On growth, feeding and reproduction in the chiton *Mopalia muscosa* of Santa Monica Bay[1]

RICHARD A. BOOLOOTIAN

Department of Zoology, University of California, Los Angeles, USA

KURZFASSUNG: **Über Wachstum, Ernährung und Reproduktion bei dem Chitonen *Mopalia muscosa* der Santa Monica Bucht.** An Hand von Untersuchungen in der freien Natur und im Laboratorium werden neue Informationen vorgelegt über wichtige ökologische Parameter von *M. muscosa*. Bei dieser Art kommt das Schalenwachstum während des Winters fast oder gänzlich zum Erliegen. Die Art ist herbivor und lebt vor allem von Rot- und Grünalgen. Beim Fortpflanzungsgeschehen können zwei Laichperioden unterschieden werden, von denen eine vor allem in den Winter fällt, die andere in den Vorfrühling.

INTRODUCTION

The work reported herein was undertaken primarily to study the annual reproductive cycle of the chiton *Mopalia muscosa*. Data on the reproductive cycle of marine invertebrates are not extensive (GIESE et al. 1959). In the majority of cases an annual reproductive cycle has been recorded, but many species breed more than once during the cycle, some showing a monthly rhythm (KORRINGA 1947). Information on reproduction, feeding and growth of amphineurans is conspicuously absent in the literature. In fact, the volume "Physiology of mollusca" (WILBUR & YONGE 1964) provides little data on these subjects. Although the annual reproductive cycle is emphasized here, consideration is given also to growth and food preferences of *M. muscosa*, one of the most common intertidal chitons of Southern California.

METHODS AND MATERIALS

Growth was studied in the field by capture-recapture methods an in the laboratory by controlled feeding experiments. Sites of collection were Flat Rock Point, Sunset Point, and Latigo Point, all within Santa Monica Bay, California. Field animals were collected carefully, weighed, measured, marked and released at the exact point of removal. Recaptured animals underwent the same determinations and were again released.

[1] This study is supported by National Science Foundation Grant G9561; it is dedicated to Professor A. BÜCKMANN on his 65th birthday, January 17, 1965.

Animals in the laboratory were kept in circulating sea-water tanks and fed specific species of algae for 14 or 18 day periods. The same determinations were made for these animals as for the field populations.

Food preferences of *M. muscosa* were studied by examining the intestinal contents of 15 animals collected at each of the three sites per month. The digestive tracts of all animals from one site were combined since a single animal does not have enough material for analysis.

The annual reproductive cycle of *M. muscosa* was determined by measuring the gonad index (the volume of the gonad divided by the weight of the animal and multiplied by 100) of 15 animals from each site per month for one year, collected during low tides.

Each animal was weighed and measured, the foot removed, and the animal eviscerated, permitting easy removal of the gonad. The digestive tract was preserved in neutralized formalin for the food preference determinations mentioned above. The gonads of three chitons of each sex per site per month were fixed in Bouins, embedded in paraffin, then sectioned at 15 μ and stained. Each slide was examined to determine the percent of mature ova ($\pm$ 5 %), size of mature ova, and nature of protein coat, if any, for all females. Percent of male gonadal ascini filled with mature sperm was noted.

RESULTS

Growth

Out of 176 marked chitons, 31 were recaptured one or more times, totaling a 25 % recapture. Of the 31 animals, 23 lost weight and 8 gained weight. From November 1960 through March 1961, no growth of the shell was noted, although some animals gained weight. During April, however, shell growth occurred from 1.1 to 3.2 mm on the marked plates (Table 1).

All 31 recaptures were recorded at Flat Rock Point and Sunset Point. Of the 36 chitons marked at Latigo Point in November 1960, none were found after the annual winter deposition of sand was removed. Shell growth slows or stops during the winter (when the gonad index is increasing) and resumes again during the spring and summer, after the annual spawn.

Chitons used in the laboratory food preference studies were also examined for growth, but none was observed. The laboratory animals did not feed normally. This same difficulty was encountered by GIESE et al. (1959).

Feeding

A total of 76 *M. muscosa* were fed various species of algae in the laboratory. A control group of 6 animals was fed nothing. Only one of the feeding experiments showed weight gain; but even so, only 36.4 % of these animals gained. In this particular experiment, the animals were fed a mixture of algae which was attached to

Table 1

Recaptures of marked *Mopalia muscosa*

Flat Rock Point					Sunset Point				
Specimen number	Period 1960–61	No. times recaptured	% change in body weight	Growth in mm	Specimen number	Period 1960–61	No. times recaptured	% change in body weight	Growth in mm
4	Nov – Apr	1	— 02.5	none	13	Nov – Dec	2	— 12.0	none
10	Nov – Feb	2	— 35.8	none	38	Nov – Dec	1	— 06.3	none
14	Nov – Dec	1	— 03.1	none	49	Nov – Nov	1	+ 04.5	none
15	Nov – Apr	2	+ 03.7	none	50	Nov – Dec	2	— 06.5	none
19	Nov – Dec	1	+ 03.3	none	51	Nov – Nov	1	+ 07.0	none
20	Nov – Feb	2	— 00.4	none	55	Nov – Dec	1	— 05.0	none
21	Nov – Dec	1	+ 03.0	none	56	Nov – Dec	1	— 03.3	none
24	Nov – Jan	2	— 01.6	none	67	Nov – Dec	2	— 04.5	none
26	Nov – Apr	2	— 03.6	none	68	Nov – Dec	1	— 08.6	none
27	Nov – Feb	3	— 03.2	none	74	Dec – Mar	1	— 04.7	none
28	Nov – Apr	1	+ 08.8	1.6	78	Dec – Mar	1	— 13.7	none
30	Nov – Apr	1	— 02.6	1.1	83	Dec – Mar	1	— 09.4	none
31	Nov – Feb	2	— 08.2	none		*1961*			
35	Nov – Apr	1	+ 18.0	3.2	88	Feb – Mar	1	— 06.0	none
36	Nov – Jun	2	— 30.0	none	94	Feb – Mar	1	— 06.5	none
40	Nov – Apr	1	+ 05.0	1.6	98	Feb – Mar	1	— 06.1	none

Table 2

Laboratory feeding experiments

Experiment Number	No. of chitons	Algae used	Duration of experiment	No. losing weight	% weight lost (X)	No. gaining weight	% weight gained (X)	No. dead chitons
1	18	*Pelvetia fastigatus*	14 days	15	10.1	2	1.1	1
2	18	*Gigartina*	14 days	15	10.9	2	13.5	1
3	18	*Ulva lactuca*	14 days	15	4.8	1	10.8	2
4	22	*Ectocarpus Erythrotrichia Ulothrix Antroceras Polysiphonia Isthmia Navicula*	18 days	8	5.6	8	1.0	6
5 (control)	6	none	14 days	5	3.9	0	0	1

rocks (on which chitons live) taken from Sunset Point. In the other experimental groups, the foods were the same but were not attached to any rocks. Hence it may be possible that animals maintained under these conditions feed only on attached algae.

Table 3

Intestinal contents of 15 *Mopalia muscosa* from Flat Rock Point

Month	Major gut content	Secondary gut content	Other materials in lesser quantities
Dec 1960	*Corallina officinalis*	sand	small *Balanus* and *Chthamalus;* larval pelecypods; amorphous red and green algae
Jan 1961	„	„	all the above plus *Ulva, Ectocarpus* and *Gelidium*
Feb 1961	„	„	amorphous red and green algae, larval barnacles; *Mytilus*
Mar 1961	„	„	„
Apr 1961	„	*Gelidium,* sand	„
May 1961	„	„	„
Jun 1961	„	„	all the above plus sponge spicules and diatoms
Jul 1961	„	„	amorphous red and green algae

Table 4

Intestinal contents of 15 *Mopalia muscosa* from Sunset Point

Month	Major gut content	Secondary gut content	Other materials in lesser quantities
Dec 1960	amorphous red and green algae	sand	*Gelidium* and larval *Mytilus*
Jan 1961	„	„	*Bryopsis,* larval gastropods, barnacles
Feb 1961	„	„	larval barnacles
Mar 1961	„	*Gelidium, Gigartina*	*Polysiphonia,* sand
Apr 1961	„	„	„
May 1961	„	„	small barnacles
Jun 1961	„	sand	„
Jul 1961	„	„	larval barnacles, pelecypods

But from this laboratory maintained population, conclusions on the food preferences of *M. muscosa* cannot be made (Table 2).

Examination of gut contents proved more fruitful. Many chitons were found to have an empty stomach. The undigested products, however, were formed into fecal pellets. Gut content was found to be different for each of the three sites (Tables 3, 4, 5).

Table 5
Intestinal contents of *15 Mopalia muscosa* from Latigo Point

Month	Major gut content	Secondary gut content	Other materials in lesser quantities
Dec 1960	amorphous red and green algae	*Gelidium, Gigartina*	sand
Jan 1961	*Corallina officinalis*	amorphous red and green algae	sand, *Gelidium, Gigartina*
Feb 1961	*Gelidium, Gigartina*	*Corallina*, amorphous red and green algae	sand
Mar 1961	"	*Corallina*	sand, larval pelecypods
Apr 1961	"	amorphous red and green algae	sand, larval barnacles
May 1961	sand	"	*Gelidium, Gigartina*, sand, larval barnacles
Jun 1961	amorphous red and green algae	sand	*Corallina*, barnacles
Jul 1961	"	"	"

The main gut content was the same as the dominant algae found in the niche of *M. muscosa* at each site. The animals at Flat Rock Point had *Corallina officinalis* as the main food. Sand, larval barnacles *(Balanus, Chthamalus)*, larval *Mytilus*, and other amorphous red and green algae occurred in smaller quantities. Animals at Sunset Point had amorphous red and green algae as their main gut content; sand was second in volume. Other identifiable foods in lesser volumes were the red algae *Gelidium, Gigartina*, and *Polysiphonia*, larval barnacles, *Mytilus*, and gastropods. Animals at Latigo Point had *Gelidium* and *Gigartina* as the main gut content. These chitons had a greater variety of food in their diet. It appeared that they eat more red algae than do those chitons from the other two sites. This group also had sand, larval barnacles and larval pelecypods as gut items.

The sand and larvae were probably consumed only incidentally while feeding. Larval forms settle on the food items of chitons and are ingested along with the algae. It seems that little value would be derived from larval barnacles and molluscs since they comprise such a small fraction of the total diet. Diatoms and sponge spicules were found in gut content samples but in such sporadic and rare quantities that they cannot be considered of any importance to *M. muscosa*.

Reproduction

Reproductive activity of each population showed two distinct cycles. The gonad index of *M. muscosa* at Flat Rock started at a low level in August (2.9 %), increasing until November. The gonad index dropped in December, whereafter it continued to increase until the major spawn during February and March. However, another increase in April was followed by a spring spawn. During the summer months the gonad

index remained at a low level, and the chitons began to grow in body size, adding to their shell. In the fall the cycle repeated itself. Chitons at Flat Rock spawned three times during the year with the largest spawn occurring during February and March (Fig. 1).

M. muscosa at Sunset Point and Latigo Point have the same reproductive cycles (Figs. 2 and 3). However, the Department of Parks dumped tons of sand and rock at Sunset Point as a deterent to wave erosion. The sand covered the area under study to

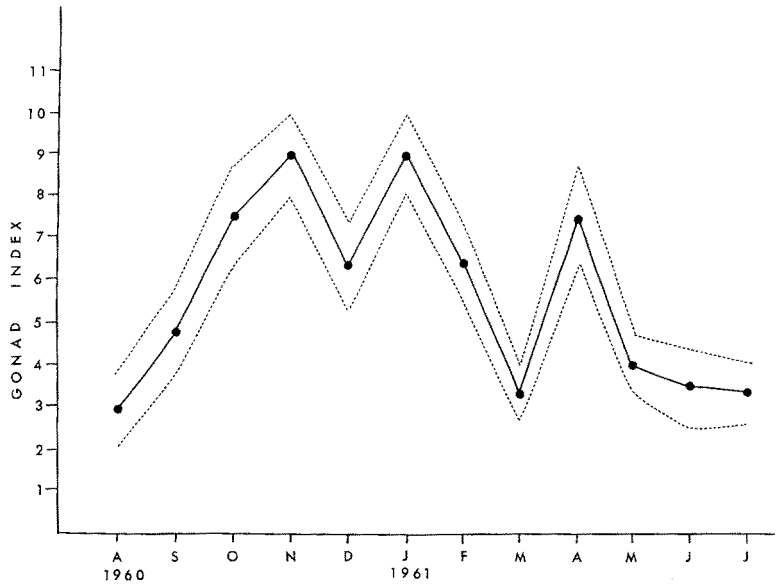

Fig. 1: Annual reproductive cycle of *Mopalia muscosa* from Flat Rock Point, 1960 to 1961. The points are the mean values, the bands representing the 95% confidence limits

a depth of several feet. Wave action removed the sand in five weeks. But this stress had a profound affect on the chitons; the covering either induced the animals to spawn at least a month earlier than the Latigo Point population, or the animals could not feed actively and gonads were resorbed.

Both of the latter-mentioned populations started out in August with a fairly high gonad index followed by a slight spawn in September. The Latigo Point population had a gonad index which increased for the next three months, and then was followed by a winter spawn starting in January and ending in March. There was another significant increase in the gonad index in April, followed by the spring spawn. Following this spring spawn, the gonad index increased during the summer and the cycle repeated itself (Fig. 3).

The gonad index of the Sunset Point population closely paralleled, but was somewhat lower than the Latigo Point population until the induced spawn in December. After that time the Sunset Point population reproductive cycle was out of phase with the Latigo Point population. Nevertheless, following the effects of the stress,

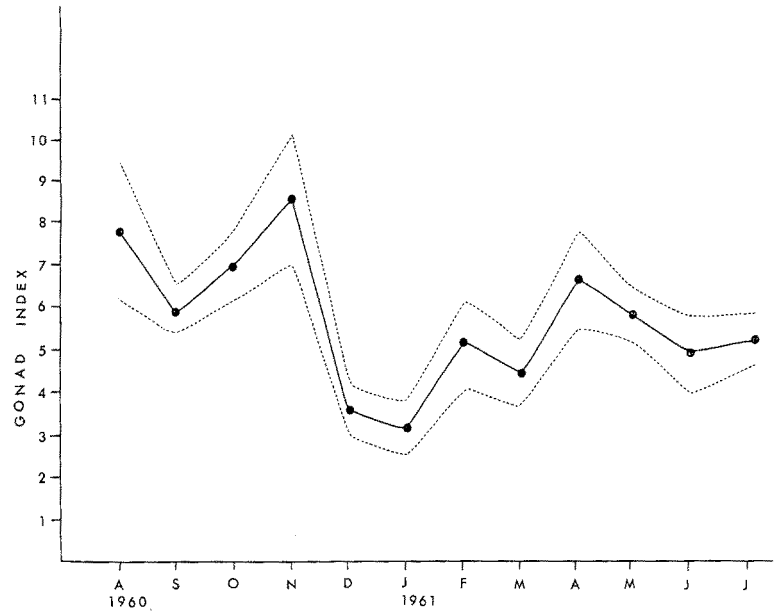

Fig. 2: Annual reproductive cycle of *Mopalia muscosa* from Sunset Point, 1960 to 1961. The points are the mean values, the bands representing the 95 % confidence limits

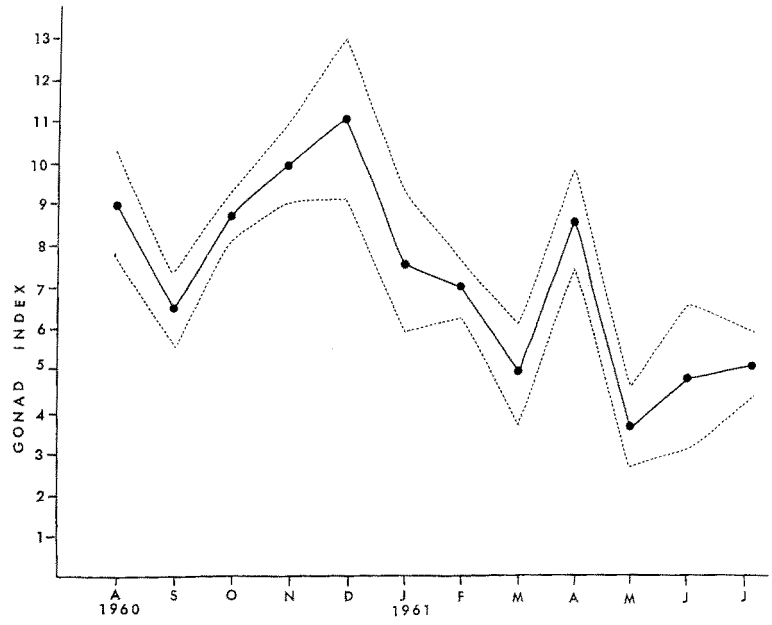

Fig. 3: Annual reproductive cycle of *Mopalia muscosa* from Latigo Point, 1960 to 1961. The points are the mean values, the bands representing the 95 % confidence limits

a gradual increase in the gonad index was noted until the spring spawn in May and June (Fig. 2).

M. muscosa at Latigo Point apparently had three separate spawns in September, March and May. *M. muscosa* at Sunset Point had two distinct spawns and possibly a third September, December and perhaps early June.

These studies show that the reproductive cycles of *M. muscosa* in Santa Monica Bay follow a cyclical though variable pattern. It is possible that the animals at each geographical locality spawn every month, as suggested by the relatively high gonad index throughout most of the year. However this was not ascertained.

Table 6

Arbitrary but easily recognizable stages of chiton gonad development

A. Female			
Spawning	=	S	low gonad index; high % mature ova; spawned or spawning
Recently Spawned	=	RS	low gonad index; low % mature ova
Redevelopment	=	RD	high gonad index; low % mature ova; gametogenic activity high; less than 25 % ova mature
Mature	=	CS	high gonad index; high % mature ova; these *can spawn;* more than 75 % ova mature
B. Male			
Spawning	=	S	low gonad index; high % mature spermatozoa; spawned or spawning
Recently Spawned	=	RS	low gonad index; empty cavities
Redevelopment	=	RD	high gonad index; cavities less than half filled with mature spermatozoa
Mature	=	CS	high gonad index; cavities filled with mature spermatozoa; these *can spawn*

To facilitate the study of prepared gonadal tissues, several gametogenic categories were established. These are listed in Table 6. From the prepared slides, information was obtained concerning sexual maturity, size of mature ova, and percent of gonadal cavities filled with viable spermatozoa. Seven months of data for each location have been tabulated in Tables 7, 8 and 9.

DISCUSSION

Growth

There is a paucity of information on chiton growth. HEATH (1905) asserts that *Mopalia lignosa* and *M. muscosa* have an average growth rate of 25 mm the first year, 8 to 11 mm the second year, and 17 to 22 mm the third year. He noted average

Table 7

Flat Rock Point. Microscopic examination of the histological preparations for gametogenesis and relative amounts of mature gametes present in the gonadal cavities. From 15 specimens collected monthly, three of each sex were selected for this study. For each month, the mean gonadal index is given ($\bar{X}$ G.I.)

Length mm	Width mm	Weight grams	Gonad Index	Sex	% ova or spermatozoa mature	Gametogenic stage
Dec 1960 $\bar{X}$ G.I. = 6.38						
60	41	19.33	8.28	F	85	CS
51	37	12.10	8.30	F	95	CS
55	33	12.09	4.97	F	80	CS
45	30	6.81	5.87	M	75	CS
46	32	8.02	5.00	M	75	CS
54	38	14.73	9.50	M	75	CS
Jan. 1961 $\bar{X}$ G.I. = 3.12						
53	34	11.66	6.58	F	85	CS
50	32	9.92	10.01	F	90	CS
51	37	14.30	3.50	F	75	S
48	32	10.82	12.00	M	75	CS
53	35	13.91	8.62	M	75	CS
43	29	7.18	6.96	M	75	CS
Feb 1961 $\bar{X}$ G.I. = 6.34						
50	33	11.90	6.88	F	80	CS
37	25	4.11	9.74	F	75	CS
51	36	16.05	4.99	F	80	CS
54	35	13.37	8.97	M	75	CS
41	29	6.66	6.00	M	75	CS
50	33	11.22	6.24	M	75	CS
Mar 1961 $\bar{X}$ G.I. = 3.36						
58	29	8.31	2.40	F	30	RS
40	25	5.55	1.80	F	20	RD
44	33	11.39	3.08	F	01	RS
62	39	25.20	3.94	M	40	S
42	28	6.42	4.68	M	75	CS
48	33	11.01	2.72	M	25	RS
Apr 1961 $\bar{X}$ G.I. = 7.51						
58	37	15.52	9.66	F	75	CS
45	30	7.86	4.45	F	90	CS
52	33	10.52	7.60	F	75	CS
47	38	8.00	6.25	M	75	CS
45	27	8.34	1.20	M	10	S
42	28	6.50	6.15	M	75	CS
May 1961 $\bar{X}$ G.I. = 4.02						
56	40	23.38	5.13	F	15	RD
49	34	12.40	4.03	F	10	RD
52	33	10.25	1.95	F	75	S
58	37	13.28	6.02	M	75	CS
42	28	7.73	3.88	M	75	CS
56	33	14.42	6.93	M	75	CS
Jun 1961 $\bar{X}$ G.I. = 3.49						
63	40	21.65	3.46	F	50	RD
54	39	14.31	6.28	F	95	CS
58	35	11.75	0.85	F	25	S
60	43	21.70	4.60	M	25	S
57	37	14.66	3.41	M	75	CS
47	30	8.32	1.20	M	60	CS

Table 8

Sunset Point. Microscopic examination of the histological preparations for gametogenesis and relative amounts of mature gametes present in the gonadal cavities. From 15 specimens collected monthly, three of each sex were selected for this study. For each month, the mean gonadal index is given ($\bar{X}$ G.I.)

Length mm	Width mm	Weight grams	Gonad Index	Sex	% ova or spermatozoa mature	Gametogenic stage
Dec 1960 $\bar{X}$ G.I. = 3.56						
50	34	9.34	4.38	F	05	RD
52	35	11.48	2.61	F	01	RS
53	35	10.66	2.50	F	01	RS
55	35	13.60	3.68	M	50	RD
53	36	10.21	4.89	M	75	CS
59	39	18.56	2.15	M	50	CS
Jan 1961 $\bar{X}$ G.I. = 3.12						
49	35	10.02	4.00	F	05	RD
60	36	17.25	2.89	F	03	RD
53	37	13.83	2.89	F	05	RD
53	34	10.39	3.85	M	75	CS
65	45	23.19	0.85	M	10	S
66	37	19.82	4.54	M	75	CS
Feb 1961 $\bar{X}$ G.I. = 5.15						
53	36	12.68	6.30	F	25	RD
46	27	5.26	1.90	F	03	RS
37	25	4.32	2.32	F	35	RD
47	34	9.55	6.28	M	75	CS
54	36	15.28	4.58	M	75	CS
51	34	12.09	4.15	M	60	CS
Mar 1961 $\bar{X}$ G.I. = 4.40						
60	38	15.51	6.44	F	20	RD
45	31	7.33	2.05	F	03	RS
52	35	12.05	4.15	F	03	RD
53	37	14.78	4.06	M	75	CS
47	32	9.61	3.12	M	60	CS
49	32	9.12	5.49	M	75	CS
Apr 1961 $\bar{X}$ G.I. = 6.64						
60	37	16.28	8.60	F	50	CS
46	30	9.48	7.38	F	60	CS
52	35	12.08	8.00	F	50	CS
45	30	7.45	8.05	M	75	CS
47	33	8.90	6.74	M	75	CS
47	30	10.00	7.69	M	60	CS
May 1961 $\bar{X}$ G.I. = 5.81						
49	34	8.21	4.87	F	65	CS
47	30	8.87	4.50	F	65	CS
50	34	10.68	5.61	F	65	CS
54	37	12.74	5.49	M	50	S
53	35	10.72	6.52	M	75	CS
43	31	8.59	5.82	M	75	CS
Jun 1961 $\bar{X}$ G.I. = 4.86						
63	41	19.35	3.61	F	10	RD
57	39	15.29	6.59	F	90	CS
48	34	9.08	5.50	F	10	RD
52	35	11.34	3.52	M	75	CS
53	38	15.78	3.16	M	75	CS
53	36	14.63	6.83	M	75	CS

Table 9

Latigo Point. Microscopic examination of the histological preparations for gametogenesis and relative amounts of mature gametes present in the gonadal cavities. From 15 specimens collected monthly, three of each sex were selected for this study. For each month, the mean gonadal index is given ($\bar{X}$ G.I.)

Length mm	Width mm	Weight grams	Gonad Index	Sex	% ova or spermatozoa mature	Gametogenic stage
Dec 1960 $\bar{X}$ G.I. = 11.13						
58	38	15.86	10.02	F	75	CS
58	41	15.11	4.63	F	35	RD
46	30	7.39	5.41	F	65	CS
65	45	19.25	12.47	M	75	CS
52	35	10.56	7.68	M	75	CS
50	35	8.17	6.13	M	75	CS
Jan 1961 $\bar{X}$ G.I. = 7.52						
53	37	13.39	11.12	F	85	CS
52	36	19.25	8.83	F	85	CS
44	33	7.64	2.62	F	70	RS
71	50	31.40	8.60	M	75	CS
59	43	19.05	4.20	M	50	RD
39	29	6.79	5.14	M	75	CS
Feb 1961 $\bar{X}$ G.I. = 6.76						
71	42	27.07	7.40	F	45	RD
48	31	9.95	10.05	F	65	CS
40	26	5.00	4.00	F	50	RD
68	45	28.17	3.91	M	75	S
58	30	14.56	7.54	M	75	CS
50	25	7.32	10.92	M	75	CS
Mar 1961 $\bar{X}$ G.I. = 4.95						
57	38	14.40	6.95	F	80	CS
47	34	8.46	4.73	F	05	RD
45	30	7.10	1.41	F	01	RS
61	40	18.20	3.30	M	25	RS
48	34	9.10	2.20	M	75	RS
49	33	9.45	2.12	M	25	RS
Apr 1961 $\bar{X}$ G.I. = 8.66						
59	40	21.25	10.35	F	75	CS
40	28	8.75	6.86	F	65	CS
36	25	5.52	7.25	F	65	CS
51	32	11.06	10.85	M	75	CS
59	40	21.25	10.35	M	75	CS
50	35	13.76	10.90	M	75	CS
45	29	6.80	4.41	M	75	CS
May 1961 $\bar{X}$ G.I. = 3.66						
78	48	39.92	2.50	F	85	S
54	36	13.40	1.49	F	50	S
38	25	5.95	1.68	F	55	S
53	35	10.33	6.77	M	75	CS
56	35	14.89	6.71	M	75	CS
46	39	6.82	2.93	M	75	S
Jun 1961 $\bar{X}$ G.I. = 4.83						
55	35	12.58	3.97	F	65	RD
59	34	15.42	3.97	F	50	RD
67	40	23.53	5.94	F	70	RD
55	41	14.98	12.97	M	75	CS
62	40	17.23	0.87	M	10	RS
46	30	8.10	12.34	M	75	CS

length for three year old *M. muscosa* to be 55 mm. HEATH did not discuss the methods by which growth was ascertained. BARNAWELL (1954) found the following growth rates in four species of *Mopalia* of San Francisco Bay:

1. *M. hindsii*	20 to 50 mm	per year
2. *M. hindsii var.*	20 to 50 mm	per year
3. *M. muscosa*	15 to 34 mm	per year
4. *M. ciliata*	11 to 40 mm	per year

BARNAWELL marked the animals and recorded length and width of the body, and shell character. His data consisted of 17 recaptures of 8 individuals over a seven month period. Although the present paper reports more recaptures than does BARNAWELL, growth data is incomplete because no significant increase in the ventral measurements, shell growth or weight changes were found.

CROZIER (1918, 1921) studying *Chaetopleura tuberculatum* in Bermuda observed that these animals have a growth rate of 10 mm per year and a mean life span of eight years and that age could be determined through the study of growth rings on the valves. He assumed that one growth ring was formed each year and states that this is assured by: 1) inspection throughout the years of the growth of young chitons appearing after the close of the breeding season; 2) by the direct observation that a growth line is formed during the winter period; and 3) by findings based upon the counts of growth lines coinciding with those derived from the modes in the frequency distribution of sizes in the chiton population. CROZIER also states that variations in environmental conditions (for example, wave action, pH, oxygen tension, temperature, and food) also cause a variable degree of growth in the same species, but without experimental proof.

AREY & CROZIER (1919) found that growth of *C. tuberculatum* decreases with advancing age; and that the maximum duration of life is eleven years. GRAVE (1932) established that *C. apiculata* is sexually mature in one year and is full grown in three or four years. The present study indicates that growth slows or stops entirely during winter months.

Feeding

Most investigators state that chitons are herbivores (MACGINITIE & MACGINITIE 1949; RICKETS & CALVIN 1960). The data here presented strongly suggests a herbivorous diet, with various species of red and green algae being predominant foods. However, BARNAWELL (1960), found that four species of *Mopalia* were carnivorous or at least had large amounts of animal matter in their stomachs. The percent of animal matter ranged from 15 to 59 percent. Data here shows very little animal matter in the intestines. It is likely that the food was incidentally ingested and not actively sought.

Reproduction

Many investigators since CLARK (1855) have described the breeding habits of chitons, but very few have used methods which are acceptable and reliable. Most work

was based on some subjective characteristic of the gonads, such as size, color, shape, and so on. Casual field observations of chitons spawning are also included in the literature. The method of determining the gonad index used by GIESE et al. (1959) seems to be the most reliable method.

HEATH (1905) noted that isolated males of *Mopalia lignosa* will spawn but that females of the same species will not spawn until stimulated to do so by the sperm or some chemical carried with or in the sperm. During the year that this work was undertaken, observations on *M. muscosa* spawning in the field were not seen; nor could spawning be induced in the lab. HEWATT (1938) at Monterey observed *M. muscosa* spawning in September, while MACGINITIE & MACGINITIE (1949) state that *M. muscosa* spawns in July and August in Puget Sound and in November at Corona del Mar.

BARNAWELL (1954) found that *M. hindsii* in San Francisco Bay had two peaks of gonadal development. One peak was in December and one was in April. Following each peak was a spawn. He assumes that *M. muscosa* in the same area spawns throughout the year because of the high percentage of animals with well-developed gonads which can be found at any time. However, *M. muscosa* have the highest percent of developed gonads from October through January, and the main spawn probably takes place in February and March. GIESE et al. (1959) at Monterey showed that *M. hindsii* spawned in March in 1957 but did not have a sudden decline in the gonad index in any month in 1958.

There is a great variation in the spawning times noted in literature. Some are casual observations, some are semi-subjective, and some are quite objective. Differences in spawning might be attributed to differences in latitude, temperature, light, food, and so forth. And the triggering mechanism(s) which incite spawning may very considerably.

In the present study, correlation of gonadal activity of the three populations with the histological information yielded some interesting data, particularly for the Flat Rock Point group. It appeared that a part of each population was out of phase with the rest of the individuals in that population, with respect to the gonad index. Spawning times at Flat Rock Point in 1960 to 1961 were December and March for Group I and February and May for Group II. The two spawning cycles are suggested in both the Latigo Point and Sunset Point annual cycles, but correlations are lacking.

Information from the histological study indicated that the male chitons were seldom completely devoid of viable sperm. Males, with rare exceptions, had over one-half of all gonadal cavities filled with sperm cells. Examination of the female gonads indicated that many of the females had less than fifty percent of the gonad filled with mature ova (ova within the size range of 140–168 μ).

Further studies on these three populations of *M. muscosa* are necessary to determine whether populations spawn continually throughout the year or during a restricted period, as suggested by Figures 1 to 3. Though histological details of the gonads revealed the presence of mature gametes in all months of the year, it is not known whether there exists a mechanism regulating the amount of gametes shed. Further investigation is necessary to determine the factors which control, regulate or influence reproduction in these marine organisms.

SUMMARY

1. In *M. muscosa* shell growth slows or stops during the winter months.
2. *M. muscosa* in Santa Monica Bay are herbivorous and eat red and green algae as their main foods.
3. *M. muscosa* exhibit two distinct spawning periods which occur mainly during winter and early spring.

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