Sexual Reproduction and Early Development of the Solitary Coral *Fungia scutaria* (Anthozoa: Scleractinia)

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Received 23 May 1983; accepted 15 July 1983

**Abstract.** *Fungia scutaria* spawned vigorously with a lunar periodicity during the summer months of 1981 and 1982. Spawning activity declined in the fall of both years and was absent in winter and spring (1983). There was only one short spawning event per lunar cycle. Each event occurred in the evening between 1700 and 1900 hours 1 to 4 days following the full moon. *Fungia scutaria* exhibits gonochorism. Females ejected eggs through their mouths into the seawater above. Many of these negatively buoyant eggs settled onto the oral discs and were moved off the edge by ciliary-mucoid activity. Spermatozoa from males were similarly expelled in a jet of gastrovascular fluid. Spawned eggs were small and lacked endosymbiotic zooxanthellae. Rapid development led to ciliated solid planulae by the next morning. Within 24 h a mouth had begun to develop. Planulae may have been able to feed within 39 h. Infection with zooxanthellae occurred 4-5 days following spawning. Planulae may have become competent for settlement by 7 days, but attempts to document settlement produced ambiguous results.

*Fungia scutaria* is an extensively studied species in Hawaii (Edmondson 1929; Bosch 1967; Yamazato 1970; Maragos 1972; Jokiel and Cowdin 1976; Coles and Jokiel 1977; Jokiel and Coles 1977), and attempts have been made to document its sexual reproduction (Edmondson 1946; Harrigan 1972). However, until now, sexual reproduction has not been observed in this species. In this paper I document the timing and mode of reproduction in the solitary coral *Fungia scutaria*. In addition, information on the development and behavior of the planulae is presented.

**Materials and Methods**

Approximately 30 specimens of *Fungia scutaria* Lamarck (approx. size range: 5–20 cm length), from various shallow water locations in Kaneohe Bay, Oahu, Hawaii, were maintained together for several months in an outdoor aquarium at the Hawaii Institute of Marine Biology. The aquarium received a continuous flow of unfiltered sea water pumped from Kaneohe Bay. Water temperature was recorded on a daily basis.

At 1800 hours on 20 July 1981, intensive spawning of eggs was fortuitously noted in the aquarium. In addition, 2 specimens that had been isolated from the aquarium and placed in separate chambers outdoors were found spawning eggs in synchrony with the aquarium-held corals. In response to these observations, 10 corals were isolated from the field and observed for further spawning during the next 5 days. Throughout the following several months (until November 1981), the aquarium was monitored for evidence of spawning activity. Observations were also carried out during September through October of 1982 and January through April of 1983. For these latter observations, 5 specimens were selected each day from the aquarium beginning 4–5 days before the full moon and ending 6–7 days following the full moon. Each of the selected corals was placed into a separate aerated bowl outdoors and monitored for spawning activity. The aquarium was also examined for evidence of spawning activity.

Spawned eggs from the aquarium and chambers were sampled and observed for evidence of fertilization (indicated by the onset of cleavage). Fertilized eggs were washed 4 times in filtered sea water (0.45 μm pore size) and maintained in finger bowls containing aerated filtered sea water at about 25 °C under fluorescent light during typical daylight hours. Most of the developing larvae reared this way died in about 4 days. Subsequent observations were carried out on planulae that had developed in the outdoor aquarium. Fully developed planulae found in the aquarium 8 days after the spawning event were prepared for SEM following a 1-h fixation in saturated mercuric chloride, then 24 h in buffered 10% formalin-sea water, followed by desalting and dehydration.

**Introduction**

Much information concerning the reproductive biology of scleractinian corals has recently become available (reviewed by Fadlallah 1983). Long-accepted assumptions, such as the generality of planula brooding by corals (Hyman 1940; Vaughan and Wells 1948; Wells 1966), are under scrutiny. New hypotheses surrounding the relationships between the mode and timing of reproduction and the life history adaptations of corals are being proposed (e.g., Connell 1973; Stimson 1978; Rinkevich and Loya 1979a, b; Szmant-Froelich et al. 1980; Kojis and Quinn 1981, 1982a, b; Fadlallah and Pearse 1982a, b; Richmond and Jokiel, in press). Unfortunately, the information is inadequate to support or refute many of these hypotheses (Fadlallah 1983). Consequently, new observational data on the mode and timing of reproduction and the subsequent development of the larvae in corals are needed.
Results

Spawning occurred simultaneously in the aquarium and isolated chambers, predominantly between 1700 and 1900 on 20 July 1981, 4 days after the full moon. High tide in Kaneohe Bay occurred at approximately 1730. The water temperature was 27.8 °C, near the seasonal maximum. Average daily solar input was also near the seasonal maximum.

Because preparations were underway on the previous day for an unrelated experiment using isolated specimens of Fungia scutaria, any spawning on that day would probably have been noticed. No further spawns occurred until 17 August 1981 when thousands of freshly spawned eggs and sperm were found in the aquarium between 1700 and 1900. It was not possible to estimate the proportion of corals spawning.

There were no subsequent spawning events observed during the next several days. Thus spawning appears to occur only once per lunar cycle.

No observations were carried out during a similar period in September, but the presence of many planulae in the bottom sediments of the aquarium about 1 week after the full moon suggested that a spawn had taken place. In October 1981, 2 days following the full moon, the intensity of spawning was much reduced. In November 1981, 2 days following the full moon, only 1 coral of more than 30 in the aquarium was observed releasing spermatozoa. A few planulae were found on the aquarium as late as November, but these were considerably less in number than were those observed throughout August and September. No observations were made from December 1981 to April 1982.

Evidence of sexual reproduction (spawning of eggs and sperm or the presence of planulae in the aquarium) was not observed during May and June of 1982. Careful observations were not made throughout July and August, but on 5 September 1982 an intense spawning event occurred in the early evening, 1 day following the full moon. In addition to the general spawning activity in the aquarium, all of the isolated corals spawned. The isolated corals spawned again on 5 October. Two of the latter group were among the 5 that spawned in September. A spawning event was again noted occurring on 3 November, but the reproductive output was very much reduced relative to the previous 2 months. No spawning activity could be documented during January through April of 1983.

Individuals observed in the process of spawning expelled either eggs or spermatozoa, never both. However, 3 corals isolated in aerated glass bowls during the September 1982 event yielded eggs that developed into ciliated planulae, implying simultaneous hermaphroditism and self-fertilization, or parthenogenetic development of the eggs. Another possibility may be that some spermatozoa were released prematurely by other corals in the aquarium and contaminated the seawater into which the corals were isolated. The latter possibility seems to be the most reasonable explanation since the 2 corals that were isolated prior to and during the 20 July 1981 event released eggs that never developed. These 2 corals were receiving a continuous flow of highly filtered seawater (0.65 μm). Furthermore, examination of gonadal tissue from many specimens (>20) has failed to document hermaphroditism (Wright, personal observation).

The eggs are expelled through the mouth in a jet of gastrovascular fluid, presumably a result of the contraction of the body wall. In calm conditions, such as those existing in the aquarium, the negatively buoyant eggs settled onto the oral disc. Ciliary-mucoid activity transported the eggs to the edge of the corallum where they fell, massed in mucus, to the substrate below. Fecundity was not accurately estimated. However individual egg production numbered in the thousands.

Spermatozoa are usually expelled in a similar fashion, except that they remain suspended in the water. On one occasion (November, 1981), packets of spermatozoa were observed massed in mucus on the surface of one coral. After a short quiescent period, these spermatozoa became active and the packets broke up.

The eggs (Fig. 1A), averaging 83.6 ± 4.4 (X ± SD, N = 10) μm in diameter, were densely granular and lacked the endosymbiotic zooxanthellae characteristic of maternal gastrodermal cells. Fertilized eggs cleaved within 1 hour. Cleavage was polar and complete. Early solid blastulae (Fig.1B) were observed within about 4 h of spawning. Sparingly ciliated planulae were obtained by the following morning (Fig.1C). These early planulae were oval in shape and appeared solid. Their movement was predominantly restricted to creeping along the bottom with occasional slow swimming.

By 24 h an oral pit had formed, and by 39 h a mouth was clearly visible. The interior appeared to be filled with yolky cells. Ciliary currents drove particulate matter towards the mouth. Some of this material was ingested. When a suspension of freshly isolated zooxanthellae (from homogenate of Fungia scutaria, washed 3X in filtered sea water with centrifugation) was added to some of these planulae, their mouths dilated, and some yolky material was lost. Ingestion of zooxanthellae was not observed. Several days later a few of these planulae possessed zooxanthellae.

Planulae kept without the addition of zooxanthellae never became infected for as long as they lived (most to about 4 days). However, by the 4th day about 50% of the planulae found in the aquarium with adult corals possessed zooxanthellae. Nearly all of the aquarium planulae possessed zooxanthellae by the 5th day. The sediments of the aquarium contained many motile zooxanthellae swarmer. These swarmer usually attached themselves by their flagella to glass slides, algae, detritus, and sometimes to the planulae themselves. However, there was no obvious taxis between planulae and zooxanthellae swarmer.

These barrel-shaped planulae (Fig.1D), ranging in size from about 90 to 120 μm in length, were highly active, swimming aborally and spinning about the oral-aboral...