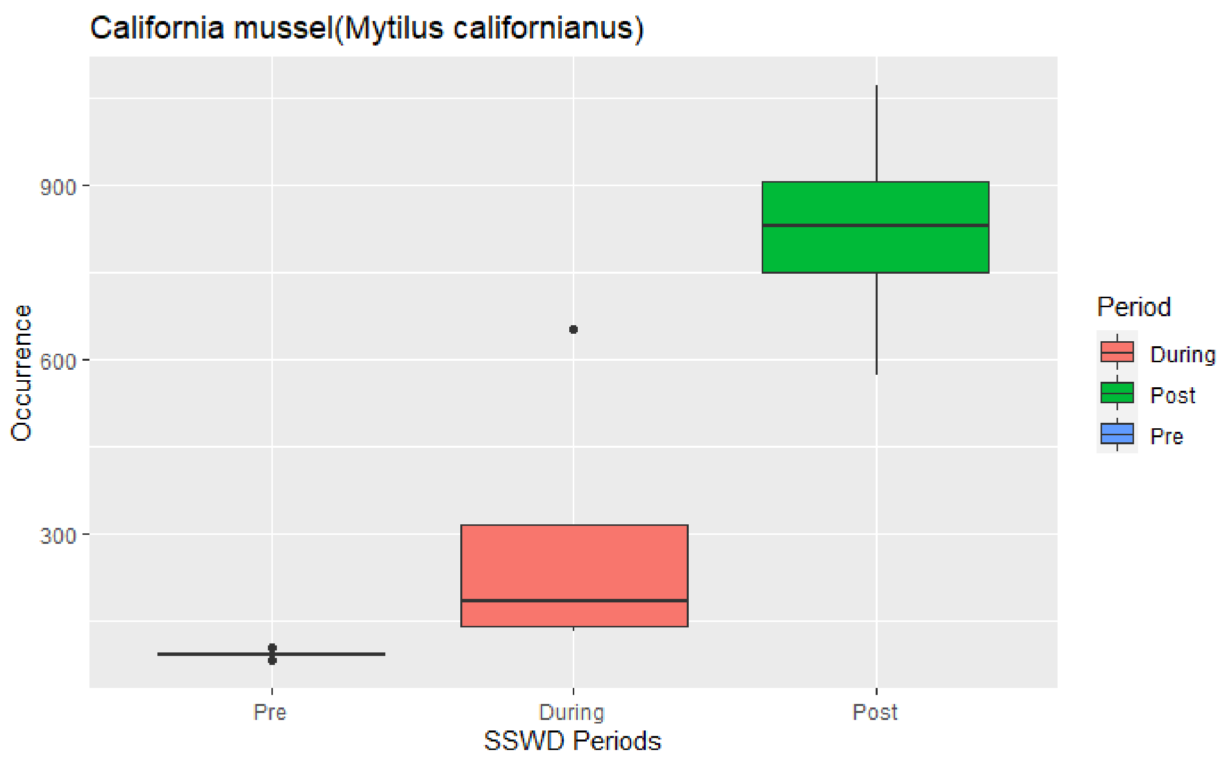


Figure 13. California mussel (*M.californianus)* occurrence differences over SSWD periods. The California mussel had a significant increase in occurrence through the SSWD period.

Table 13. California mussel (*M.californianus)* ANOVA result

	Df	Sum sq	Mean sq	F-value	Pr(>F)
Period	2	1247632.30	623816.20	21.76	0.00015

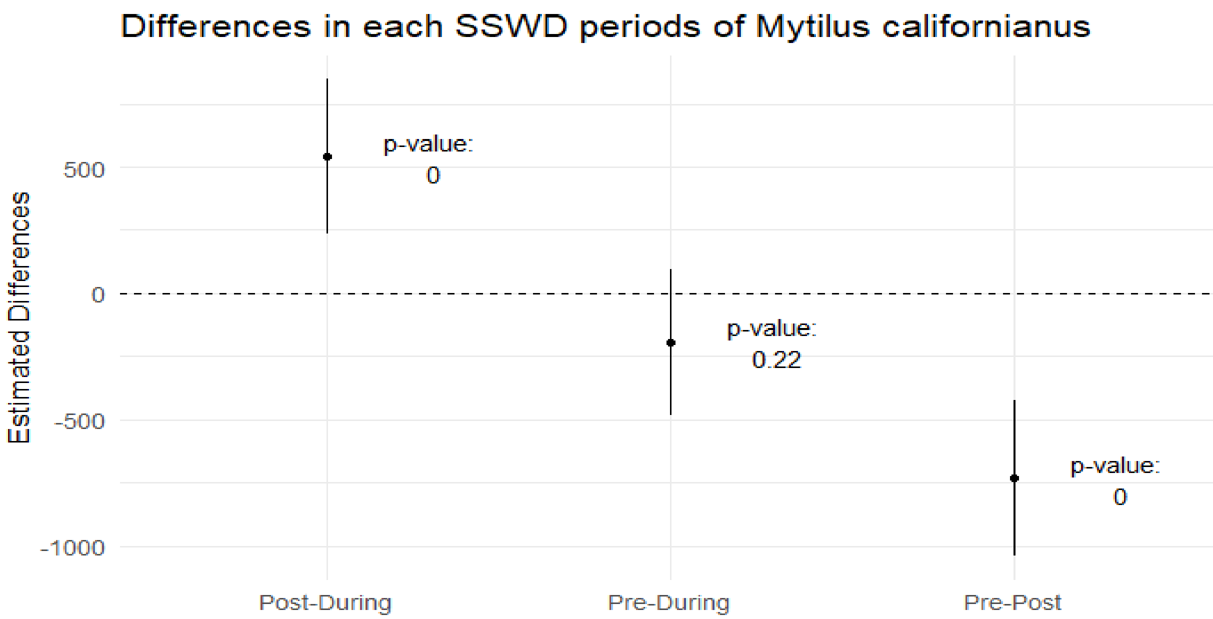


Figure 13.1 California mussel (*M.californianus)* comparative differences between each SSWD period. Significant differences in occurrences if p <0.05. Pre-SSWD and During-SSWD were shown not to have any significant occurrence differences.

Table 13.1 California mussel (*M.californianus)* Tukey HSD results. Significant differences in occurrences between each period if p <0.05

Term	contrast	Null value	estimate	conf.low	conf.high	adj-p.value
Period	Post-During	0	540.70	233.92	847.47	0.0016
Period	Pre-During	0	-191.0	-480.23	98.23	0.21
Period	Pre-Post	0	-731.70	-1038.48	-424.92	0.00013

Sunflower sea star *(P.helianthoides):*

I found evidence that fails to reject the null hypothesis: there are no occurrence differences for the Sunflower sea star in the SSWD period (p =0.22, Table 14). The box plot shows differences, but the ANOVA says otherwise (Figure 14). Due to the high p-value, no post hoc test was needed to measure the differences between the SSWD periods.

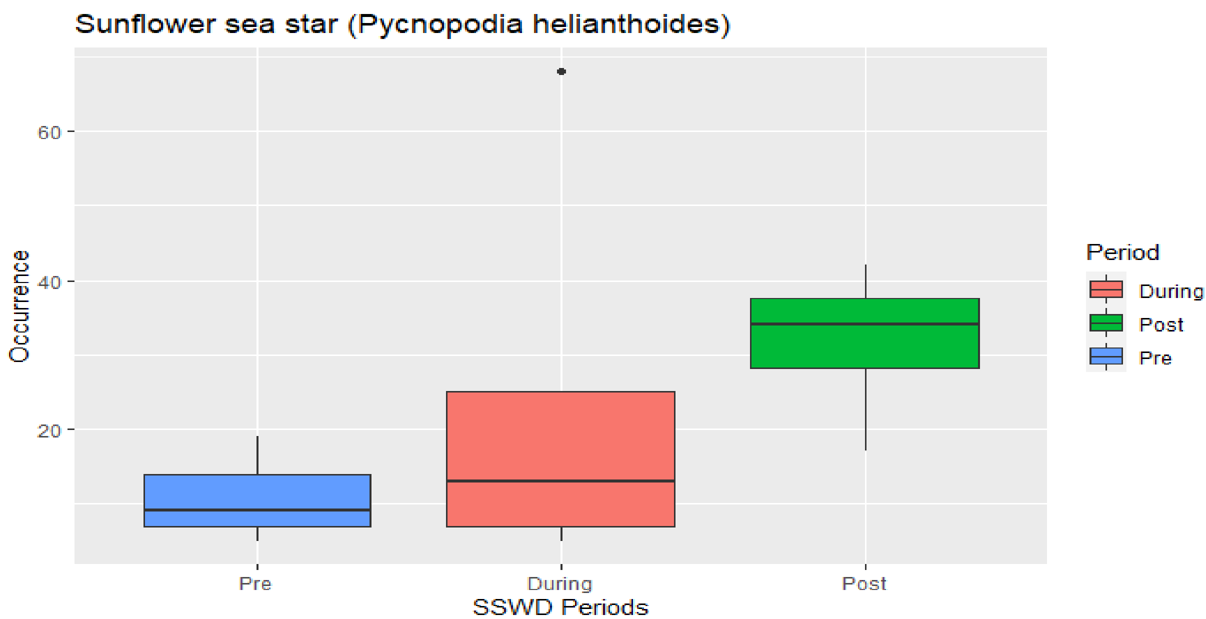


Figure 14. Sunflower sea star (*P.helianthoides)* occurrence differences over SSWD periods. The sunflower sea star occurrence in this graph appears to have increased occurrence through the SSW period.

Table 14. Sunflower sea star (*P.helianthoides)* ANOVA results

	Df	Sum sq	Mean sq	F-value	Pr(>F)
Period	2	1014	507.20	1.76	0.22

DISCUSSION

Sea Star wasting Disease has decimated a critical keystone species in rocky intertidal zones across the Pacific Northwest. The purple sea star (*Pisaster ochraceus)* was a control for my secondary data study to compare interspecies competition of the Northern striped dogwinkle (*N.ostrina)*, the predator-prey relationship of the California mussel (*M.Californianus)*, and intraspecies competition of the sunflower sea star (*Pycnopodia helianthoides)*. My results showed a connection between the purple sea star and my species of interest, the northern striped dogwinkle and California mussel, for pre-SSSWD and post SSWD periods. In my ANOVA of the purple sea star, northern striped dogwinkle, California mussel, and sunflower sea star within each period of SSWD, I found that not all species were affected equally by the SSWD period.

Interspecies competition:

After evaluating my data with a chi-square test of independence, I rejected the null hypothesis that there was no relationship between the purple sea star and northern striped dogwinkle during the SSWD periods. The two species may have some relationship during the SSWD periods. These findings suggest that the occurrence of each species during the pre and post SSWD periods had an impact on their presence in the intertidal zone. Although my test yielded statistical significance, it does not give more detail on how and why each species influences the other. Species ecology has many variables and covariables that affect each interaction, and only testing species and occurrence does not explain how the ecological cascade is involved. For example, Miner et al.'s study on SSWD and intertidal sea star recovery references many variables such as population density and geographical patterns that were not correlated with the SSWD transmittance (Miner et al. 2018). This lack of association between impact and density (and, therefore, a potential tool for predicting impact) contrasts with the patterns detected in other well-documented disease events. The degree of impact was directly correlated with population density (Miner et al., 2018). In other words, their studies found inconsistency in population density and SSWD transmittance in pre-SSWD and post-SSWD.

My test also shows that during both SSWD periods, there was a relationship between purple sea stars and northern striped dogwinkle. My response variable, which was occurrence (present or absence), was not a favorable choice to make inferences about ecological cascades. For instance, as I saw in my study, *N.ostrina* is considerably smaller than *P.ochraceus,* affecting its ability to outpace the California mussel population.

Therefore, looking at occurrence data as a response variable might not effectively represent the actual population dynamics of mussels, which are small and plentiful, and sea stars, which are rarer. The predatory whelk *Nucella spp.* consumes mussels, but its population-level predation pressure has non-significant impacts on mussel bed lower boundaries (Hart 2010; Cerny-Chipman et al., 2017). If areas of low or high abundance of predators or prey could cause regional-scale variation in total reproductive output, this could then feedback into recruitment patterns (Hughes et al. 2000). In figure 1, there is a significant contrast between the purple sea star and the Northern striped dogwinkle, implying that the Northern striped dogwinkle does not have a considerable presence in the intertidal zone to replace the purple sea star as a keystone species.

My approach was simple when I determined the interspecies interactions. In a natural ecosystem, it is more complex; many species interact and compete with each other for prey. Local communities are commonly composed of predators that share prey, such as whelks and sea stars in California- Oregon; however, these competing predators may disperse in different ways that occurrence does not necessarily capture. Such interactions theoretically affect only the demographically closed predator and are equivalent to including any other source of mortality caused by something with dynamics unlinked from the prey (Navarrete et al. 2000). In the future, I may look for a quantitative food web that interacts with the purple sea star and run a more robust analysis.

Predator-Prey relationship:

My predator-prey analysis suggests a relationship between *P.ochraceus* and *M.californianus* during SSWD. The ochre sea star, Pisaster ochraceus, acts as a keystone predator of rocky intertidal ecosystems (Paine 1966). It preys preferentially upon the competitively dominant California mussel Mytilus californianus (Feder, 1959). The difference between the predator-prey analysis and interspecies in this study is the richness of the data; the predator-prey dataset had a large sample size and a good predictor variable. Although I had enough data to find some relationship with the species during the SSWD, it was not enough to conclude any evidence of trophic cascade. For instance, the increased abundance of *M. californianus* does not show if the species was doing better without the sea star predator. Sites with weak initial predation experience little change in mussel survival when predators are removed (Menge et al., 1994). In addition to abundance data, other predators prey on *M. californianus,* which can influence and control their presence in addition to sea stars. For example, Otter predation on mussels in Monterey Bay increased in the absence of sea stars, though it is unclear whether they could serve as a control on the mussel population (Smith et al., 2021). Although I found a relationship between purple sea stars and California mussel occurrence in the SSWD periods, there was insufficient data that was evidence of trophic level effects amongst predator-prey. It does provide an entry point to delve into more complex datasets and find any significance to SSWD and the intertidal ecosystems.

Intraspecies competition:

My intraspecies analysis suggests differences in the mean of the sunflower sea star and purple sea star. Beginning in June 2013, sea stars from about 20 species along the west coast of North America faced the devastating sea star wasting disease (SSWD) and died by millions from Anchorage, Alaska, to Baja California, Mexico (Miner. et al. 2018). The data analysis supports my hypothesis that I would see differences in the seastar population before and after this outbreak. The purple sea star *(P.ochraceus)* and sunflower sea star (*P.helianthoides)* were the few sea stars with a steady decline even before the SSWD outbreak, making them species of critical concern (UCSC MARINe). *P. helianthoides* was one of the first species affected by SSWD in June 2013 and soon was absent from intertidal and shallow subtidal areas in numerous places (Pacific Rocky Intertidal Monitoring, 2015; L. G. Hemery, pers. obs.). Although both sea star species were heavily affected by SSWD, the purple sea star presence has steadily recovered post-SSWD. The sunflower sea star shows little to no recovery, which my analysis also demonstrated (Figure 3). A hot El Nino weathering pattern may have influenced the severity of the SSWD outbreak in 2014-2016 when sea temperature rose three degrees celsius. The temperature was one of the most critical parameters describing ecological niches and distributions of sea stars, and temperature changes have been related to previous SSWDs (Hemery et al. 2016). If the temperature is the main contributor to the severity of the SSWD outbreak, then my results seem to support this claim. In my analysis, the sunflower sea star showed little to no recovery in occurrence through the SSWD periods (Figure 14).

My approach to answering my subquestion revealed some flaws in my experimental design: there are differences in the occurrence between the sea star species, but there are no other variables to measure how different each species varied. My ANOVA results contradict my hypothesis that the species of interest were no differences in means of occurrence in the SSWD periods. For instance, my sunflower sea star ANOVA showed when comparing all SSWD periods, the differences in means were not statistically significant. Previous studies showed increases in relative count yielded less than 0.67:1 changes in relative biomass), which suggests that abundances alone are a poor metric of ecological interaction strengths of sea stars of different sizes (Moritsch and Raimondi 2018). Moritsch and Raimondi's approach contrasts my approach by using biomass data of the sea stars to measure recovery from pre-and-post SSWD. My dataset consists of occurrences that can only explain whether the species was present or absent. The absent data value for my dataset needs to be viewed cautiously. Most of my data come from citizen science surveys that may not have formal training to distinguish absence. Nevertheless, my data analysis shows the relationship of each SSWD period and how it affected *P.ochraceus and P.helianthoides*'s presence.

Limitations:

I was limited to only occurrence data, which shows where a species is present or absent. Presence data is manageable as it is a binary variable of whether the species was there. Absence data is more complex as many factors contribute to species' absence, such as abnormal weather, predator threat, food source, or invasive species. In contrast to my approach, Moritsch and Raimondi provide a different approach to analyzing SSWD trophic effects. Recruitment, indicated by sea stars arriving that are too young to have experienced the outbreak, is a marker of post disease reproduction (Moristch and Raimondi 2018). Seastar biomass serves as a proxy of predation pressure on the mussel bed due to its correlation with prey size and mass of soft tissue consumption (Feder, 1956; Robles et al., 2009). Both variables could have added more depth in addressing trophic effects than my approach. Recruitment is an excellent explanatory variable as it can measure the sea star species' overall population health after the epidemic rather than if they were present or not. Biomass data also indicates whether the sea stars were active in finding prey during the SSWD epidemic. If their biomass is lower than their standard weight, their presence in the intertidal zone also decreases, increasing herbivore abundance. Although my data analysis found some results, more complex and specific models can be used with this data to find the probability of a species's occurrence. If I were to address this analysis again, I would collect more explanatory such as abundance, reproduction count, biomass, and species length, and run an ANCOVA test for each variable and their relationship to the SSWD period in conjunction with climate data.

Broader Implications:

I found a relationship between the purple sea star and the species of interest through my species-to-species analysis. The occurrence of the Purple sea star had some relation to the occurrence of the Northern striped dogwinkle, California mussel, and Sunflower sea star, which can be shown throughout the SSWD periods. There were some significant findings with the purple sea star, northern striped dog winkle, and California mussel between each SSWD period; the pairings of each had significance ($p<0.05$), and others did not. The most surprising comes from the sunflower sea star, which was found to have no differences in occurrences during all three SSWD periods.

Although certain aspects of my analysis were flawed, I could still detect critical patterns in occurrence before, during, and after SSWD in purple sea stars, mussels, whelks, and sunflower sea stars. Notably, sunflower sea star occurrences never recovered after SSWD. These results contribute to the growing number of studies that have assessed the ecosystem and trophic effects of SSWD and climate change.

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APPENDIX A: GBIF Data Citation

California mussel data (2008-2012)
Citation: GBIF.org (22 January 2022) GBIF Occurrence Download
https://doi.org/10.15468/dl.7ymt8z

California mussel data (2013 - 2017)
Citation: GBIF.org (09 April 2022) GBIF Occurrence Download
https://doi.org/10.15468/dl.maa5n7

California mussel data (2017-2021)
Citation: GBIF.org (25 March 2022) GBIF Occurrence Download
https://doi.org/10.15468/dl.ec36zh

Northern striped dogwinkle data (2008 - 2012)
Citation: GBIF.org (22 January 2022) GBIF Occurrence Download
https://doi.org/10.15468/dl.gtcwrs

Northern striped dogwinkle (2013 -2017)
Citation: GBIF.org (09 April 2022) GBIF Occurrence Download
https://doi.org/10.15468/dl.67hb7g

Northern striped dogwinkle (2017-2021)
Citation: GBIF.org (22 January 2022) GBIF Occurrence Download
https://doi.org/10.15468/dl.z55a8q

Purple sea star data (2008-2012)

Citation: GBIF.org (20 January 2022) GBIF Occurrence Download https://doi.org/10.15468/dl.kerp2b

Purple sea star data (2013-2017)

Citation:GBIF.org (09 April 2022) GBIF Occurrence Download https://doi.org/10.15468/dl.8un3hw

Purple sea star data (2017-2021)

Citation: GBIF.org (20 January 2022) GBIF Occurrence Download https://doi.org/10.15468/dl.rd8cja

Sunflower sea star data (2008-2012)

Citation: GBIF.org (09 April 2022) GBIF Occurrence Download https://doi.org/10.15468/dl.nuyf6k

Sunflower sea star data (2013-2017)

Citation: GBIF.org (09 April 2022) GBIF Occurrence Download https://doi.org/10.15468/dl.dawtqu

Sunflower sea star data (2017-2021)

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APPENDIX B: R AND PACKAGES

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