Difference in arm to body length ratio of *Pisaster ochraceus* at two locations with varying wave exposure

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Introduction

Pisaster ochraceus is a major predator on rocky shores in the Pacific Northwest. This species is known for its varying color morphs including orange, brown and purple. Harley et al. (2006) stated that the populations of *P. ochraceus* are 6%-28% orange, a small percentage is brilliant purple and most of the population is a brownish purple color. The reasons why this color polymorphism exists in the population are largely unexplained. Harley suggests that there is an underlying genetic component, "but regional-scale variation in color appear to be under ecological control" (2006).

The size of *P. ochraceus* is largely dependent on the availability of food either in the lab or in the field. Morris et al. in "Intertidal Invertebrates of California" (1980), wrote, "Laboratory-reared animals provided with abundant food eat more, grow faster and have a 'fatter' appearance than animals living in the field". They are estimated to live over 20 years under field conditions. In our area their main diet consists of *Mytilus californianus*, acorn barnacles, limpets and other gastropods.

In Charleston, Oregon, *P. ochraceus* inhabit a variety of rocky shores with varying wave exposure, as well as the floating docks. Both habitats provide species of mussles, barnacles, limpets and other gastropods, but selection varies according to the specific habitat. Based on previous field observations we noticed various structural variations in local populations of *P. ochraceus* at the Middle Cove of Cape Arago and on the Charleston boat basin. These structural differences include the length of the sea stars arms compared to the width of their bodies. These observations led us to consider the difference between the two habitats such as wave action, tidal fluctuations and food availability. Because of these differences we predicted the *P. ochraceus* on the floating docks would have shorter arm length compared to the body diameter while sea stars at middle cove would have longer arms compared to the body diameter.

Materials and methods

To investigate our hypothesis we chose two field sites to compare two populations of *Pisaster ochraceus*. We chose the Middle Cove of Cape Arago as our exposed shore site and the small boat basin in Charleston, Oregon as our protected site. This project was conduced entirely in the field using a small flexible ruler and field notebooks to

record our data. At Middle Cove we surveyed 16 specimens of *P. ochraceus* in a somewhat random order. This site offered numerous specimens to measure so we were able to find about an equal number of the orange and purple morphs. At the smaller boat basin we were able to collect data on ten purple morphs of *P. ochraceus*, but were unable to locate as many as we did at middle cove. We did find one orange morph, but were unsuccessful at reaching it to collect data on it.

After our first measurement at Middle Cove we decided on a standard way to measure the sea stars. We needed only three measurements to determine the width of the sea stars round body. Since a direct diameter measurement could not be done consistently we took three measurements from "armpit" to "armpit" around the sea star, realizing that they were all roughly equal and that 3 measurements would be sufficient. To measure the arm length we measured all five arms above the oral surface spines (figure 1) from the armpit to the tip of the arm. We continued measuring this way at middle cove and at the boat basin.

With our final measurements we determined an average arm length and body width for each *P. ochraceus* recorded. We also made note of the body morph color to determine if that made any difference in size and distribution of the color morphs at each site. We then made an arm to body length ratio scale:

- <1 Implies a bigger body and shorter arms
- >1 Implies a smaller body with longer arms
- = Implies a body with body and arms of about equal lengths

This arm to body ratio scale allowed us to compare both populations more easily since the size of the *P. ochraceus* varied quite drastically. We then conducted a standard paired t-test for our two location's purple population ratio values. We did the same to compare the orange and purple *P. ochraceus* from middle cove to test for any significant differences between the two color morphs.

Results

Table 1 and 2 summarize the data collected for *P. ochraceus* at Middle Cove and the Inner Boat Basin respectively. No orange morphs were found in the boat basin, so only purple morph data was collected for that site. There was a significant relationship ($P < 0.01$, paired *t*-test) between the average arm to body ratio of the *P. ochraceus*

populations at Middle Cove and the Inner Boat Basin (Fig. 1). *P. ochraceus* at Middle Cove have a higher arm to body ratio, indicating that the arms are longer relative to the body diameter. *P. ochraceus* in the Inner Boat Basin have a lower arm to body ratio, signifying that the arms are shorter relative to the body diameter. However, there was no significant difference ($P > 0.05$, paired *t*-test) between the purple and orange morphs of Middle Cove (Fig. 2).

Discussion

The results support our hypothesis that *P. ochraceus* in Middle Cove would have longer arms compared to the body diameter, and *P. ochraceus* in the Inner Boat Basin would have a shorter arm length compared to the body diameter. Figure 1 indicates that *P. ochraceus* have a higher arm to body ratio at an exposed shore such as Middle Cove, and a lower arm to body ratio at a floating dock such as the Inner Boat Basin. The *P. ochraceus* on exposed shores have to deal with high wave exposure and tidal fluctuations, whereas *P. ochraceus* on floating docks have no wave exposure and no tidal fluctuations to deal with. Due to these differences, species at Middle Cove experience high predation and desiccation stress. On the other hand species in the Inner Boat Basin have no desiccation stress; this allows for sufficient food for predators such as *P. ochraceus* and for optimum growth to occur. As stated in our introduction, laboratory-reared animals provided with sufficient food grow to be fatter in appearance (Morris et al., 1980). Based on this statement, the difference between the population at Middle Cove and the Inner Boat Basin could be due to the fact that the boat basin provides an optimum environment to survive to an older age. This would indicate that the two populations have an age difference rather than having a clear structure morph difference.

Individuals of *P. ochraceus* that live on exposed shores have to endure severe wave exposure and desiccation stress. One explanation for how *P. ochraceus* at Middle Cove has adapted to these stresses is having a smaller body diameter and longer arms. The smaller body diameter allows for increased water retention during low tide and allows the animal to squeeze into tight crevices. The longer arms provide the animal with increased surface area for a greater number of tube feet, allowing the sea star increased suction along the rocks.

There was no significant size difference between the purple and orange morphs at Middle Cove (Fig. 2). This suggests that the color morph of *P. ochraceus* had no bearing on the arm to body ratio. Our results did suggest that the orange morph is rarely found on floating docks. In fact, the *P. ochraceus* found on floating docks in the Puget Sound are primarily purple (Kozloff 1993).

Continued research into this topic would include conducting more random sampling at a wider variety of sites. We would also test the wave exposure and air exposure each site receives to better understand each sampling group. We would also gain insight by looking at the diet of *P. ochraceus* at each sampling site. Depending on time constraints, we would also test growth rates of *P. ochraceus* in the lab based on diet and environmental conditions.

References

Harley, C.D.G., M.S. Pankey, J.P. Wares, R.K. Grosberg, and M.J. Wonham. "Color Polymorphism and Genetic Structure in the Sea Star Pisaster ochraceus." Biol. Bull. 211 (2006): 248-262.

Kozloff, Eugene N.. Seashore Life of the Northern Pacific Coast. Seattle, WA: University of Washington Press, 1993.

Morris, Robert H., Donald P. Abbott, and Eugene C. Haderlie. Intertidal Invertebrates of California. Stanford, CA: Stanford University Press, 1980.

Table 1: Average body and arm length and arm to body ratio of purple and orange morphs of *Pisaster ochraceus* at Middle Cove.

Morph	Body Length Average (cm)	Arm Length Average (cm)	Arm/Body Ratio
Purple	7.2	8.08	1.12
Purple	8.6	10.8	1.26
Purple	9.23	8.22	0.89
Purple	7.8	9.96	1.28
Purple	6.5	8.44	1.3
Purple	6.1	7.68	1.26
Purple	9.37	8.66	0.93
Purple	7.1	7	0.99
Orange	9.1	9.02	0.99
Orange	10.7	9.32	0.87
Orange	9.17	10.64	1.16
Orange	7.43	7.3	0.98
Orange	6.4	7.92	1.24
Orange	8.63	8.46	0.98
Orange	8.67	8.89	1.02
Orange	6.7	8.44	1.26

Table 2: Average body and arm length and arm to body length of purple and orange morphs of *Pisaster ochraceus* in the Inner Boat Basin.

Morph	Body Length Average (cm)	Arm Length Average (cm)	Arm/Body Ratio
Purple	15.2	17.4	1.14
Purple	19.4	19.06	0.98
Purple	26.2	22.4	0.86
Purple	22.4	17.8	0.79
Purple	21.6	21.4	0.99
Purple	20.5	20.7	1
Purple	22.7	18.8	0.83
Purple	19.2	19.7	1.02
Purple	22.1	20.3	0.92
Purple	15.5	13.8	0.89

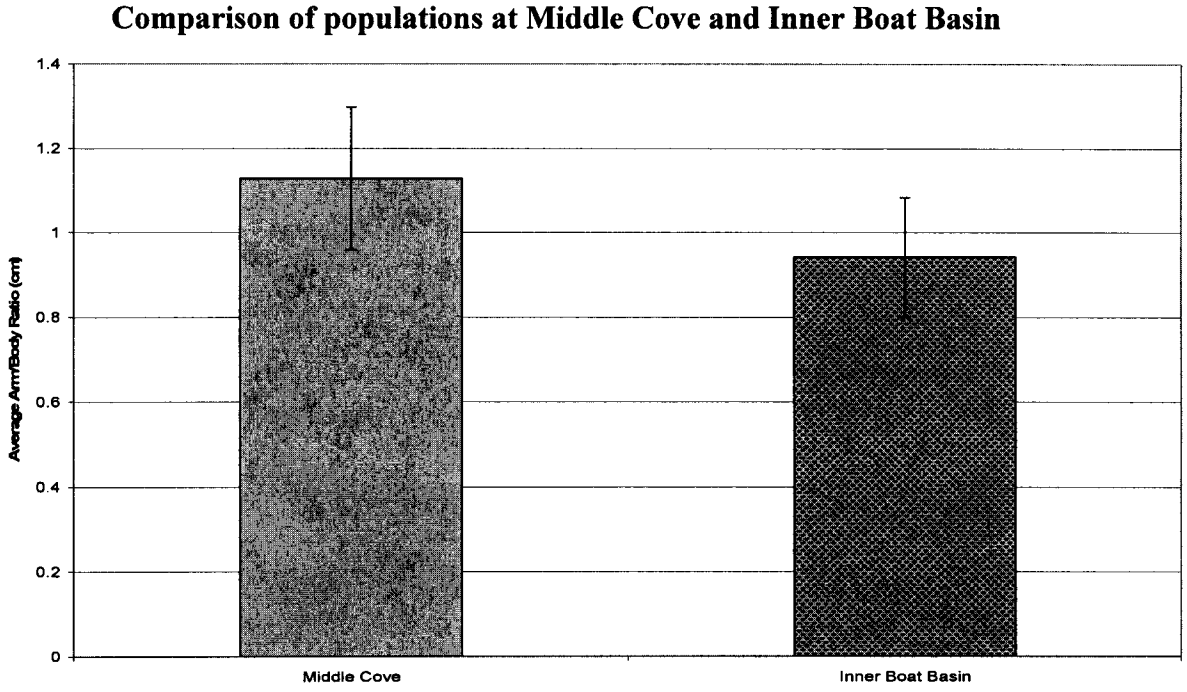

Figure 1: Comparison of the average arm to body ratio (± SE) of purple morph *Pisaster ochraceus* populations at Middle Cove and the Inner Boat Basin.

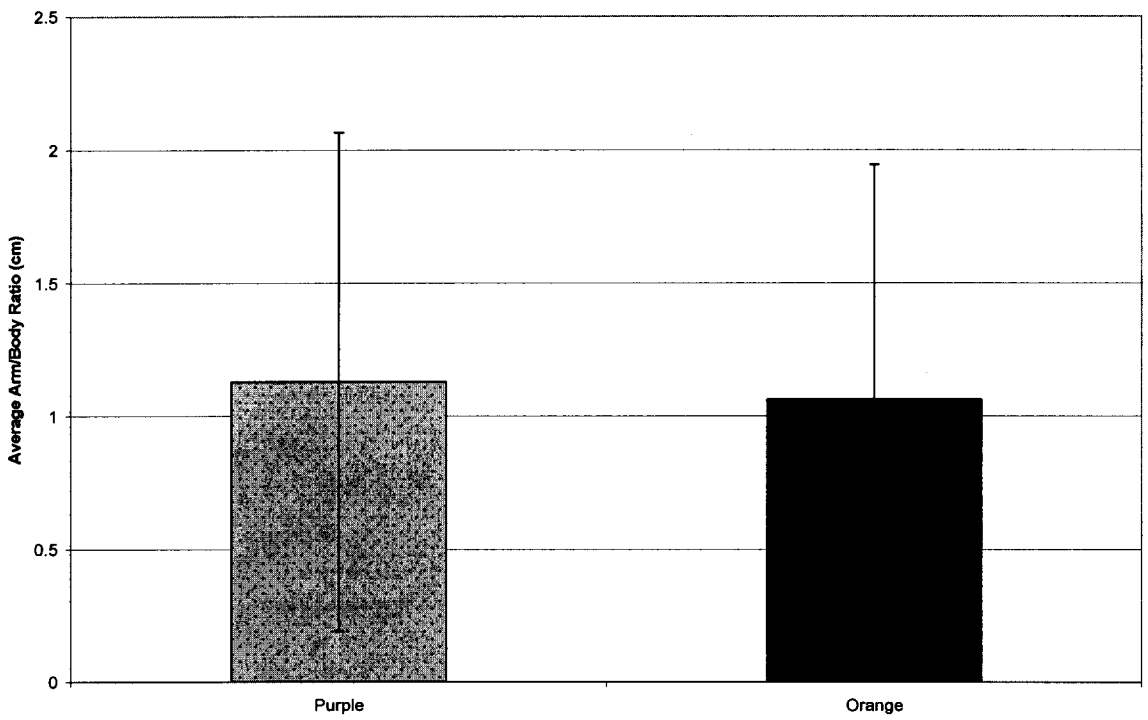

Figure 2: Comparison of the average arm to body ratio (± SE) of the purple morph *Pisaster ochraceus* in the Inner Boat Basin to the orange morph *P. ochraceus* at Middle Cove.

Figure 3: A purple *Pisaster ochraceus* found at Middle Cove. The yellow lines indicate where all *P. ochraceus* were measured for arm length, depending on the orientation of the arms. The orange lines indicate where 3 measurements could have been taken for body width. All measurements were taken from the 'armpit'.