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Arm Deflation in the Rare Thorny Sea Star, *Poraniopsis inflatus* (Asteroidea: Poraniidae), A Defensive Response to other Sea Stars?

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The Thorny Sea Star, *Poraniopsis inflatus,* is rare in the Northeastern Pacific. It lacks pedicellariae or other overt defenses for protection against other predatory sea stars. During an earlier study, a *P. inflatus* confronted by an asteroid-eating sea star was observed to exhibit a possible defensive reaction: "arm deflation." It was 15 years before another *P. inflatus* specimen could be obtained and that hypothesis confirmed by testing with individuals of 18 other sea-star species. Contact with individuals of four predatory sea-stars, *Asterina miniata*, *Crossaster papposus*, *Solaster dawsoni*, and *Pycnopodia helianthoides*, elicited the reaction in the *P. inflatus*. The specimen collapsed ("deflated") an arm closest to the predatory star, possibly by expelling coelomic fluid, exposing more of its embedded thorns (hence its common name) which may discourage other sea stars from attempting to eat it.

Key Words: Thorny Sea Star, *Poraniopsis inflatus*, escape response, defensive reaction, predator-prey interaction.

The diverse sea star fauna of the Northeastern Pacific has been relatively well-described (D'yakonov 1968; Lambert 1981, 2000; Austin 1985; Kozloff 1987). As early as 1911, Fisher stated that there were "more sea stars of more species" found in the Oregonian biome between Alaska and California there than anywhere else in the world. Given that over 100 species have been reported from that region (Austin 1985), it is obvious that statement has substantial credence. While numerous field observations in this region along with laboratory and field experiments have demonstrated the ecological importance of a few relatively common asteroid species in many shallow-water communities (Paine 1966, 1974; Mauzey et al. 1968; Engstrom 1974; Quinn 1982; Duggins 1983), the natural history and ecological relationships of most sea-star species in the region remain largely unknown. This is particularly true of the rarer, generally deeper-water, species where even a few experimental natural history observations, such as those by Anderson and Shimek (1993) on *Poraniopsis inflatus* (Fisher 1910), may contribute important information to the overall knowledge of this group.

Predatory, highly mobile and, often, ecologically dominant predators, sea stars are well known for eliciting escape responses in many other animals including other asteroids. Documented escape responses in sea stars include rapid directed locomotion escapes, ray autonomy, arms raised in defensive postures, and presenting their suckered tube feet to the predator (Mauzey et al. 1968). Some sea stars possess an arsenal of formidable pedicellariae on their aboral surfaces. These structures, spines modified as small biting jaws, have been hypothesized to keep the star's aboral surface clean (Hyman 1955), but are known to be used by some species to capture prey (Robilliard 1971; Chia and Amerongen 1977), and also to repel predators (Mauzey et al. 1968). Sea stars lacking these effective defensive structures or defensive behaviors run the risk of being eaten by other asteroids, such as *Solaster dawsoni*, which are known to consume other sea stars (Mauzey et al. 1968).

A member of the Asteroid taxonomic Family Poraniidae, *Poraniopsis inflatus* (Fisher, 1910) lacks pedicellariae. Initially described as *Alexandraster inflatus*, Fischer 1906, revised to *Poraniopsis inflata* by Fisher in 1910, and finally revised to *P. inflatus* by Clark in 1993 (Lambert 2000), this species ranges from Alaska to southern California, but is rare throughout that region. In the century since its description, only 12 specimens have been documented from British Columbia and Washington (Lambert 1981, 2000; Anderson and Shimek 1993). It is found in high-energy shallow environments (Anderson and Shimek 1993) and on the shallow continental shelf (Alton 1966); whether it is found in between these two disparate habitats is unknown. Little is known of the natural history, including any possible defensive or escape responses, of this rarely seen or collected sea star (Lambert 1981 2000; Anderson and Shimek 1993).

Characterized by its deep orange color and the reticulated pattern of squarish plates with large white spines protruding from the plate junctions on its aboral surface (Lambert 2000), *P. inflatus* is a fat-armed pudgy sea star that appears "puffed-up" or inflated, hence its apt species name (see Cover). Under normal conditions the spines are partially obscured by the swollen papullae, or dermal gills, covering the plates.

Ecological data on *P. inflatus* are extremely limited. Anderson and Shimek (1993) reported on its diet in a public aquarium and Dalby et al. (1988) reported its elicitation of the swimming escape response of the sea anemone, *Stomphia didemon*. We could find no other reports of any natural history or ecological attributes for *P. inflatus*. Such a paucity of observations indicates the importance of a chance observation of what appeared to be a unique reaction in response to contact by another sea star, *Asterina miniata*, at the Seattle Aquarium. The serendipity of this casual observation lead to this study wherein we describe and document this defensive, and possibly an escape, response, determine what other sea stars might elicit it and illuminate some reactions of other sea stars to *P. inflatus*. Unfortunately, that first solitary *P. inflatus* specimen was subsequently partially eaten by a *Crossaster papposus* and died before it could be used for further confirmatory observations. Emphasizing the importance of experimentation on rare animals whenever possible, it was 15 years before a subsequent specimen was found and collected, even though numerous dives were done by collectors from the Seattle Aquarium in appropriate habitats for *P. inflatus*. Obviously, we would have preferred to perform our experiments on several *P. inflatus* specimens, however, the potentially excessively long waiting time before other specimens might be found made it imperative to gather data from this one individual. Although asteroids such as *P. inflatus* may be successfully maintained for extended periods and experience no apparent aging or senescence, the same cannot be said of human investigators. With the collection frequency of one specimen every fifteen years, it seemed prudent to do our tests with the individual at hand rather than waiting until a larger, more desirable, sample could be collected.

Materials and Methods

Specimen Maintenance and Release

A single specimen of *Poraniopsis inflatus* was collected under a 0.5 m rock 20 m deep at Slant Rock, Cape Flattery, Washington State (N48°23.490', W124°41.860') using scuba on 24 August 2007 and transported to the Seattle Aquarium per Anderson (2001) where it was placed in a low, flat aquarium with running sea water. Subsequently fed live sponges, *Halichondria* spp. (Anderson and Shimek 1993; Anderson 2001), the specimen was maintained in that tank for the duration of the study. During routine handling of the sea star (e.g., for measurement), no "deflation" was ever observed. A year after its collection, and after the completion of the tests described herein, due to this species' rarity, the specimen was released in the same spot where it was collected.

Experimental Procedures

For each experimental trial the *P. inflatus* was in its tank, normally feeding on a sponge. A specimen of another sea star species was placed in the tank with one of its rays touching the *P. inflatus*. The reactions of both specimens, if any, were noted and photographed for the next hour and then the other asteroid was removed. During a previous study (Anderson and Shimek, 1993) a *P. inflatus* was partially eaten by a *Crossaster papposus* so contact between the two sea stars was limited to initial reactions. Only one encounter was performed per day, allowing the *P. inflatus* specimen time to recover between bouts, with a minimum of two days between encounters. Only one specimen of each other species was tested with the *P. inflatus*. The responses of the *P. inflatus* specimen to specimens of 18 other sea star species were documented (Table 1). Responses specifically noted were (1) any possible "deflation" of the arms of *P. inflatus* (Figure 2) and () any movement away from the other sea stars.

Results

Twelve of the 18 other sea stars tested caused a reaction in the *Poraniopsis inflatus* individual. It responded most strongly to specimens of four other sea star species (*Asterina miniata, Crossaster papposus, Solaster dawsoni*, and *Pycnopodia helianthoides*). When contacted by the arm of these specimens, the *P. inflatus* deflated the arm touched by the other sea star (Table 1; Figure 1). The mean "deflation" time was 4.5 min (S.D. ±1.7 min). The *P. inflatus* responded less strongly to eight other sea stars by moving off the sponge it was eating and away from them (mean distance 15 cm in five min (S.D. ± 4.5 cm) (Table 1). The mechanism of the deflation was not investigated.

There was no clear pattern of elicited behavior correlated to families or orders of predators, e.g., one member of the Asteriidae caused a reaction and six others did not (Table 1). The behavior of "deflation" and movement from other sea stars was shown in three of the four orders tested. The animals from the fourth order, the Platyasterida, represented locally by only one common species, *Luidia foliolata*, lack suckered tube feet and normally feed on sessile infaunal animals. It is likely impossible for such a sea star even to capture another star; such animals would not represent the threat posed by individuals of species from the other three orders.

Discussion

It is perhaps not surprising to discover a potential escape response such as arm deflation in a sea star

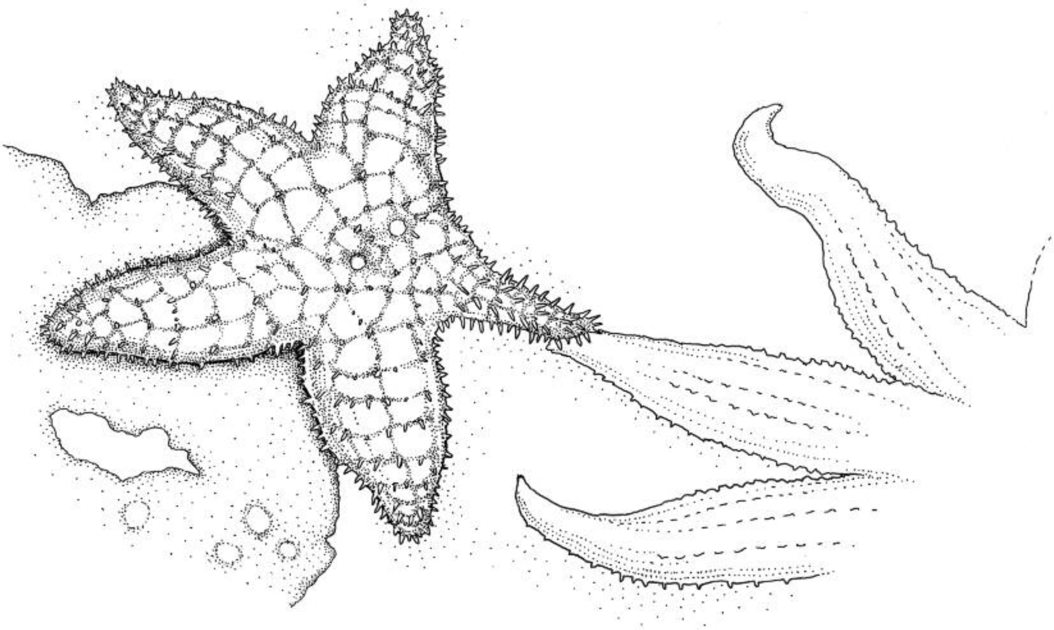

FIGURE 1. Illustration of the reaction of *Poraniopsis inflatus* to four other sea stars. It deflates the arm closest to the predator and exposes thick embedded spines. Illustration by Marla Coppolino.

that doesn't have pedicellariae (Hyman 1955). Other sea stars possessing pedicellariae use them to pinch oncoming sea star predators. Additionally, while the prey stars may flee from their predators (Mauzey et al., 1968), *Poraniopsis inflatus* individuals do not appear to be able to move fast enough to escape other predatory sea stars. We measured an escape velocity of just 15 cm in five min, even when contacted by potential predators. Consequently, natural selection may have lead to the evolution of another type of response. This is particularly relevant considering that many predatory sea stars, including the rapidly-moving *Pycnopodia helianthoides*, used in this study, have been shown to have good chemosensory abilities, and are able to use chemical means to detect, find, and follow prey (Dale 1997; Brewer and Konar 2005; Thompson et al. 2005). *Poraniopsis inflatus* individuals are just too slow to escape these predators.

The lack of pedicellariae may reflect the animal's habitat. Sea star pedicellariae are also used to keep the aboral surface clean of settling organisms and falling detritus (Hyman 1955). Although its depth range is considerable, from 11 to 366 m, (Lambert 2000), we found our specimens in diving depths of 3 to 20 m in high energy environments with considerable and persistent wave action from the ocean (see Hedgpeth 1978). In such habitats, currents would tend to remove any particulate matter from the aboral surface of a sea star. The nearshore high energy environment is well-oxygenated but the deeper ocean environments are often dysaerobic, suggesting a wide tolerance from high to low oxygen. The one specimen noted from Hood Canal (Furlong and Pill 1970) also suggests a tolerance for low oxygen conditions as this fjord has periodic low oxygen conditions (Devol et al. 2007).

Little is known about rare sea stars, such as *Poraniopsis*. Procuring them, usually by trawling, is often damaging to them and few trawlers are equipped to maintain aquariums that duplicate the cold temperatures and low oxygen levels found at the animals' normal depths, so keeping such trawled animals alive is problematic. Scuba diving is limited in its habitat, so few *in situ* observations have been made on *P. inflatus*. Even then, the substantial rarity of the animals precludes being able to perform many tests requiring statistics. An N of one is very limiting; however, when the waiting time to collect a second animal can reliably be estimated at decades, it is necessary to do what tests one can to begin to provide information about the species.

Even the limited data found by an investigation such as this raises a number of additional questions about *P. inflatus*. The observations on the original *P. inflatus* specimen that was attacked by an *Asterina* and a *Crossaster* indicate that *P. inflatus* is acceptable to at least these predators. That and the apparent arm deflation behavior coupled with its slow locomotion suggest that arm deflation may release coelomic fluid. It is possible that fluid is noxious to other sea stars, or interferes with their chemoreception. Perhaps deflation

Table 1. Results of tested contacts between *Poraniopsis inflatus* and other asteroids.

Order/Family	Asteroid	Reaction: Response	Distance Moved (cm)	Deflation Time (min)
Order Platyasterida				
Family Luidiidae				
	Luidia foliolata	None		
Order Valvatida				
Famly Goniasteridae				
	Hippasteria spinosa	None		
	Mediaster aequalis	Moved Away	10	
Family Radiasteridae				
	Gephyreaster swifti	Moved Away	12	
Family Asterinidae				
	Asterina miniata	Arm Deflation		4.1
Family Asteropseidae				
	Dermasterias imbricata	Moved Away	19	
Order Spinulosida				
Family Solasteridae				
	Crossaster papposus	Arm Deflation		4.9
	Solaster dawsoni	Arm Deflation		6.5
	S. stimpsoni	Moved Away	13	
Family Pterasteridae				
	Pteraster tesselatus	None		
	Family Echinasteridae			
	Henricia leviuscula	None		
Order Forcipulatida				
Family Asteriidae				
	Evasterias troschelii	Moved Away	22	
	Leptasterias hexactis	Moved Away	19	
	Orthasterias koehleri	Moved Away	10	
	Pisaster ochraceus	None		
	P. brevispinus	None		
	Pycnopodia helianthoides	Arm Deflation		2.5
	Stylasterias forreri	Moved Away	15	
		Mean	15	4.5
		Std. Dev.	4.5	1.7

releases a chemical that interferes with the duo-gland adhesion system found on the tube feet of potentially predatory sea stars (Hermans 1983) that prevents them from moving efficiently or from adhering to the nearby, slowly-trundling-away, *P. inflatus*. Released coelomic fluid may be procurable from near a "deflating" sea star and likewise a volume displacement measure would have shown us if there was fluid loss or merely displacement.

In our tests, we removed the other sea star after an hour to prevent any harm to our rare and precious *P. inflatus*. It would have been interesting to observe any further reactions between the two sea stars but we did not want to risk damaging our *P. inflatus*. The deflation of the arm nearest a predatory sea star exposes more of the "thorns" at the surface of *P. inflatus* and thus possibly either discourages the predator or presents a non-edible surface toward it. Whatever the mechanism, the process of *P. inflatus* becoming "deflatus" likely allow it to live in an environment amidst numerous predatory sea stars that might otherwise eat it. Other questions obviously remain, such as, "Does deflation in one arm cause enhanced inflation in the others?" "Will it reinflate if the other sea star is still present?" "Does deflation rate and effectiveness vary depending on the individual?" These and other questions await a prepared investigator and the collection of the next specimen(s) of *P. inflatus*.

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