Reproductive and Larval Biology of *Acanthaster planci* (L.) in Great Barrier Reef Waters[1]

J. S. LUCAS[2]

Abstract

A small dispersed population of *Acanthaster planci* on Lodestone Reef was regularly sampled from June 1972 to April 1973. There was a progressive increase in gonad index from mid-winter (June) to mid-summer (December) and then a rapid decline to a low level in late January. These changes were similar in magnitude and timing to those in aggregated populations of *A. planci* in Great Barrier Reef waters.

Mean oocyte diameter and abundance of spermatozoa varied with gonad index. Oogenesis was very rapid in November and December, and ovaries contained a single mode of mature oocytes in December. Oocytes and spermatozoa were shed during the short breeding season in mid-summer when water temperature was about 28°C and optimal for larval survival. There was no evidence of shedding at any other time, although at least a small proportion of starfish in all samples had some mature gametes.

Larvae were reared from hatching at five temperatures—24, 26, 28, 30 and 32°C, and at three salinities—30, 32.5, and 35‰. Survival at day 8 was highest in the lowest salinity and at the medial temperature, 28°C. No larvae developed to brachiolaria at 24 or 32°C. Larval development and metamorphosis were completed at 28°C in a minimum of 17 days. Development was completed at 26‰, but not at 22‰ salinity. Larval temperature requirements may limit the southern distribution of *A. planci* and the salinity responses of larvae will be important in northern Great Barrier Reef waters.

INTRODUCTION

Previous attempts at rearing *Acanthaster planci* (L.) in the laboratory (Henderson, 1969; Henderson and Lucas, 1971; Yamaguchi, 1973) suggest that rate of development and survival are strongly influenced by temperature, that bipinnaria stage larvae are more tolerant of salinity changes than brachiolariae, and that brachiolariae show substrate selection at settlement. One objective of this study was to more precisely quantify the effects of salinity and temperature on the larval development of *A. planci* by attempting to rear larvae at a series of salinity-temperature treatments. This apparently was the first of this type of experiment with echinoderm larvae, although similar experiments have been conducted with crustacean larvae, *e.g.*, Costlow, Bookhout and Monroe (1960).

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[2] Zoology Department, James Cook University of North Queensland, Queensland, 4811, Australia.

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Concurrent with the larval studies, an investigation was made of the reproductive biology of *A. planci* to establish its breeding season and hence the environmental conditions prevailing at the time of larval release. Good evidence for a short, well-defined breeding season in Great Barrier Reef waters was provided by the gonad index data of Pearson and Endean (1969). However, workers who generally used criteria other than gonad index have concluded that *A. planci* has more extended breeding seasons at other localities (Vine, 1972), and Cheney (1972) found that aggregated and dispersed populations in Micronesia have different gonad characteristics. Pearson and Endean's data are for aggregated populations of *A. planci*; thus a dispersed population was selected for this study and histological examinations of the gonads were made in addition to gonad index measurements.

MATERIALS AND METHODS

Gonad Samples. Samples of *A. planci* were obtained from June 1972 to April 1973 from Lodestone Reef, an inner patch reef 43 miles NNE of Townsville with a small dispersed population of starfish. The samples varied from 9 to 17 starfish, a total of 98 starfish being collected in 75 diver-hours. Total diameters of the starfish ranged from 17–42 cm, with a mean of 30 cm. Three samples were collected from Bowden Reef, another inner patch reef 73 miles E by N from Townsville, from January to March 1973. This reef had several aggregated populations of *A. planci* at the southern end.

Three measurements were made on the gonads of each starfish collected from Lodestone: 1. Gonad index. This was measured according to the method of Pearson and Endean (1969). 2. 1-Methyladenine (1-MeAde) response. Several gonad lobes were placed in 10^{-5} M 1-MeAde in seawater and other lobes were placed in plain seawater as controls. Emission of gametes was noted after several hours. [1-MeAde is normally produced by the follicle cells in the starfish ovary and causes ovary contraction and oocyte maturation divisions (Hirai and Kanatani, 1971)]. 3. Oocyte diameter or spermatogenesis zones. Gonad lobes were fixed in seawater Bouin's medium, sectioned at 7 μ and stained with haemotoxylin and eosin. The minimum diameter of 50 oocytes was then measured in each female following the technique of Pearse (1965). In each male, lobule width was measured at ten positions in the testis lobe sections and at each of these positions the widths of the two spermatogenic zones and the central zone of spermatozoa were also measured. Each section presented a complex pattern of lobule sections, and positions of measurement were selected on the bases: where there was a circular cross-section of a lobule or where there was a longitudinal section of a lobule with parallel walls and where the sectioned lobule width approximated to the normal width of lobules in that testis.

Larval Development. In preliminary feeding experiments with various mixtures of three flagellates, *Dunaliella primolecta, Monochrysis lutheri*, and *Amphidinium carteri*, at total concentrations of 3,000 cells/ml, it was found that *A. planci*

larvae only developed beyond bipinnaria when *Amphidinium* was present. It was used in subsequent experiments at 1500 cells/ml with one of the other flagellates at the same concentration. It was also found that larvae could be reared successfully in small glass bowls with ca. 33 larvae in 100 mls of water. The bowls had no aeration or circulation and they were partially submerged in water baths to control temperature.

Three replicates of ca. 33 larvae were subjected to each of 15 salinity-temperature treatments. The salinity and temperature ranges were selected as conditions that the larvae may encounter in the field. Larvae were obtained from eggs fertilized *in vitro* and maintained overnight in large containers with seawater (35‰S) on a shaker bath at 28°C. Early on day 1, the newly-hatched larvae were transferred stepwise to the experimental temperatures and salinities. The larvae were fed daily with flagellates and transferred with a pipette to fresh conditions every alternate day. On day 8, pieces of coralline alga were added to bowls containing brachiolariae to act as settlement substrates.

RESULTS AND DISCUSSION

Gonad Index. The pattern of gonad index variation in the dispersed population of *A. planci* at Lodestone Reef, shown in Fig. 1, was the same as that found in the densely aggregated populations at Cairns (Pearson and Endean, 1969). Mean gonad index rose progressively from mid-winter (June) to mid-summer (December) and then declined to a very low level in late January. Samples from Bowden Reef also showed a sharp decline at this time. Mean gonad index in December was lower at Lodestone than in the aggregated populations studied by Pearson and

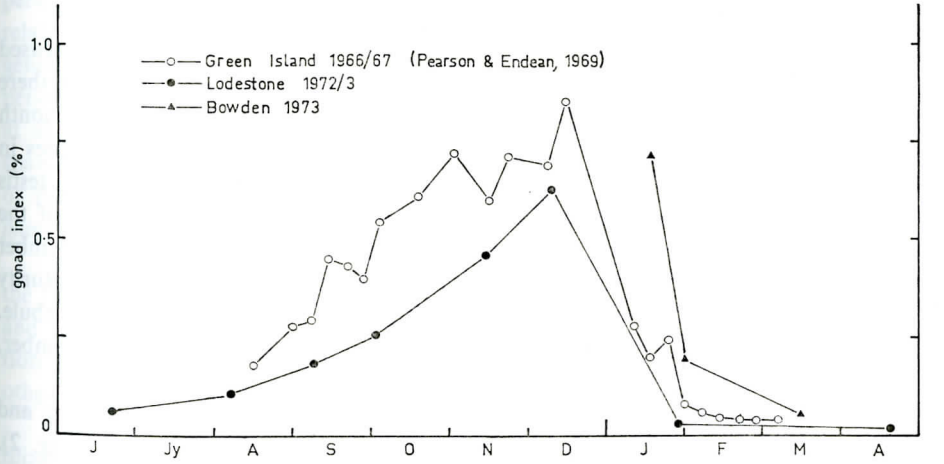

Fig. 1. Mean gonad indices of *A. planci* samples from Lodestone Reef, June 1972-April 1973, and Bowden Reef, January-March 1973. Some data from Pearson and Endean (1969) are included for comparison.

Endean (1969), but there was considerable variation within samples and no clear distinction between dispersed and aggregated populations as found by Cheney (1972) in Micronesia.

Gametogenesis. Correlated with the variations in mean gonad size (Fig. 1) were variations in mean oocyte diameter in ovaries and mean width of the spermatozoa zones in testis lobules (Fig. 2). A small proportion of mature oocytes

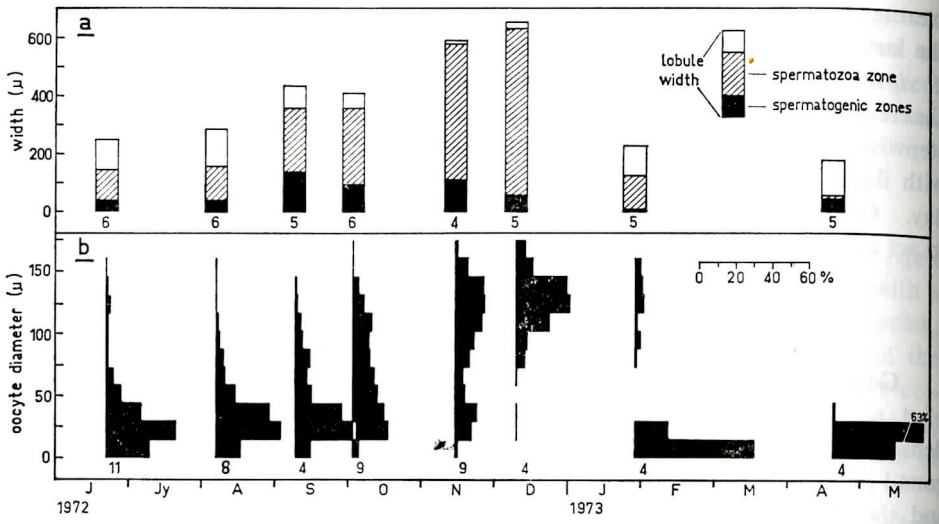

Fig. 2. Histological examinations of *A. planci* gonads from Lodestone Reef, June 1972-April 1973. a. Mean widths of testis lobules, spermatogenic zones and spermatozoa zones in testis sections. b. Oocyte size/frequency distributions in ovary sections. Numbers of individuals in each sample are shown.

was present in June-September; then the proportion of mature oocytes increased after September to become the dominant mode in November. In December there were few immature oocytes. Thus some oocytes must complete oogenesis in a month from November to December, which is very rapid oogenesis compared to rates in starfish from higher latitudes (Chia, 1964; Pearse, 1965; Crump, 1971). In testis lobules, intensity of gametogenesis appears to be reflected in the thickness of the peripheral gametogenic layer. Thus, gametogenesis was strongest from September to November, and was very low in January and February (Fig. 2a). Testis maturity is reflected in lobule width and width of the central zone of spermatozoa in the lobule. The spermatozoa zone increased in size particularly from October to December, until there was little free space in the lobule.

Breeding Season. Mature oocytes were present from June to February and mature spermatozoa were present in all samples from Lodestone Reef (Fig. 2). From June to February, ovaries containing at least some mature oocytes and testes containing a substantial zone of spermatozoa could be induced to contract and shed mature gametes, either spontaneously on removal from the starfish (testes) or after

treatment of the excised gonads with 1-MeAde solution (ovaries). The proportion of starfish with gonads making these responses was low from June to September and in January and February, but the potential to shed gametes existed for nine months during the year. Despite this, there was no evidence of gamete release in the field except during the mid-summer breeding season. Spent gonads, readily recognizable in histological section by thick wavy walls and clusters of phagocytic cells in the lumens, were only seen in January and February.

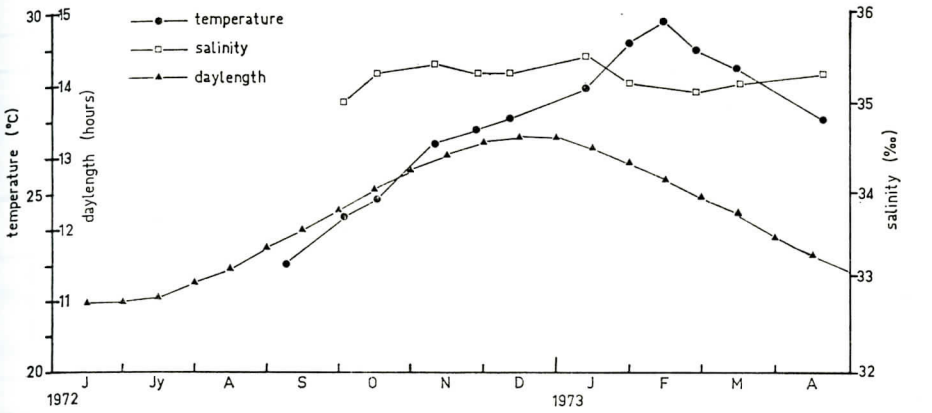

Fig. 3. Variation in surface water temperature and salinity at the level of the inner patch reefs off Townsville (R. A. Kenchington, unpubl. data) and variation in daylength at Townsville, June 1972-April 1973.

The environmental factors influencing the course of reproductive events in echinoderms are complex, but lunar cycles, daylength, food, salinity, and temperature may be important (Boolootian, 1966). Food and salinity (Fig. 3) are relatively constant at Lodestone Reef and are unlikely to be stimulating gametogenesis or spawning. The period of very active gametogenesis corresponds to the period of increasing temperature and daylength (Fig. 2 and Fig. 3); spawning occurs at about 28°C, medial to the favorable range for larval survival (Table 1), and spawning commences at the time of maximum daylength. Temperature or daylength or both would seem to be important in controlling the reproductive events of *A. planci*.

Although the dispersed *A. planci* at Lodestone Reef shed their gametes during the breeding season, the starfish were apparently as widely dispersed in December and January as at other times. This situation is not conducive to good fertilization rates and the reproductive effectiveness of the Lodestone population, and other dispersed populations of *A. planci*, is questionable.

Larval Development. Percentage survival of *A. planci* larvae 8 days after fertilization in 15 salinity-temperature treatments is shown in Table 1. Temperature, salinity, and a salinity-temperature interaction all have highly significant effects on larval survival (Table 2). It is surprising to find in a marine animal that survival is

Table 1. Percentage survival on day 8 of *A. planci* larvae. Three replicates of ca. 33 larvae at 5 temperatures and 3 salinities.

		Salinities (‰)			
		30.0	32.5	35.0	Mean
Temperatures (°C)	24	54.8	51.5	16.6	41.0
	26	56.3	24.2	12.4	31.0
	28	83.5	40.5	36.6	53.5
	30	59.4	72.4	11.5	47.8
	32	2.7	0	0	0.9
	Mean	51.3	37.7	15.4	

Table 2. Analysis of variance of the survival data of Table 1 using an arcsine transformation of the data (transformed value = arcsine (proportion surviving)$^{1/2}$)

Source of Variance	Degrees of Freedom	Mean Square	Variance Ratio	p
Temperature	4	2984.7	31.61	$\ll .01$
Salinity	2	2265.6	23.99	$\ll .01$
Temp.-Sal.	8	323.4	3.43	$< .01$
Residual	30	94.4		
Total	44			

inversely related to salinity, at least to 30 ‰S (Table 1). Similar effects of lowered salinity were observed in preliminary experiments. The larvae also appeared to be developing more rapidly in the lower salinities, a phenomenon which was also observed in *A. planci* bipinnaria by Henderson (1969). In other experiments where *A. planci* bipinnaria were transferred progressively to lower salinities, larvae completed development and metamorphosis in 26 ‰S, but not in 22 ‰S.

A. planci larvae survive over a narrow temperature range of 5°C or less. Larvae died rapidly at 32°C and none developed beyond bipinnaria at 24°C, although they became devious and died slowly at the lower temperature. Few larvae reached brachiolaria stage at 26°C. At 28 and 30°C many were early brachiolaria at day 8 and in this experiment they began settling at day 9, apparently prematurely because none completed metamorphosis normally. In other experiments the minimum periods to metamorphosis and juvenile starfish were 16 and 17 days, respectively, at 28°C. This was shorter than previous reports for period of development (Henderson and Lucas, 1971; Yamaguchi, 1973).

Some ecological consequences of the temperature and salinity tolerances of *A. planci* larvae are apparent. Larval temperature requirements may be a critical factor in the southern distribution of *A. planci* in Great Barrier Reef waters where maximum water temperature is 27–28°C. South of Townsville it is expected that the breeding season of *A. planci* occurs late in summer corresponding to maximum water temperatures. At Townsville and further south the inner patch reefs are at least 35 miles off-shore and salinity is little affected by river discharge. North

of Townsville the reef system is closer to the mainland and salinity will be influenced by river discharge at times of heavy rainfall, at least at the level of the inner patch reefs, *e.g.*, in January 1972, salinity at 1 m and 10 m depths was lowered by 3.7 and 2.1‰, respectively, at Feather Reef off Mourilyan Harbour (R. G. Pearson, pers. comm.). Lowered salinity will indirectly effect *A. planci* larvae through its effect on the phytoplankton (Qasim, Bhattathiri and Devassy, 1972) and it will have a direct effect in improving survival.

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