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NOTE

The cost of arm autotomy in the starfish *Stichaster striatus*

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ABSTRACT: Arm autotomy in asteroids, as tail autotomy in vertebrates, typically occurs when the animal is attacked and appears to facilitate escape. One assumes autotomy has a cost, but it rarely has been demonstrated in the field in vertebrates and never demonstrated in asteroids. The concentration of lipid was 40% less and the amount of kilojoules 85% less in the pyloric caeca of the asteroid *Stichaster striatus* Müller & Troschel (Echinodermata: Asteroidea) with autotomized arms than in those of individuals with intact arms collected in the field. As the pyloric caeca are used as nutrient reserves, individuals with autotomized arms would have a lesser capacity to withstand low availability of food and, as the caecal reserves can be used for gametogenesis, a decreased capacity for reproduction.

KEY WORDS: Autotomy · Regeneration · Echinodermata · Asteroidea · Starfish · Sea stars

Tail autotomy by vertebrates (lepidosaurians, salamanders, and rodents) usually does not occur unless an animal is attacked by a predator, and appears to facilitate escape (Arnold 1988). Arm autotomy by asteroids also occurs during attack and leads to escape (Mauzey et al. 1968, Viviani 1978, Birkeland et al. 1982). Arnold (1988) pointed out that the value of autotomy depends on the balance of its costs and benefits; only if the latter exceed the former would autotomy be selectively advantageous. Costs can include both the allocation of resources to regenerate the lost structure and the decrease in the ability to obtain resources.

That the vertebrates mentioned above regenerate the tail implies the tail is functional but not essential according to Goss' (1969) paradigm, and that the benefits of autotomy exceed the cost. Goss' paradigm has been applied to asteroid arms (Lawrence 1991). Although one would anticipate costs associated with arm loss in the field, actual documentation is essential.

Stichaster striatus Müller & Troschel (Echinodermata: Asteroidea) is abundant along the warm-temperate region of the South American coast from Peru to southern Chile (Madsen 1956). Individuals autotomize a single arm when attacked by the asteroid *Luidia magellanica* (Viviani 1978). Autotomy is common, as the frequency of individuals with regenerating arms is high (15% near Concepción in 1972, Bay-Schmith 1975; 38% near Iquique in 1977, Viviani 1978; 32% near Dichato in 1993, authors' unpubl. data; 18% at Coquimbo in 1993, Lawrence & Vásquez unpubl.). This paper documents the cost of autotomy of the arm of *Stichaster striatus*, and is apparently the first report of the cost of arm autotomy of an asteroid in the field.

Materials and methods. We collected *Stichaster striatus* near Dichato, Chile (36.3° S, 72.6° W) on 22 October 1993. The radius of an intact ray was measured. The pyloric caeca were dissected from all the arms of intact individuals, and both the intact and regenerating arms of individuals with autotomized arms. Gonads were not present as *S. striatus* in the region have a precipitous spawning in the latter part of September (Bay-Schmith 1975). The pyloric caeca were weighed, dried at 60 °C for 1 wk, and reweighed. The concentration of organic material was measured by ashing at 500 °C for 4 h (Paine 1971). The concentration of total lipid in the dried tissue was measured gravimetrically by the method of Freeman et al. (1957). The energetic equivalent of the lipid was calculated using the conversion factor of Brody (1945). Statistical significance was calculated by ANOVA after appropriate transformation to satisfy the conditions of normality and equal variance.

Results. Characteristics of the *Stichaster striatus* are shown in Table 1. The values for the weight of the pyloric caeca in an intact arm and the percent organic material in the pyloric caeca did not differ significantly in individuals with 1 or 2 regenerating arms ($p < 0.1$) and were combined for comparison with individuals with all arms intact. Individuals with all arms intact

Table 1. *Stichaster striatus*. Characteristics of starfish with all intact arms and with 1 or 2 autotomized arms. Means ± 1 SE are given; n = 10 except for % lipid where n = 6 for individuals with all intact arms and n = 7 for individuals with autotomized arms. All values are significantly different between the 2 groups (ANOVA, $p < 0.01$). The kilojoules equivalent to the lipid in the pyloric caeca were calculated from the mean values

	Individuals with all intact arms	Individuals with autotomized arms
Radius length (cm)	11.2 ± 0.3	9.8 ± 0.3
Wet weight (g) of the pyloric caeca:		
in an intact arm	0.76 ± 0.09	0.23 ± 0.03
in all arms	3.6 ± 0.4	0.9 ± 0.1
Organic material (% dry weight)	95 ± 0.4	93 ± 0.05
Total lipid (% dry weight)	47 ± 2.2	28 ± 2.9
kJ of lipid in the pyloric caeca:		
in an intact arm	9.8	1.8
in all arms	46.7	6.7

were slightly but significantly larger ($p < 0.01$) than those with regenerating arms. The weight of the pyloric caeca in an intact arm, and the concentrations of organic material and lipid in the pyloric caeca of an intact arm were statistically significantly less in the individuals with regenerating arms than in those with all arms intact ($p < 0.1$). The difference in the concentration of lipid is particularly pronounced. The concentration of organic material in the pooled pyloric caeca of the regenerating arms was 90% of the dry weight, less than that in the intact arms of the regenerating individuals. The combination of size difference and lipid-concentration difference results in a much smaller amount of lipid and energy in individuals with regenerating arms.

Discussion. Pyloric caeca are nutrient reserve organs in the arms of asteroids, and the size and concentration of lipid present are indicative of the energy reserves of an individual (Giese 1966, Lawrence & Lane 1982, Lawrence 1987). The smaller size and amount of lipid and energy in the pyloric caeca in the regenerating individuals indicate a smaller amount of energy reserves than in individuals with all arms intact. This could result from either an impaired ability to feed or a utilization of nutrients in the pyloric caeca to support regeneration. Laboratory experiments have shown that removal of arm tips decreases feeding in *Pisaster ochraceus* (Harrold & Pearse 1980) and pyloric caeca production is low in *Luidia clathrata* unless food resources are abundant (Lawrence et al. 1986, Lawrence & Ellwood 1991).

Arnold (1988) pointed out autotomy is highly complex and that ramifications of its occurrence extend to many aspects of an animal's biology. Here we emphasize the cost, which is difficult to demonstrate in the field. Indeed, the effect of tail loss by lizards on locomotion, reproduction, ability to escape predation and to withstand starvation has been demonstrated primarily experimentally and not in the field (Arnold 1988). The correlation reported here between arm loss and low amounts of nutrient reserves in *Stichaster striatus* indicates individuals that autotomize arms would have a reduced capacity to withstand low availability of food and, as the caecal reserves can be used for gametogenesis, possibly a decreased capacity for reproduction. It is essential to consider arm loss and regeneration when interpreting the biology of asteroids in the field.

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