# Direct and Indirect Effects of *Pisaster ochraceus* on tide pool communities

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**Abstract** *Pisaster ochraceus* is a major predator in intertidal ecosystems in the western United States and may play a pivotal role in tide pool community distribution and diversity. The purpose of this study was to determine the effects of *Pisaster* presence on a dominant gastropod genus (*Tegula*), as well was the indirect effects on the tide pool community in Bodega Bay, CA. Short-term experiments were conducted that involved adding *Pisaster* to previously *Pisaster*-free pools and monitoring *Tegula* flee response. Long-term experiments were conducted by bagging *Pisaster*, attaching the filled bags within pools, and monitoring how presence alone affected the entire pool community (mobile species and percent cover of sessile species). The key factor in both short and long-term experiments was solely *Pisaster* presence, in both experiments *Pisaster* were unable to prey. Short-term experiments clearly ($p< 0.07$) showed an immediate *Tegula* flee response with the addition of *Pisaster* into pools. Long-term experiments showed a decline in *Tegula* abundance and in mobile species richness and diversity in treatment pools. No change was seen in sessile species richness or diversity over the course of the experiment. This study suggests *Pisaster* has a clear direct effect on *Tegula* and other mobile species while indirect effects on sessile species may not occur.

**Introduction**

Species in ecological communities interact directly and indirectly with other species throughout the food web. Direct effects are the result of competition for resources, both food and space, and predation. Indirect effects are often the effect of a predator on the prey's food resource and the remaining community (Trussell et al. 2004). Differences in direct and indirect effects within an area can be attributed to variation in predator foraging efficiency or colonization and survival ability of the predator within a habitat (Wootton 1993). Studies in marine habitats have shown that predators can indirectly increase species richness and diversity by consuming some prey (Palumbi and Freed 1988). This means that mechanisms that regulate predation density can have a dramatic effect on different species within natural communities (Navarrete and Menge 1996).

*Pisaster ochraceus* is an important predator in many rocky intertidal communities. *Pisaster*, a carnivorous starfish, influences the coexistence of a host of invertebrate and algal species in the space-limited intertidal zone of the West Coast of North America (Paine, 1966, 1969, 1974). *Pisaster* is an intense consumer feeding commonly on mussels (*Mylitus spp.*), barnacles (*Balanus glandula*), snails, limpets, and chitons. Numerous studies have quantified the effects of *Pisaster* presence on mussel species. These studies have shown that the presence of *Pisaster* in intertidal communities decreases the density of mussels and increases overall diversity within the intertidal (Paine 1966, 1969, 1974). Additional studies have shown the effect of *Pisaster* presence on whelk, after four months of starfish removal it became apparent that starfish had significantly negative effects on the total density of whelks (Navarrete and Menge 1996). *Pisaster* clearly affects many species in the intertidal ecosystem.

Studies have shown that predatory starfish elicit both a flight and avoidance response in many of its mobile prey (Fawcett 1984, Bullock 1953, Feder 1963). This response is seen in limpets, chitons, and gastropods. Risk cues from predators result in rapid movement from these species either directly away from the predator or upward out of the tide pools. The question remains if these responses occur only during predator feeding and initial arrival in the pool or constantly while the predator is in close proximity to its prey.

Within the intertidal area, the most diverse habitats are wave-exposed sites where predation by a species such as *Pisaster* occurs (Menge et al. 1994). Bodega Marine Reserve (Bodega Bay, CA) is home to Horseshoe Cove, a well-protected area that includes both rocky and sandy

shores.  The rocky intertidal area has moderately high species diversity. *Pisaster* is an important predator in the mid-intertidal region of this area.

In this study, I will attempt to determine the direct effects of the *Pisaster* on *Tegula* species and indirect effects on community structure.  To evaluate these interactions and effects between *Pisaster* and the intertidal community experimental manipulations will include treatments with predators present, absent, and the natural environment (Navarrete and Menge 1996).  *Pisaster* will be caged and unable to feed to determine the effect of presence alone.  *Pisaster* have been shown to live up to twenty-one months without feeding so starvation will not be a factor (Feder 1970).  I will address the effect of predator presence on avoidance responses by herbivores and indirect effects on primary producer density.  I will attempt to determine if finding correlate with previous research, which showed that the interaction between *Pisaster* and *Tegula* did not seem to have important consequences for the intertidal community (Navarrete et al. 2000).

**Methods**

Methods include a short term *Tegula* flee response experiment and a long-term direct and indirect effect experiment.  All data was collected in Horseshoe Cove (Bodega Bay, CA) on the south facing side of the cove.

**Short-term Experiment**  Eight medium sized pools with an abundance of *Tegula* and no resident *Pisaster* were chosen for study.  Pools were randomized into control and experimental groups.  Any *Tegula* surrounding the pools were removed to avoid confusion it counting *Tegula* that had fled.  A single *Pisaster* was placed in each of the four experimental pools.  Pools were monitored for one hour, during which *Tegula* leaving pools were counted and collected.  At the end of one hour, total *Tegula* from each pool were counted and compared to the number of *Tegula* that had fled the pool once *Pisaster* was added. Analysis was done using a one-tailed t-test.  The purpose of the short term experiment was to determine if *Tegula* exhibited a noticeable flee response in pools containing *Pisaster*.

**Long-term Experiment**  Nine medium sized tide pools (0.5 –1.0 meter max width) were selected for study.   Pools were randomized into sets of three, one set for treatment, one for control and one to leave in its natural state.  Pools were chosen that had a diverse community structure, similar size and tidal range, and potential for being good *Pisaster ochraceus* habitat.

On February 6, 2005 during low tide, initial community structure data for each pool was gathered. Percent cover was estimated by using a 0.25 cm$^2$ quadrat broken into 25 5 cm$^2$ squares. Pools were sampled using 2-5 quadrats (depending on pool size); placement of the quadrats were mapped for consistency in sampling. Only submerged foliage and biota were considered in the estimates. If multiple layers were present, only the top layer was counted. Sessile organisms such as mussels and anemones were accounted for in these percent cover estimates. Algae were classified to either species or grouped when extremely similar (i.e. erect coralline algae spp.)

During the same tide sweeps of all organisms were performed on each pool. As with percent cover, only submerged biota were considered. All organisms were counted and classified to species. Organisms were returned to pools after counting.

Three *Pisaster* were collected from around the cove and used for the experiment. These *Pisaster* were individually placed in 20 cm$^2$ mesh bags with 5 mm square openings so that feeding would be nearly impossible. The bags were then secured by bolts to the bottom of the three treatment pools. Three empty bags were bolted to the three control pools. No additions were made to the natural environment pools. If any *Pisaster* (unbagged) were present in the pools they were removed.

Approximately once every two weeks at low tide for the following two months all nine pools were monitored. Community structure data was collected and any *Pisaster* (other than the three treatment bags) were removed and their presence recorded.

Species richness and diversity was calculated for each pool on each date. The Shannon-Weiner Index of Relative Diversity (Zar 1999) was used for diversity calculations (S-W Diversity):

$$H' = \frac{\left( \dfrac{n \log n - \sum_{i=1}^{k} f_i \log f_i}{n} \right)}{\log k}$$

Where k is the number of categories, n is sample size, and f is the number of observations in category i. Richness and diversity values were averaged over the treatment for each day and standard errors calculated. All analyses were conducted in Microsoft Excel.

## Results

A clear trend was seen in the short-term experiment. The percent decrease over one hour was 41 ($\pm$ 0.12) % for experimental pools and 10 ($\pm$ 0.07) % for control pools (Fig. 1, 1-tailed t-test, p<0.07). The remaining *Tegula* in experimental pools were observed in corners and crevices as far as possible from the predatory starfish.
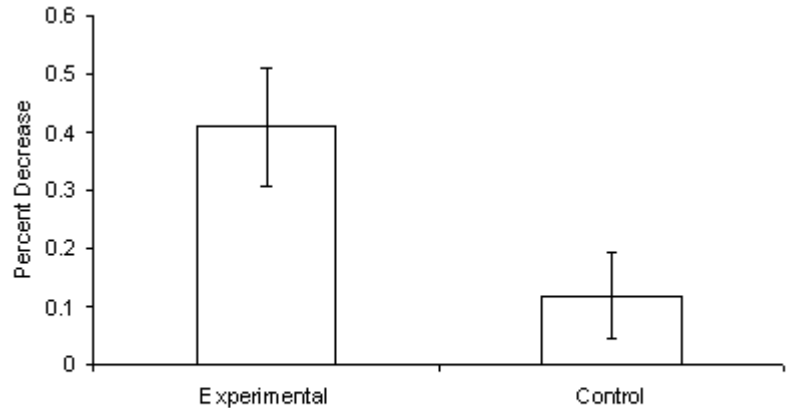


Figure 1. Percent decrease of Tegula from pools over the course of one hour.

Long-term data showed interesting results. *Tegula* abundance show a rapid decline in treatment pools (Fig. 2) while natural and control pools showed no pattern in *Tegula* abundance over time. Overall, treatment pools saw a steady decline in mobile species richness (Fig. 3) over time while changes in species richness for control and natural pools showed no trend. A clear change in mobile species diversity over time was however not seen in any group (Fig. 4).

Because *Pagurus spp*. (hermit-crab) appeared not to be affected by *Pisaster* data were also analyzed without this group. An even more pronounced decline in species richness was seen in treatment pools when *Pagurus* was eliminated (Fig. 5 vs. 3). Again, species richness declined in treatment pools while no change was seen in control and natural pools (Fig. 5). In treatment pools changes in species diversity over time for mobile species, with the exception of *Pagurus*, diversity fluctuated before declining to zero (Fig. 6); while no trend was seen in natural and control pools. For the sessile species, there was no change in species richness or diversity over time for treatment, control, or natural pools (Fig. 7, Fig. 8).
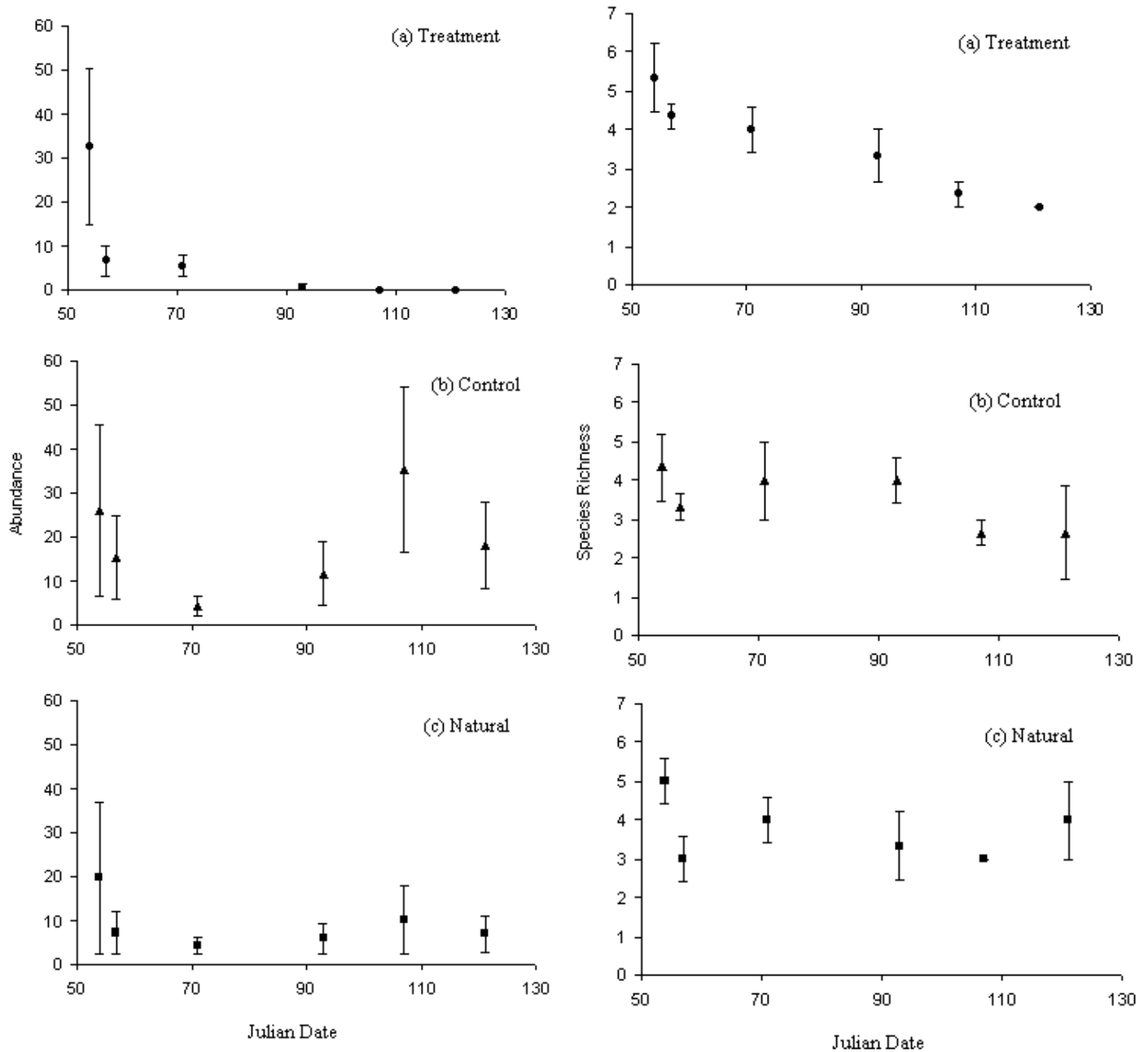
Figure 2. Change in Tegula abundance over time for (a) treatment, (b)control, and (c) natural tide pool groups.



Figure 3. Change in mobile species richness over time for (a) treatment, (b)control, and (c) natural tide pool groups.

## Discussion

Short-term experiments clearly showed the expected *Tegula* flee response to *Pisaster* presence. Although the response rate was not as high as anticipated the effect of *Pisaster* on *Tegula* presence in tide pools was seen. Further experimentation could be conducted to determine the flee rate (cm/min) as related to the initial proximity of *Tegula* to *Pisaster*. Also
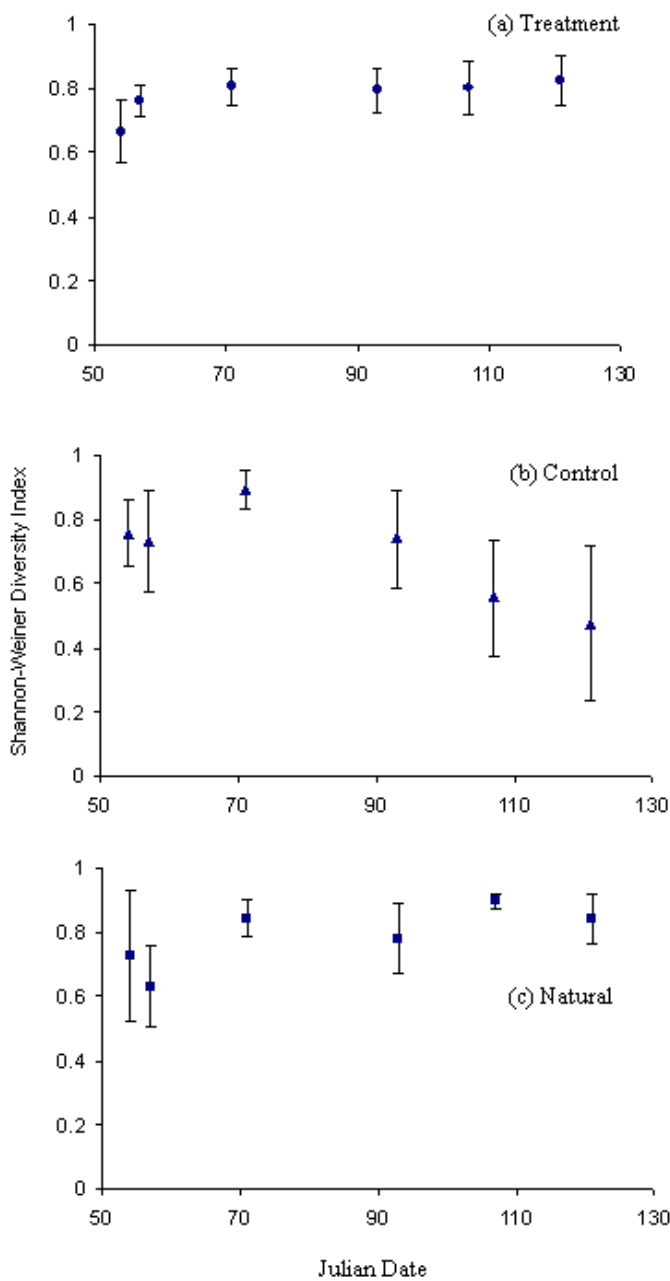
Figure 4. Change in mobile species diversity over time for (a) treatment, (b)control, and (c) natural tide pool groups.
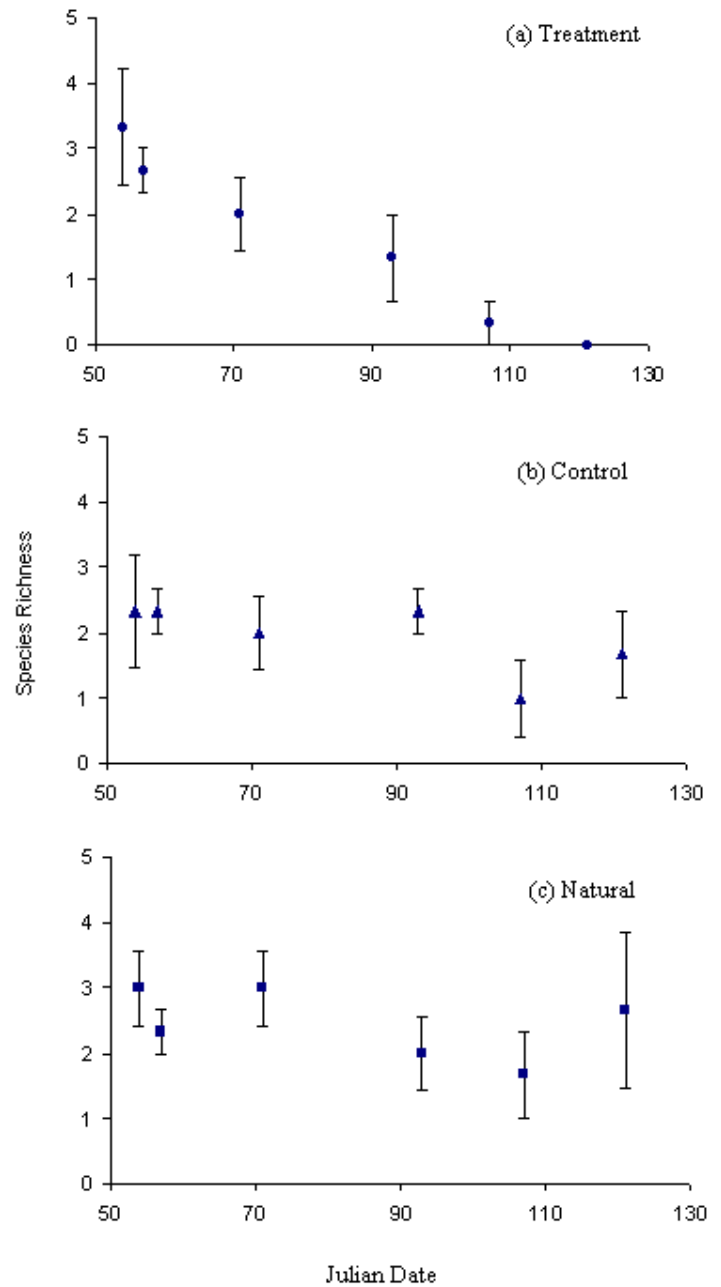
Figure 5. Change in mobile species richness with out the Pagurus genus over time for (a) treatment, (b)control, and (c) natural tide pool groups.

tests could be conducted to determine if higher flee rates would occur in pools with a smaller area or no crevices to use as in-water *Pisaster* avoidance mechanisms.

The permanent decline in *Tegula* abundance in treatment pools as compared to the variable abundances in control and natural pools over time show a definite effect of *Pisaster* on *Tegula*
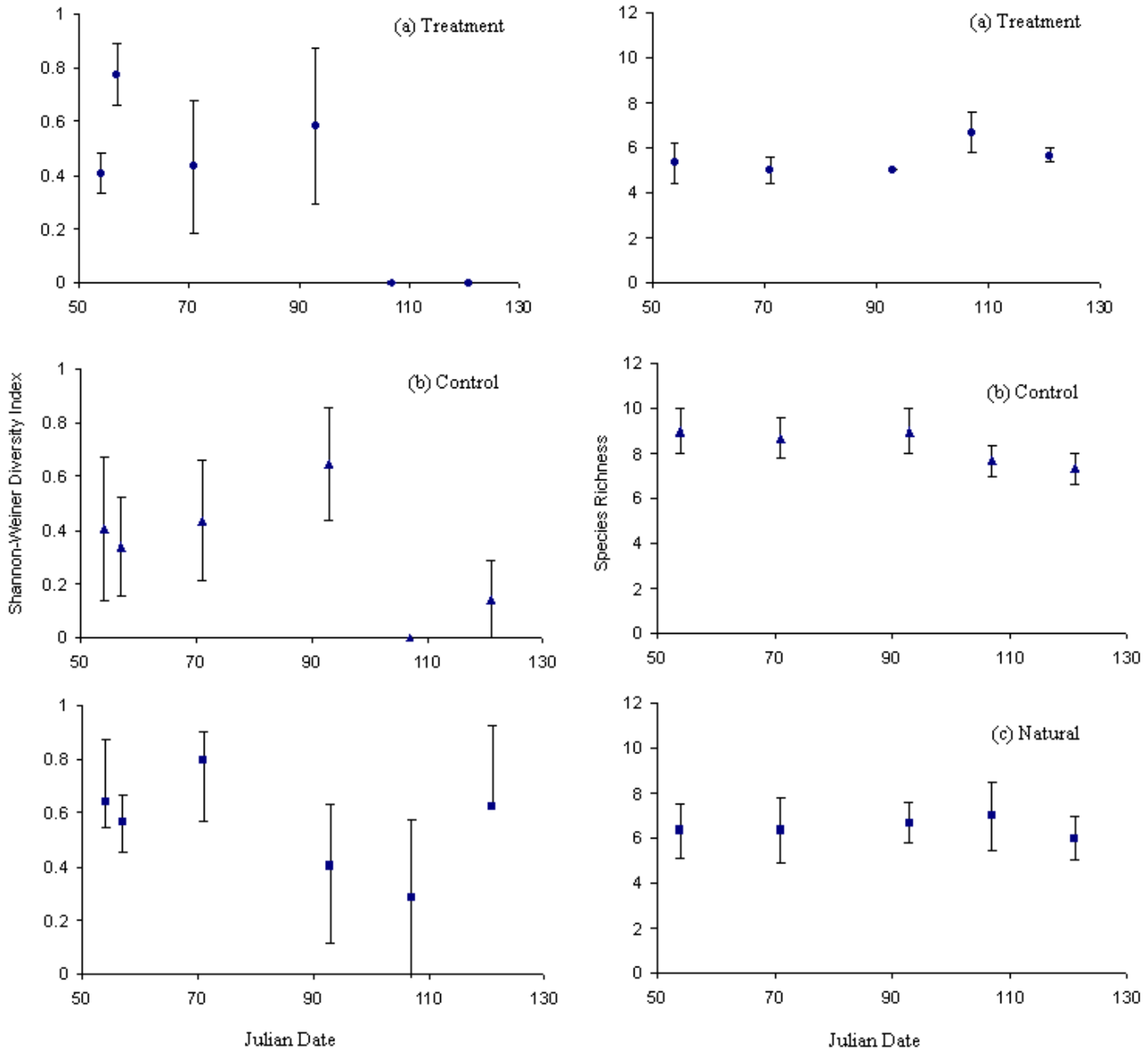
Figure 6. Change in mobile species diversity without the Pagurus genus over time for (a) treatment, (b)control, and (c) natural tide pool groups.

Figure 7. Change in Sessile species richness over time for (a) treatment, (b)control, and (c) natural tide pool groups.

presence in pools (Fig. 2).  The short-term studies confirm the initial *Tegula* flee response and the long-term experiment confirms that it is *Pisaster* presence alone that initiates this response. This presence alone leading to such a response lead to numerous hypothesizes.  Biochemical mechanisms which allow *Tegula* to detect *Pisaster* may be continuously active and result in the

flee response. Also, the variation seen in *Tegula* abundance over time in control and natural pools may be characteristic of natural species abundance fluctuations.

Mobile species richness clearly declined over time in treatment pools (Fig. 3). The majority of this decline is due to loss in one or two species of *Tegula*. Without the loss of *Tegula* species variable species richness can be seen (Fig. 3 (b), (c)). No changes in mobile species diversity were seen in any of the pools (Fig. 4). The loss of *Tegula* species did not have an effect on diversity. This may be due to *Pagurus*, the hermit crab genus, having the greatest species abundance among pools. Yet, the data do show some variation in diversity over time. This shows that tide pools species are mobile between pools and variation does not just occur between pools. The high mobility of tidal species may be a combination of tidal action, predator flee responses, and mobilization for food or nutrient gain. Further study may be conducted on the extent of mobilization, return rate, and diversity changes over time in natural environments.

Since *Pagurus* is an extremely abundant highly mobile group it was found in high numbers in most pools throughout the experiment. *Pagurus* was found in any pool regardless of predator, prey, mobile, or sessile species abundances. For this reason alone it is
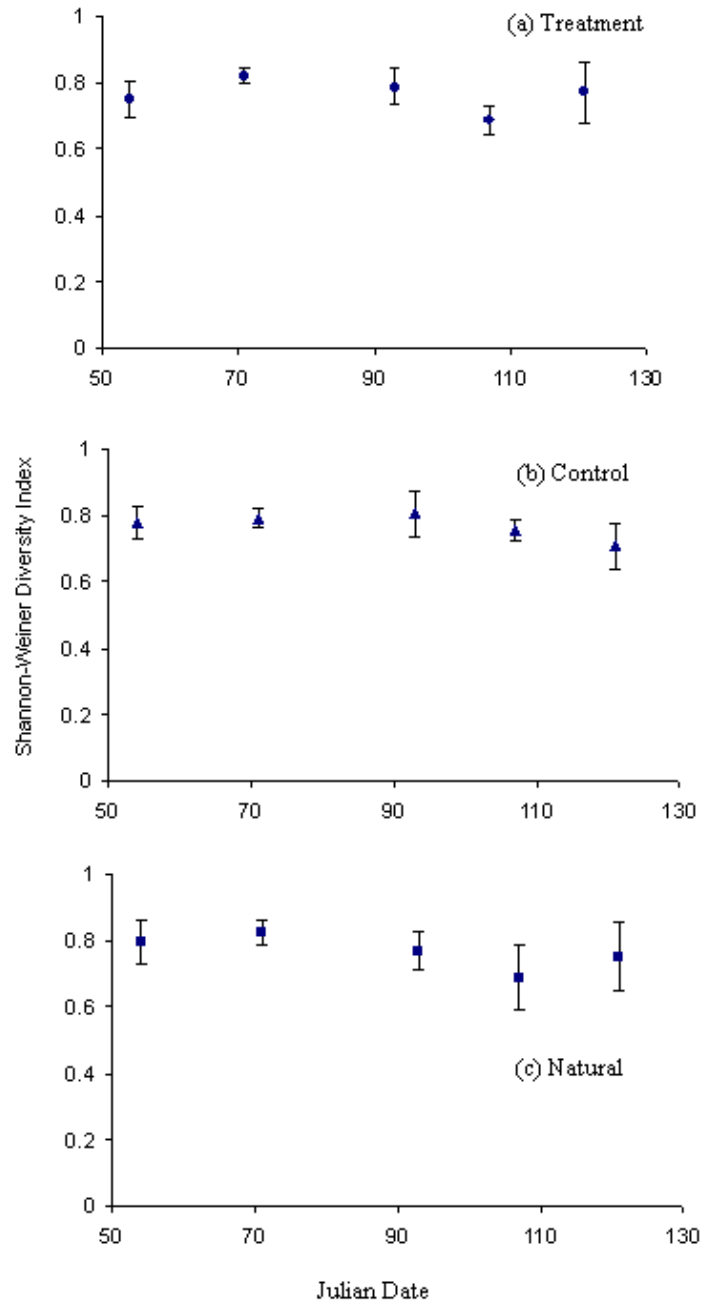


Figure 8. Change in sessile species diversity over time for (a) treatment, (b) control, and (c) natural tide pool groups.

important to consider the data collected without the inclusion of this genus. Exclusion of this genus in calculations led to more extreme differences between treatment pools and compared to control and natural pools for both species richness and diversity. Without *Pagurus*, treatment pools showed a decline in richness over time (Fig. 5). Thus, when *Pisaster* are present *Tegula* flee, other species presence significantly decline, and only hermit crabs, *Pagurus*, remain. The presence of *Pisaster* leads to the decline in all species presence but *Pagurus*. This pattern is seen again in diversity indices over time (Fig. 6). Species diversity goes to zero in pools with *Pisaster* while control and natural pools still have variable diversity rates. One must remember when considering all these calculations the relationship between richness and diversity. Yet, when *Pagurus* was included in species diversity analyses no change was seen over time in the treatment group even though richness did show a decline. Clearly the three species of *Pagurus* found at this site skewed initial diversity calculations. *Pisaster* presence directly affects tide pool species richness and diversity. Additionally the only group of mobile organisms not directly affected by *Pisaster* presence is *Pagurus*. Previous work did not determine the effect of *Pisaster* on these mobile species, or showed similar responses (Paine 1966, 1969, Navarrete et al. 2000).

No changes in sessile species richness or diversity were seen over time in treatment, control, and natural pools. Although moderate variation was seen over time no trend could be observed. These results may be due to a variety of reasons. The most probable is time; the time period in which the experiment was carried out may not have been long enough to see indirect effects on these organisms. The indirect effects on sessile species were hypothesized to be the effect of decreased grazing of *Tegula* on algae and other primary producers, yet none of these indirect effects were seen. One may hypothesize that *Tegula* grazing does not have a visible effect on sessile species richness and diversity in the given time period if at all. Further experimentation on the grazing rate of *Tegula* must occur to draw any further conclusions. Sessile data cannot be directly correlated with Paine's work since mussels were not abundant in the experimental area at any point (Paine 1966, 1969).

Flaws in data collection could have also contributed to the observed results in sessile species data. Accuracy was hard to maintain in the gathering of this data. When using quadrats to estimate percent cover only the top layer of species was counted. This layer could have easily varied over time though mixing during tides. Since such changes are common it is impossible to

tell if the fluctuations seen in data are due to natural disturbances or experimentation. Additionally the amount of species considered to be in the pools had to be submerged.  Tidal variation led to changes in percent of specie submerged and definite variation in data gathered. Although the data gathered showed no change if further study is to occur more precise sampling methods should be employed to ensure accurate results.

In many control pools no significant changes were found.  Yet often data appeared to show a slight decline in mobile species diversity or abundance (Fig. 3, 4, 6).  Further data should be collected to determine if these changes are the result of the mesh bags in pools or due to natural fluctuations over time.

Experimentation has shown that *Pisaster* presence directly affects *Tegula* abundance in both the short and long term.  Prolonged *Pisaster* presence results in a decrease in species richness and diversity while not clearly affecting sessile species.  Sessile species data may confirm previous work, which hypothesized that *Pisaster-Tegula* interactions have no effect on sessile community structure (Navarrete et al. 2000).   Further studies should be conducted over a longer time period    to ensure significance in results and see if sessile species data will change over extended time.  To idealize further studies it may be advantageous to construct laboratory pools. These pools would decrease the natural variation seen among pools and further reduce the number of confounding factors affecting this type of experimentation on possibly having adverse affects on results.

**Acknowledgements**

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