

Table 3:

Species	Diameter in microns
<i>Mopalia porifera</i> (PILSBRY, 1892)	170
<i>Mopalia imporcata</i> (CARPENTER in PILSBRY, 1892)	180
<i>Mopalia ciliata</i> (SOWERBY, 1840)	200
<i>Mopalia spec. nov.</i>	200
<i>Mopalia lowei</i> (PILSBRY, 1918)	200
<i>Mopalia lignosa</i> (GOULD, 1846)	240
<i>Ischnochiton mertensi</i> (MIDDENDORFF, 1846)	200
<i>Ischnochiton radians</i> (CARPENTER in PILSBRY, 1893)	180

Heath (1899) reports that the eggs of *Ischnochiton* (*Stenoplax*) *magdalenensis* (Hinds, 1844) [= *I. (Stenoradsia) heathiana* Berry, 1946] average about 400 microns in diameter. I find it curious that the eggs of various species of *Mopalia* are so much smaller than those of *I. (S.) heathiana*, when it is considered that the latter species has a free-swimming larval stage that lasts less than 5 percent as long as the free-swimming stage of *Mopalia* larvae. One would expect that the species with the longer free-swimming stage would require more stored food and therefore possess the larger eggs.

Larval Development

The development of *Mopalia ciliata* follows quite closely that of *Lepidopleurus asellus* (Spengler) as described by Christiansen (1954) and that of *Chaetopleura apiculata* (Say) as described by Grave (1932) in general pattern and the timing of development. The larval development of *M. ciliata* differs from that of *Ischnochiton* (*Stenoradsia*) *heathiana* as described by Heath (1899) in having more rapid initial cleavage after the egg is fertilized, in emerging from the egg case at a much earlier stage of development, and in possessing a much longer free-swimming larval stage. Table 4 summarizes some of the principal events in the larval development of *M. ciliata* in chronological order.

Discussion

All of the ten species considered in this paper which have laid eggs can be described as free spawning for, although as I have indicated in the case of *Mopalia ciliata*, some mucus is present, the eggs can be dispersed fairly easily in sea water. This would also seem to be the case for *Ischnochiton* (*Lepidozona*) *cooperi* (Carpenter in Pilsbry, 1892) as described by Heath (1905). Heath (1905) describes the eggs of *Katharina tunicata* (Wood, 1815) as being en-

closed in a ? visible mucus secretion. According to Grave (1932), the eggs of *Chaetopleura apiculata* are also enclosed in a mucus secretion, and Christiansen (1954) describes a similar condition for the eggs of *Lepidopleurus asellus*. The greatest development of a mucus or albumen secretion surrounding the eggs occurs in *I. (Stenoradsia) heathiana*, where, according to Heath (1899), the eggs are enclosed in long albuminous sheaths, which are of sufficient strength to hold the eggs together for several days after spawning.

Both *Nuttallina thomasi* (Pilsbry, 1898) and *Trachydermon* (= *Cyanoplax*) *raymondi* (Pilsbry, 1894) do not release their eggs into the surrounding water but retain them in the mantle cavity until after the larvae have gone through metamorphosis (Heath, 1905). The latter species is unique in being the only one thus far described which is hermaphroditic (Heath, 1907).

I began to suspect rather early that there might be some correlation between the time that both sexes of *Mopalia ciliata* released gametes and the tidal cycle. Figure 1 shows the gamete release times for *M. ciliata*. The reference point for this species is the low high tide occurring after collection. Figure 3 shows the gamete release times for *Mopalia spec. nov.* (see Thorpe, 1961). The reference point for this species is the next high low tide following collection. Figure 2 represents the average spring tide tidal cycle since the times between the successive high and low tides do not remain constant throughout a month or a year, and the data cover a period of several years. The low high tide for the day was selected as the reference point, which introduces a maximum error of not more than 5 percent in the times shown between the low low tide and the low high tide and a maximum error of not more than 9 percent in the times shown between the low high tide and the high low tide. The gamete release times for each species are in the same order and represent the same individuals shown in Table 1, except that the last 15 individuals in Figure 1 and the last four individuals in Figure 3 represent recent observations which were not included in Table 1.

Although not perfect in detail, there seems to be a reasonably good correlation between the time that individuals of *Mopalia ciliata* release gametes and the low high tide for the day. *Mopalia spec. nov.* follows a different pattern. The females apparently spawn on a low tide, while the males show a less predictable pattern. The difference shown by the two species is of particular interest because they are believed to be very closely related.

Table 4:

The development of *Mopalia ciliata* (SOWERBY, 1840)

Time After Fertilization	Features of Development or Behavior Typical for the Time Period Shown
0 hours	Fertilization. Polar body minute and transparent.
1-1½ hours	First cleavage occurs.
2 hours	Second cleavage occurs.
3- 6 hours	Third and subsequent cleavages are somewhat more rapid in the micromeres. Macromeres tend to be slightly larger than micromeres.
10-12 hours	Gastrulation beginning. The first cilia of the velum are developed and beating at about 12 hours.
18-24 hours	Cilia of velum encircle larvae and beat in wave-like motions. Gastrulation apparently complete at 24 hours.
24-48 hours	Larvae emerge from egg cases during this period. Development to this stage temperature dependent, i. e., larvae developed at 12-15° C. above normal ocean temperature emerge from egg cases in 12 to 24 hours; those developed at 3-5° C. above normal emerge at 24 hours. Larvae developing at normal ocean temperature emerge in 36 to 42 hours. Apical cilia develop just prior to emergence from the egg case.
2- 4 days	Larvae are free swimming in aerated water; in non-aerated water they remain at the bottom and move only slightly. Photonegative. Larvae most active at the end of this period; swimming may be in a loose spiral, with the larvae rotating rapidly, or in a straight line without rotation.
4- 5 days	The anlagen of the ocelli and the valves begin to develop towards the end of the fourth day. The anterior valves are the first to be apparent. Larvae becoming elongated in the antero-posterior axis and flattened dorso-ventrally.
5- 8 days	Larvae noticeably less active. The predominant movement towards the end of this period is creeping. All eight valves and CaCO ₃ spicules of the girdle present on the eighth day. End of free swimming stage.
8-16 days	"Metamorphosis" complete at 16 days where the larvae are not retarded by unfavorable conditions. The anus has developed. Ocelli still present. Valves are still covered by epithelium. Velum and apical cilia have been lost. Anlagen of the radula develop during this period. When examined under a microscope, the larvae attach to the slide by posterior portion of the foot, which portion in stained preparations has a glandular appearance.

Brewin (1942) has shown that *Cryptoconchus porosus* (Burrow, 1815) releases gametes every 15 days for a period of 2 to 2½ months, and spawning is apparently correlated with the phases of the moon. Gamete release by *C. porosus* occurred regularly during the middle of the day and was not correlated with the tidal cycle. Brewin was also able to show that the results obtained in the laboratory coincided with

the dates and times of gamete release by the animals in their natural habitat.

Christiansen (1954) and Heath (1905) have reported that egg laying in chitons occurs only after males have released sperm. Their statements were apparently based upon small numbers of observations. From experiments with *Mopalia lignosa* and *Ischnochiton heathiana*,



Stohler, Rudolf. 1962. "Busy-cotopus (B.) canaliculatus in San Francisco Bay." *The veliger* 4, 211–212.

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