Counting the stars: Sea star densities 8 years after the onset of sea star wasting disease in a Monterey Bay kelp forest

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Introduction

Etiology, spread, and biological implications of terrestrial diseases, particularly those with economic importance, have historically been well-studied (Dorn and Mertig 2005, Gamliel-Atinsky et al. 2009, Kedmi et al. 2010). Logistical ease and relatively simple life histories render these ideal study systems. Anthropocentrism extends to marine ecosystems as well, deepening the literature bias towards commercially relevant species (Sweet and Bateman 2015). These biases are exacerbated in the marine environment by challenges in detecting diseases in wild populations, such as being consumed or swept away before being identified as unhealthy (Harvell et al. 1999, Ward and Lafferty 2004). Coupled with changing ocean conditions, there are numerous knowledge gaps with respect to diseases impacting subtidal populations.

As the ocean increases in both acidity and temperature, understanding their respective roles in disease ecology becomes critical (Schiel et al. 2004, Hartin et al. 2016, Muller et al. 2017). Warming sea temperatures and marine diseases have often correlated with one another (Williams et al. 2014, Lamb et al. 2018). Historically, heat has been discussed as a physiological stressor leading to immunocompromised individuals, but may have more direct associations with certain outbreak events including sea star wasting disease (Staehli et al. 2009, Aquino et al. 2021). Temperature can also impact the spread of disease by concentrating populations due to habitat loss (e.g., warming oceans cause *Macrocystis* die-off) (Holmes 1996, Mabin et al. 2019).

Human activity is another contributing factor to disease ecology. Human-ecosystem interactions such as fishing, aquaculture, runoff, ecotourism, and more are on the rise and are projected to increase in the future (OECD and Food and Agriculture Organization of the United Nations 2020, Monz et al. 2021). This intensified relationship makes the distinction between natural and anthropogenically-induced events increasingly important to mitigate negative impacts we have on the environment (Clements and Chopin 2017). Humans impact community structure (Myers and Worm 2003) and are a known vector of terrestrial pathogens, introducing them to marine organisms (Bengtson et al. 1991).

In the last three decades, reports of marine disease outbreaks resulting in mass mortalities have increased (Harvell et al. 1999, Ward and Lafferty 2004). This trend has been verified for corals, molluscs, marine mammals, turtles, and echinoderms (Harvell et al. 2004). Abalone withering syndrome (Crosson et al. 2014), coralline fungal disease (CFD) (Williams et al. 2018), mycobacteria/haplosporidia in *Pinna nobilis* (Šarić et al. 2020), and an unknown pathogen in tropical urchin *Diadema antillarum* (Lessios et al. 1984) are among the more well-known examples.

Moving southward from Oregon in 2013, sea star wasting disease (hereafter SSWD) appeared in Monterey Bay during late summer (Menge et al. 2016). SSWD refers to a set of morphological symptoms affecting the class Asteroidea, including highly visible necrotic lesions, deflation, ray loss, disintegration, and death (Hewson et al. 2014). It is the largest marine epizootic of a noncommercial species to date (Eisenlord et al. 2016, Montecino-Latorre et al. 2016). Studies have mainly focused on the intertidal *Pisaster ochraceus* (ochre star) because of its accessibility and easily observed ecosystem functions (Eisenlord et al. 2016, Moritsch and Raimondi 2018, Miner et al. 2018). Long term monitoring of this species revealed severe SSWD-associated population declines (Miner et al. 2018) and subsequent loss of intertidal habitat resulting from reduced predation on *Mytilus californianus* (Moritsch and Raimondi 2018). Impacts of SSWD on subtidal sea star species, by contrast, are lesser known and may provide insight into broader ecological implications (Montecino-Latorre et al. 2016).

Initially, SSWD was thought to be caused by a densovirus, specifically sea star-associated densovirus (SSaDV) (Hewson et al. 2014). However, SSaDV has only been explicitly linked with SSWD signs in *P. helianthoides* (Lloyd and Pespeni 2018). *Asterias forbesi*-associated densovirus (AfaDV) is also present in some species, but was found to be associated with natural microbiota rather than SSWD, emphasizing the complexity of invertebrate-microbiome interactions (Jackson et al. 2020). Recent evidence suggests SSWD is more complex than a single virus and is instead influenced by microbial activities at the organism-water interface (Aquino et al. 2021). These activities are facilitated by a higher organic matter supply that may be induced by decreased oxygen in the water column and exacerbated by high temperature (Aquino et al. 2021).

Ecosystem functions of marine invertebrates, particularly sea stars, may be ‘hidden’ due to indirect relationships with monitored or harvested species (Galasso et al. 2015). In the most extreme cases, phase shifts can occur in the absence (or absence) of certain organisms. For instance, keystone predator *Pycnopodia helianthoides* (sunflower star) is known to consume *Strongylocentrotus purpuratus* (purple urchins), and kelp forests have been overgrazed in their absence (Schultz et al. 2016, Montecino-Latorre et al. 2016). In the tropics, *Acanthaster planci* (crown-of-thorns starfish) is known to consume coral, removing biogenic habitat for other reef-dwelling organisms (Kenchington and Kelleher 1992). Most studies tend to focus on the

importance of sea star feeding behavior, but competition with other benthic invertebrates for available substrate can also contribute to shaping ecosystems (Jennings and Hunt 2011).

We aim to investigate the long term effects of SSWD on sea stars in a historically monitored Monterey kelp forest and determine if these populations have recovered from SSWD since its 2013 onset. We hypothesize that there will be an increase in sea star density between the onset of SSWD in 2013 and 2021, and that there will be a difference in density between species. With respect to 2021 data, we predict there will be a difference in density as a function of depth and that species will have nonrandom habitat associations (e.g., rock or sand). These latter hypotheses involve factors that may help to explain observed interspecific density differences.

We conducted abundance surveys on SCUBA at Hopkins Marine Station to address whether sea stars have recovered from the 2013 SSWD event. We collected abundance data on 7 sea star species and their associated substrates. This particular site provides historical context in the form of sea star data during the onset of SSWD. Our data were conducted in close proximity to 2013 surveys to minimize confounding factors on sea star populations (e.g., fishing and other exploitative activities taking place outside federal and state reserve boundaries). Unlike many past studies, our focus is on a variety of subtidal sea star species, which allows for a more complete understanding of the long term impacts of SSWD. In addition to furthering our comprehension of SSWD, we intend to help fill a knowledge gap in habitat associations, as other studies tend to broadly focus on benthic invertebrates rather than sea stars specifically (Hemery and Henkel 2015) or ecosystems outside temperate California kelp forests (Reyes Bonilla et al. 2005).

Methods

General approach

We conducted an observational field study consisting of a series of subtidal surveys to determine whether sea star populations have recovered since the 2013 onset of SSWD. To test our hypotheses that there is an increase in density of sea stars between 2013 and 2021, we laid a series of 18 transects and collected abundance data on 7 sea star species. We compared species counts to test our hypothesis that there is a difference in density between species. To test our prediction that there is a difference in density as a function of depth, our transects ran both on and offshore, perpendicular to the underwater cable at Hopkins Marine Station. Lastly, we tested our hypothesis that species have nonrandom substrate associations, by noting if each individual was found on rock or sand.

System description

This study took place at Hopkins Marine Station in Pacific Grove, California (36.6202° N, 121.9041° W) during November of 2021. The study site is located within the Lovers Point - Julia Platt Marine Reserve and the Monterey Bay National Marine Sanctuary (MBNMS). The protections granted to the area prevent exploitative activities such as fishing, collecting, oil drilling, and construction as well as limit entry to researchers. These measures maintain the kelp forest system as species-rich and abundant. The benthic community in the site's *Macrocystis pyrifera* kelp forest is home to a diverse suite of marine invertebrates. Sea star surveys have been conducted at this location by PISCO and other groups since 1999. Historically, the area has been home to an abundance of marine invertebrates (Sagarin et al. 1999). The area surveyed covers a range of depths. The underwater cable at Hopkins runs parallel to shore, with the shallows on the west side (approximately 6m-9 m) and the deep side to the east, and is (approximately 9m-12 m).

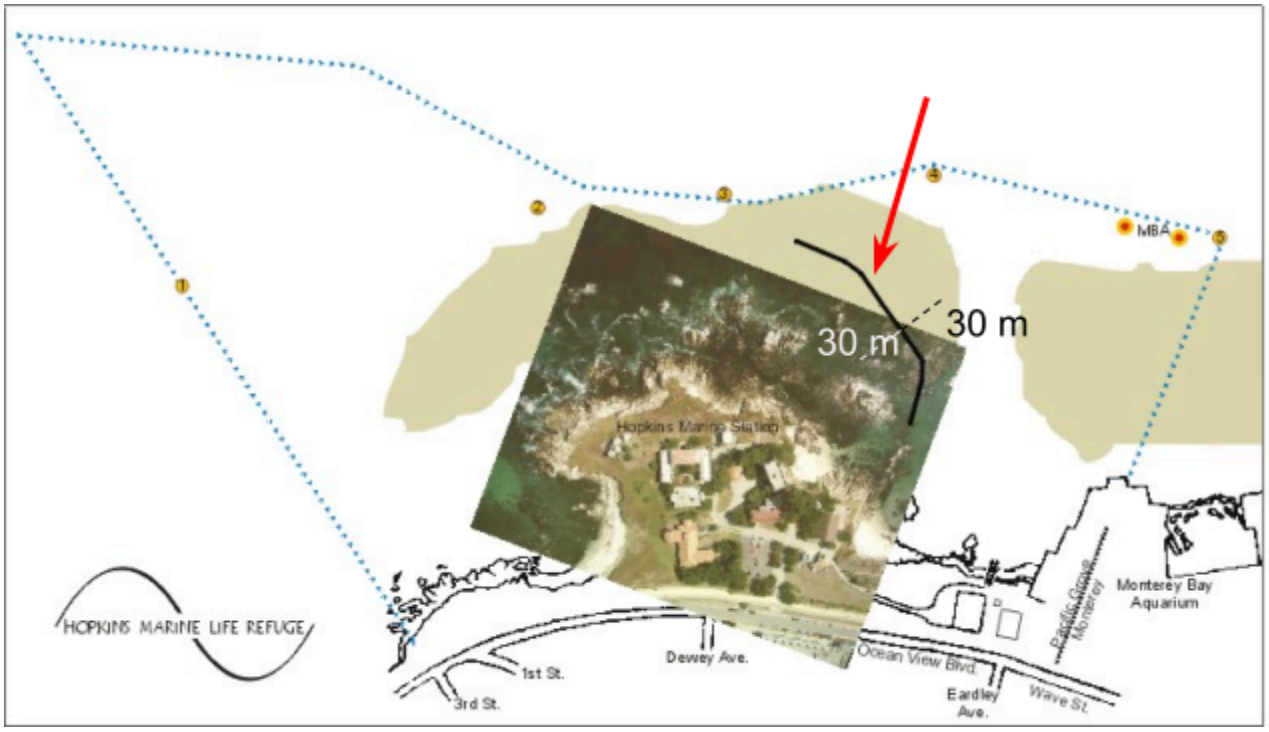

Figure 1. Map of Hopkins Marine Station, including location of underwater cable and transects. Image courtesy of Stanford University.

Hypothesis 1: Increase in Density of Sea Star Species Between 2013 and 2021

To determine whether there was an increase in the density of sea stars between 2013 and 2021, we compared data that we collected in Fall 2021 with data collected by students from the UCSC Kelp Forest Ecology class of 2013.

The goal of the previous study was to find out how sea star population density was affected by the sea star wasting event of Fall 2013.

Hypothesis 2: Differences in Density Between Species

To address the hypothesis that density is different between species, we counted how many individuals of each target species we encountered along the transects. We then calculated the densities of each species identified on each transect in order to find the mean density for each species.

Hypothesis 3: Difference in Density as a Function of Depth

To address the hypothesis that density varied as a function of depth, we calculated the mean density of each species from transects on the shallow side and deep side separately.

Hypothesis 4: Substrate Associations

The kelp forest at Hopkins has a mixture of sand and rock substrate on each side of the cable. To address the hypothesis that species had nonrandom substrate associations, we recorded the substrate type underneath each sea star.

Data collection

Sampling was conducted during midmorning on the 16th, 18th, and 23rd of November, 2021. Thirty meter transects were established along the cable at Hopkins Marine Station both towards the shore (west, 270 degrees) and away from the shore (east, 90 degrees) every 10 meters between meter marks 70 and 150. In total, there were eighteen, 30 meter long transects. Observations were made one meter to the left and one meter to the right of each transect tape so that a 2m x 30m area was covered at each meter mark, in each direction.

We collected abundance data on 7 species including *Patiria miniata* (bat star)*, Dermasterias imbricata* (leather star)*, Pisaster giganteus* (giant sea star)*, Pisaster brevispinis* (short spined sea star)*, Henricia spp.* (blood stars)*, and Pycnopodia helianthoides* (sunflower sea star).

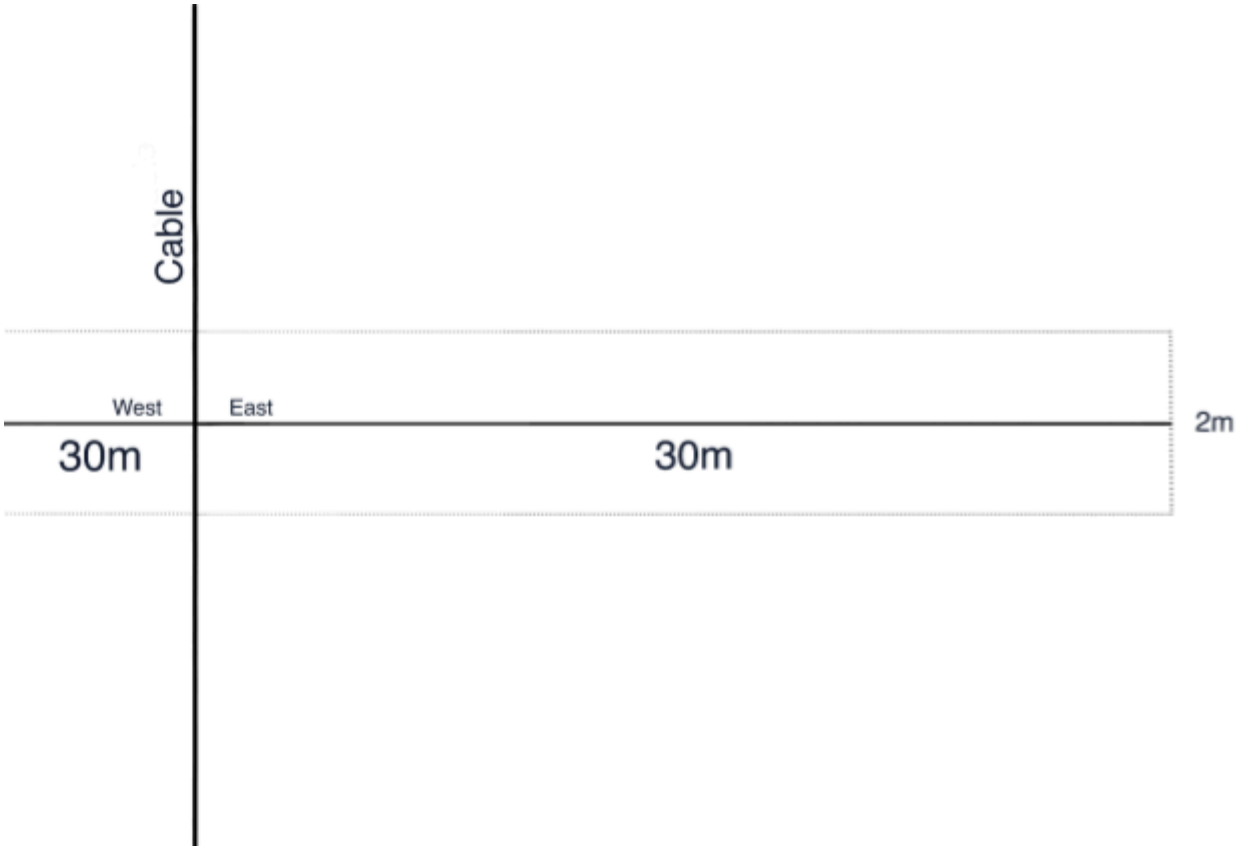

Figure 2. Depiction of sampled area.

Our data collection is not an exact replica of the methods used in the 2013 Kelp Forest Ecology class study. While our sampling protocol was to run transects perpendicular to the shore off of the Hopkins cable, the 2013 observations were made on transects running parallel to the shore at four different locations around Hopkins.

Results

General results

For four of our six species, observed densities were lower than those in November 2013 (Figure 3). The only species observed to have a higher density in 2021 than in 2013 were *D. imbricata* and *P. brevispinus.* All of the species were observed to be more abundant on rock substrate (Figure 4), with significant differences found in *P. miniata* and *P. giganteus* (Table 1). Our data analysis suggests that depth is not an important factor in determining sea star density (Table 1). This is likely because the depth difference between the shallow and deep sides of the Hopkins cable is minimal.

Hypothesis 1: Increase in Density of Sea Star Species Between 2013 and 2021

We were unable to find any *P. helianthoides* or *Henricia*. Our observed densities of *P. miniata* and *P. giganteus* were lower than the observed densities in 2013 (Figure 3).

Hypothesis 2: Differences in Density Between Species

The sea star species observed to have the highest density was *P. miniata,* with a density of 0.382 stars/m². The species with the second highest observed density was *D. imbricata,* with 0.0375 stars/m², which is notably a much lower density than *P. miniata. P. giganteus* was found to have a density of 0.0236 stars/m² and *P. brevispinus* was found to have a density of 0.00185 stars/m² (Figure 3).

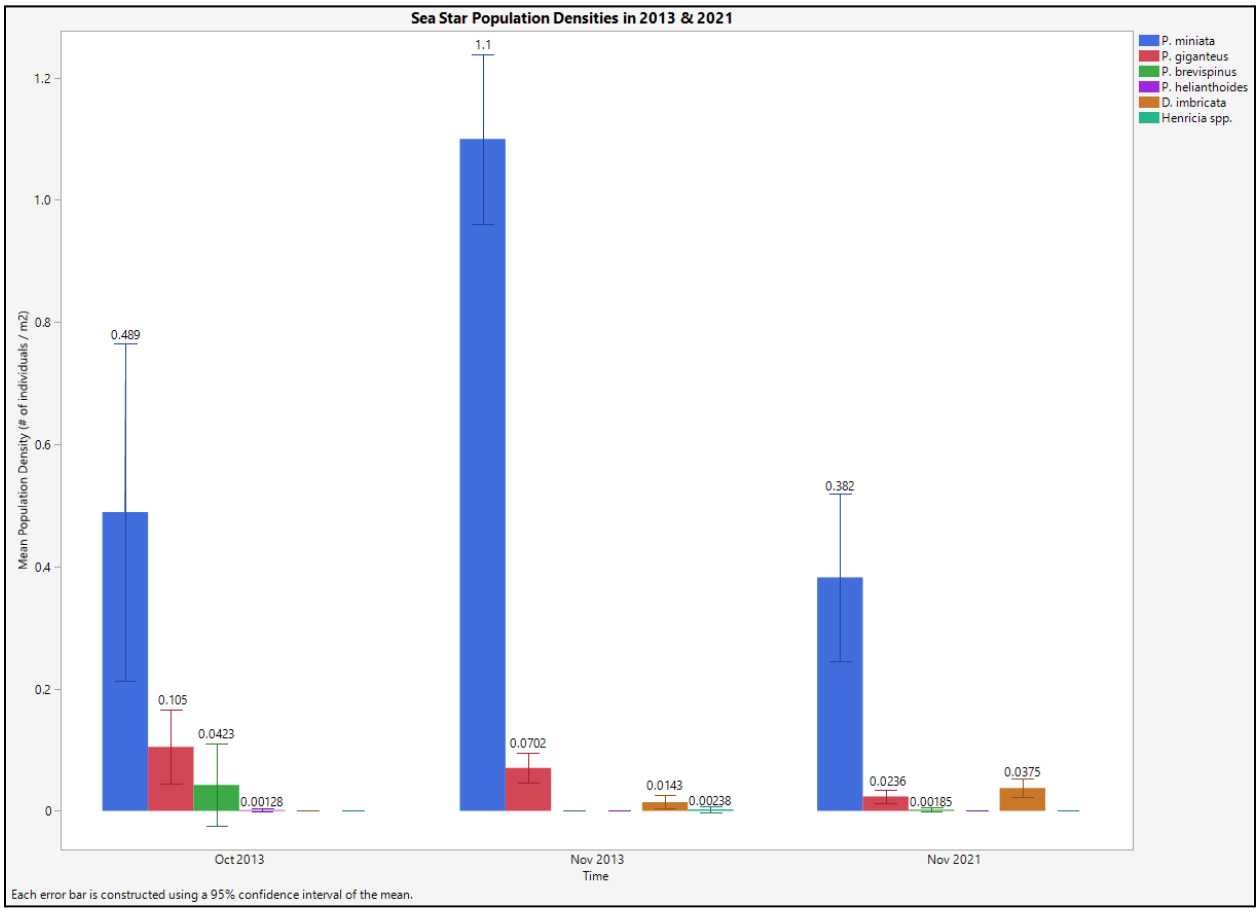

Figure 3. Sea star population densities across all three surveys. Spaces without bars or numbers represent densities of 0 (no specimens found).

Species	Depth	Substrate
P. miniata	0.0860	**0.0055**
D. imbricata	0.4997	0.0928
P. giganteus	0.7976	**0.0003**
P. brevispinus	0.3466	0.3466

Table 1. Two-tailed T-test values for each species in regards to depth and substrate. Values in bold represent statistically significant values ($\alpha = 0.05$)

Hypothesis 3: Difference in Density as a Function of Depth

Our analysis did not indicate a significant difference in population density between the shallow and deep side of the Hopkin's cable for any species of sea star sampled (Table 1).

Hypothesis 4: Substrate Associations

We found that *P. miniata* and *P. giganteus* both showed a significant preference for rock over sand ($p<0.05$). For both *D. imbricata* and *P. brevispinus*, we were unable to identify an association with either type of substrate (Table 1).

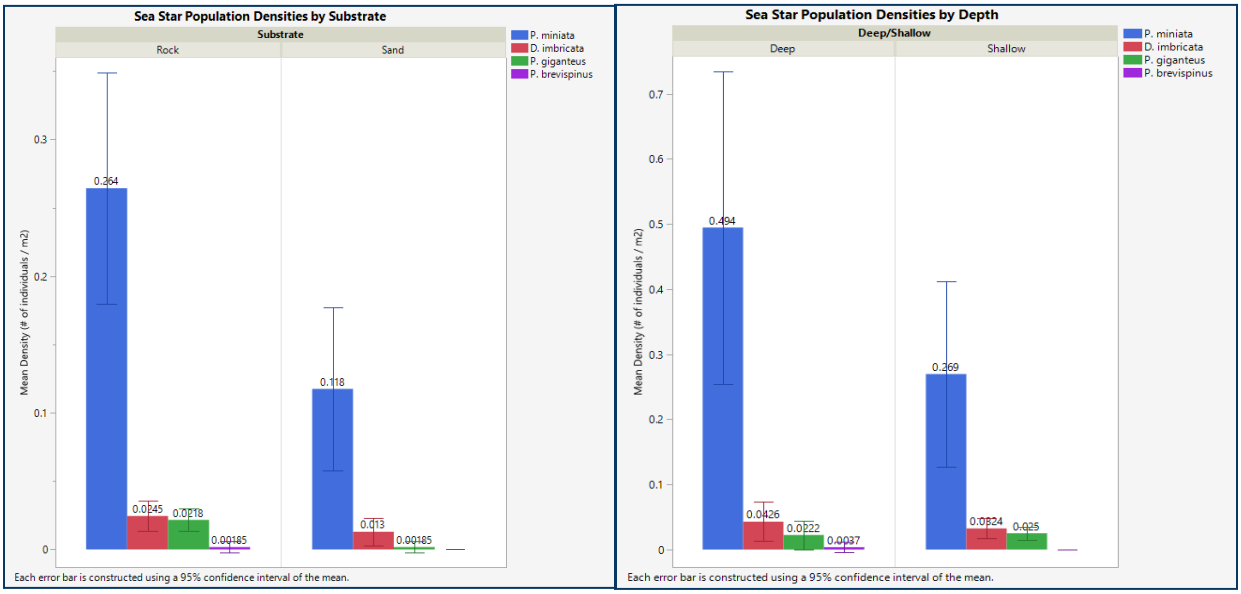

Figure 4. Sea star population densities by substrate (a) and depth (b)

Discussion

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Modifications to study design

If we were to conduct this study again in the future, we would utilize the exact sampling methods described by Wilson and colleagues (2013) to improve replicability and minimize confounding factors related to data collection. By using the same sites as the 2013 study, we would also increase coverage, because multiple sites were sampled, including Maccabee and Hopkins Marine Station, both up-coast and down-coast. Furthermore, we recommend increasing swath width in the hopes of counting more of the species we found in low abundance (e.g., *P. brevispinis*) to achieve statistical significance. Additionally, recording the approximate relief between each individual would improve our understanding of subtidal sea star habitat associations.

Future directions

Beyond a singular site at Hopkins Marine Station, sampling at other sites with historical datasets pertaining to sea star abundance/density can improve our understanding of long-term population impacts of SSWD. Surveys of other elements at each site (e.g., *Macrocystis* density, species diversity) may provide insight as to the long-term ecological impacts of these declines in sea star population density. Selecting a wide variety of sites both inside and outside of reserve boundaries allows for the assessment of human-ecosystem interactions and their impacts on SSWD-affected populations. Utilizing historical data (e.g., PISCO surveys) from before the onset of SSWD can enable us to analyze pre-disease population dynamics, while continued monitoring will provide data for comparison.

Sampling sea stars for the presence of SSWD can test the hypothesis that there is vertical disease transmission (i.e., from parents to offspring) (Jackson et al. 2020).

A recent study implicated the texture of individual stars' skin as a factor contributing to the severity of SSWD (Aquino et al. 2021). With this new information, we can potentially reevaluate impacts on individual sea star species in the context of surface rugosity rather than color, as has been explored in some previous studies (Menge et al. 2016, Work et al. 2021).

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