# ASPECTS OF THE LIFE-HISTORY OF CYMATOGASTER AGGREGATA GIBBONS

by

### CHARLES DOUGLAS GORDON

B.Sc., The University of British Columbia, 1963

# A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in the Department

of

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Zoology

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

NOVEMBER, 1965

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#### ABSTRACT

Age and growth of the shiner perch, Cymatogaster aggregata Gibbons, were analysed with the aid of scales taken from fish obtained at Keates Island, British Columbia, in 1963 and 1964. Cymatogaster exhibits a relatively constant relationship between scale growth and increment of body length throughout its life and based on this observation a new method of back-calculation was developed. The scales of Cymatogaster may have up to three different types of checks, birth checks or metamorphic annuli, spawning checks, and annuli. The highest levels of instantaneous growth rates occurred during the spring and early summer, between the time of formation of an annulus and the following spawning check. It is during this period that water temperatures reach a maximum and food is most abundant. The lowest instantaneous growth rates occurred during the fall and winter months between the formation of a spawning check and the following annulus.

Seasonal and diurnal movement patterns exhibited by <u>Cymatogaster</u> were studied by means of extensive gill net sets in 1963 and 1964 at the Keates Island study area. The fish first moved into the area in early June and left again by mid-October. In June, just prior to spawning, <u>Cymatogaster</u> exhibited a pattern of diurnal movement that involved migration from deep to shallow water during the day, and from

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shallow to deeper water at night. After the spawning period there was a complete reversal of the diurnal movement pattern. Light intensity appeared to be the most important factor governing the onshore and offshore movements of Cymatogaster.

Stomach content analysis indicated that by volume, mussels and algae were the most important items in the diet of <u>Cymatogaster</u>, although barnacles and zooplankton were sometimes eaten in large quantities. Yearling <u>Cymatogaster</u> fed actively throughout the time they were present in the study area but mature fish exhibited a marked reduction of feeding during the spawning period. The initiation of feeding was governed primarily by an increase in light intensity associated with sunrise, and little or no feeding occurred during the hours of darkness. Data indicated that the rate of passage of food through the digestive tract varied between adults and yearlings, as well as seasonally.

The relationships between age and growth, seasonal and diurnal movement patterns, and feeding habits and food preferences of <u>Cymatogaster</u> were correlated and related to factors of the physical and biotic environment.

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### ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Dr. N. J. Wilimovsky who suggested the problem and who gave many worthwhile comments and criticisms in the writing of this paper. Special thanks are also due to Dr. C. C. Lindsey, Dr. P. A. Dehnel, Dr. I. E. Efford and Dr. J. T. McFadden for their assistance in the preparation of the thesis.

The author is indebted to Mr. D. Taylor, Mr. J. Hutton, Mr. A. Webster, Mr. F. Fraser, and to the many others for their assistance in field work. The writer especially wishes to express his appreciation to Mr. K. Gay who gave liberally of his time and criticism in the field.

The problem was supported by a research grant to Dr. Wilimovsky.

#### INTRODUCTION

The shiner seaperch, <u>Cymatogaster aggregata</u>, is a member of the Family Embiotocidae and is abundant along the Pacific Coast of North America from Alaska to California. Since little was known about the life history of this fish, a research program was set up to ascertain the scale growth - body length relationship, the nature of different checks found on the scales, whether or not Lee's phenomenon is present, and the instantaneous growth rates exhibited by <u>Cymatogaster</u> during different stages of its life. In 1963 and 1964, experiments were conducted to determine if <u>Cymatogaster</u> exhibited any pronounced seasonal or diurnal movement patterns, and stomach contents were analysed to ascertain feeding habits and food preferences.

The Family Embiotocidae, which exhibits viviparity, is found exclusively in the coastal waters of the North Pacific. Since 1853, when Agassiz first described the Family, a considerable amount of research associated with viviparity has been conducted on many of its species, however, very little has been published relating to ecological aspects of its members life histories. Hubbs (1921) studied the ecology and life history of <u>Amphigonopterus</u> <u>aurora</u> and other viviparous perches of California. Hubbs and Hubbs (1954) conducted research on several aspects of the life history of another Embiotocid, <u>Brachyistius frenatus</u>. Suomela (1931) worked on the age and growth of <u>Cymatogaster aggregata</u>, and Sivalingam (1956) published on the age and growth of <u>Taeniotoca lateralis</u>. Carlisle, Schoth, and Abramson (1960), conducted a study on the Barred Surfperch (<u>Amphistichus</u> <u>argenteus</u> Agassiz) in Southern California. Clemens and Wilby (1961) summarize essentially all that is known about the life histories of the members of the Family Embiotocidae that are found off the coast of British Columbia.

In the discussion an attempt has been made to correlate the relationships between age and growth, seasonal and diurnal movement patterns, and feeding habits and food preferences of <u>Cymatogaster</u> and relate them to factors of the physical and biotic environment.

### MATERIALS AND METHODS

The present study was conducted at Keates Island, which is located at the entrance to Howe Sound. A detailed description of the research area at Keates Island is given at the beginning of the thesis section on seasonal and diurnal movements. The study area included within it three relatively distinct habitat areas; reef faces, kelp beds, and open water. Specimen collections and Scuba diving observations were made throughout 1963 and 1964. All fish were captured by the use of either nylon gill nets or a lampara seine and were preserved in a solution of 10% formalin.

The study of the life history of <u>Cymatogaster</u> includes three relatively distinct areas of research; age and growth, seasonal and diurnal movement patterns, and feeding habits and food preferences. At the beginning of each of these three separate sections of the thesis, a detailed description is given of the materials and methods used for each individual study.

#### AGE AND GROWTH

Age and growth calculations were made for a total of 603 fish. All specimens were obtained from the Keates Island study area at regular intervals through May to October in 1963.

A key scale was chosen, on the left side of the fish, and was located by counting 10 scales posteriorly along the lateral line, then 3 scales ventrally. If this key scale proved to be regenerated, then the scale immediately posterior was used.

Measurements were made of two scale dimensions, scale length and anterior scale radius. A linear relationship was found between the body length of the fish and the two scale measurements, on both arithmetic and logarithmic plots, for both sexes, throughout the entire life history of <u>Cymatogaster</u>. For the purpose of back-calculation, the measurement of anterior scale radius was chosen. Figure 1 gives the relationship between body length and anterior scale radius for male and female <u>Cymatogaster</u>. Regression lines were plotted for the body length - scale radius relationship, and very little difference was found between male and female fish with regard to scale growth and body length increment (Y = 1.8122 + 2.1086 X for males, Y = 1.7288 +2.1086 X for females, and Y = 1.7720 + 2.0983 X for com-



Figure 1. Relationship of body length to anterior scale radius of both male and female <u>Cymatogaster</u>.

bined males and females).

Scale Formation and Structure of the Scale

<u>Cymatogaster</u> are scaleless until a length of approximately 2.5 cm. (Figure 2). At this time the deposition of stainable material starts in the scale pocket (Figure 3). Figure 4 shows an embryo of 2.7 cm. where the first circuli has been laid down. After the first circulus has formed, there is continuous deposition of circuli in the scale pocket until birth, at which time the embryo is fully covered with scales (Figure 5).

The scales of <u>Cymatogaster</u> have a focus, which is roughly at the center. There are also concentric rings of circuli surrounding the focus which continue out to the leading edge of the scale. The circuli extend through all fields of the scale (Figure 6).

Examination of the scales of mature <u>Cymatogaster</u> shows that there are a number of checks present where the circuli are very close together and there is evidence of discontinuity because of broken circuli. The checks on the scales of <u>Cymatogaster</u> are usually not too difficult to distinguish except in cases where the fish had reached an advanced age. The growth increments of the older fish are small; thus the checks are much closer together and much



Figure 2. Epidermis of a 2.4 cm. embryo, cleared in KOH and stained with alizarin, showing no evidence of scale formation.



Figure 3. Epidermis of a 2.6 cm. embryo, cleared in KOH and stained with alizarin, showing evidence of stainable material in the scale pocket.



Figure 4. Epidermis of a 2.7 cm. embryo, cleared in KOH and stained with alizarin, showing first circuli laid down.



Figure 5. Epidermis of a 4.3 cm. embryo just before birth, cleared in KOH and stained with alizarin, showing fully formed and overlapping scales.

harder to distinguish.

In viviparous fishes the interruption of the regular laying down of circuli, as evidenced by checks on the scale, may be attributed to one of three main factors: the temporary retardation of growth caused by change in environment and mode of feeding after birth - a metamorphic annulus (Hubbs 1921) or birth check, the slowing down of growth in the winter - an annulus, or by growth retardation due to some stress associated with reproduction - a spawning check.

The great majority of young of the year fish had no check of any kind formed on their scales by the time they left the study area (before mid-October), and, every one of the yearling fish had at least one check on their scales by the time they returned to the study area (by the end of May). The check closest to the leading edge of the scale was presumably an annulus.

More and more circuli were laid down during the summer and the distance from the last check to the leading edge of the scale increased. By mid-August, another check had been laid down by the great majority of fish of both sexes. In the males, a few had formed this check by the end of June, the majority, however, formed it in the last part of July or early August. The females invariably did not form a check until late July or early August. The check formed in late summer is apparently associated with reproduction and thus

this check can be termed a spawning check.

In approximately 1% of the sample, a definite check was observed on the scales of young of the year fish. This was interpreted as a birth check or metamorphic annulus. Also, in 1.5% of the sample, a spawning check was formed during the first summer of the fishes life.

Check Identification

Three methods were used to try to distinguish between birth checks, spawning checks, and annuli. The first was direct observation of the time of check formation. The second was the visual appearance of the physical features of the check. The third method involved a study of the distance from the focus to each successive check.

All three types of checks were found to be quite similar in their appearance. All three checks, in the majority of cases, were continuous around the focus of the scale. All three were usually concentric with the margin of the scale and were usually quite distinct and easily recognized as a check.

There are, however, several physical features that may aid in the identification of the different type of checks.

Annuli and Birth Checks

1. An annulus never meets another annulus.

- 2. The check is definitely concentric with the margin of the scale.
- 3. There is usually a great deal of interruption of the circuli as the leading edge of the check tends to be broken.

### Spawning Checks

- Spawning checks sometimes meet an annulus at its base.
- There is usually less interruption of circuli than in an annulus.

A third method was used to attempt to distinguish between birth checks, spawning checks, and annuli. There is a straight line relationship between body length and anterior scale radius (Figure 1), therefore there should be a direct relationship between body length, the distance from the focus to each succeeding check, and the time of formation of each check. If this relationship were demonstrated, it could show the nature of each check.

Since every yearling fish had formed an annulus, and the large majority of these fish formed a spawning check during the summer, presumably on the scales of the older fish, annuli alternated with spawning checks. Usually starting with the column headed  $A_1$ , the distance from the focus to each succeeding check was recorded, (Table I). This was done for 539 scales and the average was taken for each of the

Numbe	er BC	scı	Al	SCII	A <sub>2</sub>	SCIII	A3	SCIV	A4	scv
1			2 5							
2		2.2	2.8							
3			2.6	3.4						
4			2.7	3.5						
5	1.8		2.6	3.5	3.9					
6			2.7	3.3	3.6					
7			2.7	3.4	3.9	4.3				
8			2.7	3.3	3.7	4.0				
9			2.8	3.4	3.7	4.2	4.5			
10			2.6	3.1	3.5	3.9	4.3	4 6		
11			2.6	3.0	3.4	* 4 0	4.2	4.0		
12		0 0	2.8	3.4	3.1	4.4	4.0	4.0	16	
13		2.3	2.0	3.0 **	3.0	4.1	4.5	4.5	4.0	
14			2.0	Υ <sup>Υ</sup> Υ	3.9	39	4.0	43	45	47
16		22	2.0	32	3.4	3.6	37	39	4.2	4.3
10		2.2	0.0	0.2	0.1	0.0	0	0.0	1.2	1.0
 * M	lissed SCTTT		BC = I	Birth Che	eck					
	111		SC = S	Spawning	Check					
** M	lissed SC <sub>IT %</sub>		A = /	Annulus						

Table I. Distances between Birth Checks, Spawning Checks and Annuli.

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columns. The figures gave an average distance from the focus of the scale to each birth check, spawning check and annulus (Table II). Except for the birth check and spawning check I, the average distance from the focus to each check was greater for the females than for the males.

In a few cases, the distance between two checks was very much greater than the average. This indicated either a very high growth rate during that particular period or a check that failed to form. In some cases, the distances between checks were much higher than average, but these distances were proportional. Apparently these particular fish had a higher than average rate of growth. In other cases, however, there were instances where the distance between two checks was much greater than average, but the distances between the remaining checks were normal. This indicated that a check had failed to form. Since every yearling fish had an annulus, if a check was missed, it would presumably be a secondary or spawning check. Scale samples from Cymatogaster just prior to the time of departure from the study area (late September) confirmed that a very few of these fish fail to form a spawning check. At this time the distance from the last annulus to the leading edge of the scale was almost as great as the average distance from that annulus to the one that will be formed in the coming winter (Figure 7), therefore if a check were

Sex	BC	SCI	Al	SC <sup>II</sup>	<sup>A</sup> 2	SCIII	A <sub>3</sub>	scin	A <sub>4</sub>	sc <sub>v</sub>
ď	1.90	2.36	2.62	3.20	3.64	3.91	4.12	4.28	4.52	4.70
Ŷ	1.82	2.13	2.67	3.39	3.81	4.06	4.33	4.48	4.70	4.85

Table II. Average Distance from Focus of Scale to each Successive Check.

Table III. Average Back-Calculated Body Length at Time of Formation of each Check.

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Sex	BC	$sc_{I}$	Al	scII	<sup>A</sup> 2	sc <sub>III</sub>	<sup>A</sup> 3	SCIV	A <sub>4</sub>	scv
ਾ	5.9	6.7	7.3	8.8	9.6	10.3	10.8	11.1	11.5	12.0
ę	5.6	6.3	7.4	9.0	9.9	10.5	11.0	11.4	11.8	12.4

going to be formed, it should already be present.

Figure 8 shows a typical scale of a female fish in it's fourth year of life. Figure 9 shows the scale of a yearling fish right after the formation of SC<sub>II</sub>. The specimen from which the scale was taken was captured in the first week of August. It can be seen that the circuli in the area of the check appear to be quite close together and the distance between the last few circuli is increasing. Figure 10 shows a scale where  $SC_{II}$  was not laid down. The distance between the two checks is very much greater than the average distance between  $A_1$  and  $SC_{II}$ , but conforms with the average

In summary, by observing the time of formation of a check, by studying the physical features of a check, and by taking the distance from the focus of the scale to a check and comparing it with the average distance, the nature of a particular check can be determined with relative accuracy.

Back-Calculation

According to Van Oosten (1929), "The soundness of the scale method of determining the length of the fish at successive years of its life and its annual growth increments, depends upon the validity of the following propositions:

> 1. That the scales remain constant in their number and (retain their) identity throughout the life

of the fish

- 2. That the annual increment in length (or some other dimension which then must be used) of the scale maintains (throughout the life of the fish) a constant ratio with the annual increment of body length.
- 3. That the annuli are formed yearly and at the same time each year (or some other discoverable relation exists between their formation and increment of time)."

The scales of <u>Cymatogaster</u> are fully formed before birth and appear to remain constant in both number and identity throughout life. The focus of the central part of the scales of old fish of this species is structurally identical with the scales of young fish. The regenerated scales, which replace those accidentally lost, have a central portion that is quite easily recognized. Both the annuli and spawning checks are formed at specific periods of the year, the annuli predominantly in mid-April and the spawning checks predominantly in mid-August.

By plotting the regression line of body length on a scale measurement, a relatively simple method can be derived for back-calculating the body length of fish at previous periods in their life history (Smith, 1955).

The average distance from the focus to the birth check and to each spawning check and annulus was plotted on

- Figure 6. Photograph showing concentric rings of circuli surrounding the focus and continuing out to the leading edge of the scale.
- Figure 7. Photograph showing large distance between Annulus I and leading edge of scale indicating Spawning Check II will not be laid down. (Scale taken from specimen captured in late September).

Figure 8. Typical scale of Cymatogaster in fourth year of life. Figure 9. Scale of yearling fish just after formation of Spawning Check II.

Figure 10. Photograph showing scale where Spawning Check II was not laid down.









SCII

the regression lines obtained from the anterior scale radius - body length relationship. To back-calculate the body length of a fish at any previous stage in its life history, the distance from the focus to the particular point on the scale is measured. The measurement is marked on the anterior scale radius axis and a perpendicular is extended until it intercepts the regression line. The back-calculated length is then read off the body length axis at a point opposite where the regression line is intercepted.

Figure 11 gives the points of interception on the regression line of the birth check, spawning checks and annuli of male <u>Cymatogaster</u>. Figure 12 gives the same information for the female. Table III gives the average back-calculated body lengths at the time of formation of each check and shows, except at the time of formation of the birth check and spawning check I, the average size of the females is larger than the males throughout their life history.

With the regression method of back-calculation, the variances of mean calculated lengths may be due to:

- 1. Differences in growth of individual fish.
- 2. Deviations of the individual fish from the "normal" body-scale regression.
- 3. Deviations of the examined scale(s) from the average for the individual fish.
- Errors in locating and measuring checks (Whitney and Carlander, 1954).

Figure 11. Points of interception on the regression line of the Birth Check, Spawning Checks, and Annuli for male Cymatogaster.

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Figure 12. Points of interception on the regression line of the Birth Check, Spawning Checks, and Annuli for female Cymatogaster.

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Figure 13 gives the average calculated length at the end of each year of life for both male and female.

To check the accuracy of this method of back-calculation, a number of fish were examined that had just finished forming a spawning check or annulus. The actual body length measurements were then compared with average backcalculated body lengths (Table IV). The actual lengths correspond quite closely to the back-calculated lengths. In order to recognize that a check has been formed on a scale, it is necessary to wait until the growth rate increases. It is probably due to this reason that the actual measurements of the fish are slightly higher, on the average, than the back-calculated lengths. At the time of measurement there had been an average growth of 0.15 cm. (X 22) from the last check to the leading edge of the scale.

A representative sample of length distribution within age groups is given in Table V. Within any one age group, the females tend to be larger than the males. This observation corresponds with the back-calculation work that showed females, on the average, are larger than the males at the times of check formation.

Lee's Phenomenon

For virtually every species of fish whose scales have been used for back-calculations, it has been demon-



Figure 13. Calculated length at the end of each year of life.

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Sex	Length	Al	$sc_{II}$	<sup>A</sup> 2	$sc_{III}$	A <sub>3</sub>	SCIV	<sup>A</sup> 4	$\mathrm{sc}_{\mathrm{v}}$
ੀ	Back- Calculated	7.3	8.8	9.6	10.3	10.8	11.1	11.5	12.0
	Actual	7.6	8.9	10.1	10.5	10.8	11.2	11.6	12.0
Ŷ	Back- Calculated	7.4	9.0	9.9	10.5	11.0	11.4	11.8	12.4
	Actual	7.6	8.8	10.2	10.8	11.2	11.6	11.9	12.2

Table IV. Comparison of Average Back-Calculated Body Length at time of Formation of each check with Actual Body Lengths

Length Interval	BC	S	cı	А	1	S	CII	А	2	SC	111	А	3	SC	IV	A	4	S	c <sub>v</sub>
· · · · · · · · · · · · · · · · · · ·	o" ♀	ď	Ŷ	්	ę	ď	<u>.</u> و	ď	Ŷ	්	Ŷ	°	Ŷ	ೆ	ę	ď	Ŷ	ď	Ŷ
$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$		· ·		1 ,11 7 4	1 8 10 2	1 2 3 2	2 7 8 2 1	1 6 20 11 2 1	3 20 14 8 1	2 2 4 2	2 3 1 4 1	263	1 6 4 1	1 4 7 3	2 2 2 1	1	2 2 1	1	1 2
Total #			·	23	21	8	20	41	46	10	11	11	12	15	7	2	5	1	3

	Tab	le	ν.	Length	Distri	bution	of	Age	Groups.
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strated that the computed lengths at the end of the first year of life decrease as the fish increases with age. Stated another way, the older the fish whose scale is used for the calculation, the lower the value obtained. This characteristic of length computations based on scales is usually referred to as "Lee's phenomenon of apparent changes in growth rate." (Van Oosten, 1929).

In the sample of <u>Cymatogaster</u> studied, Lee's phenomenon is not apparent. This, however, may be due to two main factors. First, <u>Cymatogaster</u> has a relatively short life span and this phenomenon of change in growth rate may not become readily apparent over such a brief period of time. Second, very few fish were obtained that were in the 4 years plus age group. It is entirely possible that if a much larger number of fish in this age group had been obtained and back-calculations carried out with their scales, Lee's phenomenon might show up.

Age at Maturity

Hubbs (1921) determined that the testes of male <u>Cymatogaster</u> were sexually mature at the time of birth. He also demonstrated that sexual maturity at birth occurred in the males of another viviparous perch, <u>Amphigonopterus</u> <u>aurora</u>. The great majority of yearling <u>Cymatogaster</u> males had formed a spawning check. Except in a very few cases, the

male gonads mature each spring from the first year of life on, and a spawning check is formed by mid-August.

In the spring no yearling female was found to contain embryos, but over 99% of the fish two or more years of age did. This figure correlates with the age and growth analysis which showed that less than 1% of the females failed to form a spawning check.

Length	(cm)	Number of Adults	Average Number of Embryos
9.5 -	9.9	12	7
10.0 -	10.4	21	9
10.5 -	10.9	56	9
11.0 -	11.4	19	10
11.5 -	11.9	23	10
12.0 -	12.4	11	13
12.5 -	12.9	8	12

Table VI. Average number of embryos carried by adult female Cymatogaster.

Fecundity

Table VI gives the average number of embryos carried by mature <u>Cymatogaster</u> females. The range was from 5 to 17 with a mean of 10. Table VI illustrates that there

is a tendency for the average number of embryos carried by the female to increase as the body length increases.

Instantaneous Growth Rates

A preliminary study was carried out, on an annual, monthly and daily basis, on the instantaneous growth rates exhibited by <u>Cymatogaster</u>. The definition of instantaneous rates of growth has been given by Ricker (1958) and Brown (1957) and will not be discussed here.

The instantaneous growth rate (i) was calculated by the formula

 $\log_{10} L_t + 1 \text{ (cms)} - \log_{10} L_t \text{ (cms)}$ where  $L_t$  and  $L_t + 1$  are, respectively, the average length of the fish at the beginning and end of each period of growth. The growth increment is the average increase in length during any one period and can be defined as

 $L_{t} + 1 - L_{t}$ 

In cases where the average daily instantaneous growth rate is given, the value was obtained by dividing the calculated instantaneous growth rate by the number of days of growth between the two relevant checks.

The mean size of a sample is defined as the average size of the fish within a sample at the mid-point of a specific period of growth. Cymatogaster grows logarithmically, thus the term, mean size, should be statistically valid and may be calculated by the formula

antilog 
$$\left(\begin{array}{c} \log_{10} L_t + 1 + \log L_t \\ - 2 \end{array}\right)$$

Larkin (1957), in a paper discussing the growth of different populations of rainbow trout, states that "... it is desirable to dispense with age as a criterion of growth rate and restrict comparisons to growth rates of fish of the same size, ie. plot instantaneous growth rate against specified size." Figure 14 gives such a plot for <u>Cymatogaster</u> and was obtained by using the average distances between birth checks and annuli (Table II). There is a general decline in the instantaneous growth rate from time of birth through to the oldest fish in the sample (Figure 19). This corresponds to the general pattern as most fish attain their highest rate of growth during their first year of life and thereafter the annual growth rate rapidly declines.

Figure 15 gives the average instantaneous daily growth rate between times of birth check, spawning check and annulus formation. These data seem to indicate that there is a very high growth rate between the time of birth check formation and the first spawning check. There follows a rapid decrease in growth rate between the time of formation of the first spawning check and the first annulus.





There is again an increase in the instantaneous growth rate between the time of formation of the first annulus and the second spawning check. It is evident that there is a pattern which is repeated throughout the life history of <u>Cymatogaster</u>, (Figure 20). The highest levels of instantaneous growth rates occur in the periods between the formation of an annulus (or birth check) and the following spawning check. This time period corresponds to the spring and summer months from mid-April to mid-August. The lowest levels of instantaneous growth rate occur in the period between the formation of a spawning check and an annulus. This time period corresponds to the winter months from mid-August to mid-April.

The fluctuations of instantaneous growth rate exhibited by <u>Cymatogaster</u> follow a pattern that would seem reasonable to expect. The lowest level of growth rate occurs over approximately an eight month period during the fall and winter when the water temperatures are low and presumably the metabolic rates are at a low level. Also, there is a tendency for <u>Cymatogaster</u> to move into deeper water in the fall as the water temperatures begin to drop, (Figure 21), and the availability of food organisms, both in quantity and number of species may be greatly reduced in these deeper habitat areas. This reduction in the availability of food coupled with a slowing down of metabolic rates may be an important factor involved in annulus formation.

After the annulus is formed sometime around mid-April, there is a tendency shown by <u>Cymatogaster</u> to start to move into shallower habitat areas as the water temperature starts to rise (Figure 21). This movement will bring the fish into contact with an increased number of food organisms which are associated with the shallower waters. As the water temperatures start to rise in the spring of the year, it is assumed that metabolic rates also increase. The rise in water temperature is also associated with the increase in numbers of planktonic organisms, for when optimum spring temperature levels are reached, plankton blooms start occurring with increasing frequency.

With an increase in metabolic rates and with an increase in the number of food organisms available, both in quantity and in number of species, it would seem reasonable to expect that there would be an increase in growth rate. This expected increase in instantaneous daily growth rate in the spring and summer months (ie. - between the formation of an annulus and the succeeding spawning check) is shown in Figure 15.

The general tendency for the growth rate of an animal to decline as it increases in size is also demonstrated by Figure 20. There is, however, an apparent increase in instantaneous growth rate between annulus 4 and spawning check V over the period between annulus 3 and spawning check IV. This may be due either to an actual increase of growth

rate in the fourth year, which is contrary to the general pattern, or, this increase may be due to sampling error. The sample size of the four year old fish is quite small, hence if fish in this sample happened to be larger than average, it would cause a large corresponding increase in the average instantaneous daily growth rate.

Figures 16 and 17 give the average monthly instantaneous growth rate of <u>Cymatogaster</u> for the months of June, July, August and September, which, due to the migratory nature of the fish in the study area, were the only months for which a sufficient number of fish were available to conduct such a study. The males, except for the yearling fish, maintain a relatively constant growth rate through June and July, then the growth rate increases by mid-August (Figure 21). During June and July the males are still showing distinct spawning colouration and there appears to be a much lower rate of feeding than in early spring. By mid-August, however, most signs of spawning colouration are gone and the rate of feeding increases. This apparently accounts for the increase in the average instantaneous growth rate at this time.

<u>Cymatogaster</u> females all show a decline in growth rate in mid-July, in some cases to a very low level (Figure 17). This period of decrease of growth rate corresponds closely with the time that the females are giving birth to their young. By the last week in June, and until the birth-



ing period is over, the feeding of the <u>Cymatogaster</u> females ceases almost entirely. This cessation of food intake presumably accounts for the decrease in growth rate during July. After giving birth, the females begin to actively feed again which probably accounts for the increase in growth rate attained by mid-August.

The probable reason for the much greater size increases exhibited by yearling fish, both male and female, over the older year classes can be seen in Figure 15 which shows that yearling fish still have a growth rate that is proportionally much greater than the older age groups.

Length-Weight Relationships

Figures 18 and 19 represent the length-weight relationship of male and female <u>Cymatogaster</u> which have been preserved in 10% formalin. Figure 18 gives a comparison between pregnant and non-pregnant females and shows that pregnancy causes a greater weight for any given length. As the total embryo weight increases, there is a proportionately greater increase in the ratio of weight to length.

Figure 19 gives a comparison between males before and after the spawning check is formed and shows that there is, on the average, less weight for a given length after the spawning check is formed. This indicates that there is an increase in weight for a given body length as the male becomes







Figure 19. Comparison of the body length body weight relationship before and after Spawning Check formation in male <u>Cymato-</u> <u>gaster</u>. sexually mature and the gonads increase in size.

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## SEASONAL AND DIURNAL MOVEMENT PATTERNS

Nylon gill nets and Scuba diving observations were used to ascertain the seasonal and diurnal movements of <u>Cyma-</u> <u>togaster</u>. Estimates were made of relative abundance, depth distributions, directional movement tendencies, schooling behavior and habitat preferences.

Figure 20 shows the Keates Island study area. The positions of the two gill net sets are indicated, one at the South-West corner and one at the North-East corner of the study beach. Collections were made on the average of once a week, during the daylight hours, from the end of May to the end of October. While the nets were fishing, diving observations were made throughout the entire study area. Each diver independently recorded information on depth distributions and relative abundance of adults, yearlings, and young of the year fish, their habitat preferences and their schooling behavior.

The gill nets were set in strings out from the shore line. The net closest to shore was designated the shallow net, and, depending upon tidal conditions, was set in 8 to 15 feet of water throughout the study period. The net farthest from shore was designated the deep net and was set in 20 to 40 feet of water.

The nylon gill nets were found to be very selective with regards to mesh size, the  $\frac{1}{2}$  inch mesh caught only young of the year, the 1 inch mesh caught mainly yearlings, and the



 $l_2^1$  inch mesh caught mainly adult fish. Because of the selectivity of the nets, the mesh sizes were alternated in the strings at opposite ends of the beach. If the  $l_2^1$  inch mesh was set at the shallow end at the South-West corner of the beach, the  $l_2^1$  inch mesh was set at the deep end of the other string.

The Keates Island study area had within it three relatively distinct habitat areas (Figure 20). The two strings of nets were set in such a way that they sampled the three areas at all times. The first area was designated a "reef-face" habitat and was characterized by the steep gradients found around the reefs at the South-West corner of the In places these rock walls fall off almost vertically beach. to depths of over 150 feet. The second area was designated a "kelp-bed" habitat area and was characterized by a concentration of several species of sea-weeds, the dominant one being Sargassum muticium. The kelp beds were found to extend along the entire beach approximately five feet above and ten feet below the zero tide level. The third area was designated an "open-water" habitat and referred to the regions over the pebble beach and over the mud and sand flats outside the kelp beds.

#### Seasonal Movements

The data obtained indicate that Cymatogaster

exhibits a complex pattern of seasonal movements that varied with the age and sex of the fish, their state of maturity, and the time of year.

There are a number of complex, interacting factors which make it very difficult to show quantitatively any distinct habitat or area preference. These factors include changes in diurnal movement patterns, seasonal changes in depth preferences and directional movement tendencies, and the rise and fall of the tides which can leave a major portion of the study area high and dry for long periods of the day. With the data available, it is also extremely difficult to distinguish between depth preferences and habitat preferences. It is for these reasons that habitat preference has been analysed only to the extent of obtaining estimates of relative abundance in each habitat area for different periods during the time Cymatogaster is in the study It is also for the preceeding reasons that habitat area. preference has been included under the section on seasonal movements.

The results obtained from the study of seasonal movements are given under two separate headings; Scuba diving observations and gill net data. The first section, pertaining to Scuba diving observations, describe seasonal changes of depth distributions, schooling behavior, and relative abundance of <u>Cymatogaster</u> both over the study beach area and in regions that could not be sampled by gill nets.

The second section, pertaining to gill net data, describes the sequential changes, from May through to October, of the relative abundance of adult, yearling, and young of the year <u>Cymatogaster</u> in the three relatively distinct habitat areas. This section also contains the results obtained from a tagging program that was conducted to ascertain whether or not <u>Cymatogaster</u> exhibited a distinct pattern of seasonal directional tendencies of movement.

If the two sections are compared, it can be seen that there is a close correlation between the results obtained by Scuba diving observations and those obtained by the use of gill nets.

## Scuba Diving Observations

Yearling <u>Cymatogaster</u> were the first of the species to be observed in the study area. Throughout the first week in June they congregated in increasingly large schools off the reef faces in depths below 50 feet. Though the great majority of individuals were observed off the reefs, several schools were seen over the mud and sand flats in open water.

Several days after their first appearance, schools of yearlings were observed over the study beach in depths as shallow as 20 feet. Shortly thereafter, by the second week in June, the majority of the yearlings had moved back

into deeper water where they remained until the last week of June. At this time, which is immediately prior to the spawning period, there was a sudden increase in the numbers of yearlings in the shallow waters over the beach. A week later, however, the great majority had again returned to deeper waters (from 50 to 90 feet) off the reef faces.

During the month of June it was observed that the yearling <u>Cymatogaster</u> exhibited a general directional tendency of movement from the South-West to the North-East. This movement was evident regardless of the direction of flow of the tidal currents.

Through most of July, August, and September, the majority of yearling fish were found in depths from 35 to 90 feet off the reef faces. During this period there were always a scattered few individuals in and around the kelp beds. These individuals showed no tendency to school.

In the last week of September there was another sudden increase in the numbers of yearlings observed in the shallow water over the beach. They remained there for a relatively short time and then returned to deeper waters. By mid-October almost all the yearlings had moved off the beach and were schooled along the reef faces in depths ranging from 60 to 110 feet. By the end of October there were no yearlings observed in the study area.

The first adult <u>Cymatogaster</u> were observed moving into the study area in early June, shortly after the arrival

of the yearlings. These fish were mature males and they were concentrated off the reef faces at depths of 60 to 100 feet. Within a relatively short period of time, three days, the majority of these fish had moved into shallow water over the beach where they remained for about a week.

Approximately a week after the first appearance of the adult males, large schools of adult female <u>Cymatogaster</u> began to move into the study area off the reef faces.

By the third week in June, the males began to move into deeper water and the females became increasingly abundant in the shallow water over the beach. In the last week of June, just prior to spawning, there was a great increase in the numbers of adult <u>Cymatogaster</u>, both male and female, found in the region of the kelp beds.

By the first week in July, corresponding to the peak of the spawning period, large schools of adults were observed in the very shallow areas over the beach, often in as little as five feet of water.

By the second week in July, the majority of adults had moved off the shallow beach into deeper water outside the kelp beds. From mid-July to early October there were relatively few adult <u>Cymatogaster</u> observed in the vicinity of the beach and kelp beds during the daylight hours. The great majority remained congregated in large schools off the reef faces in depths ranging from 35 to 110 feet. By mid-October no adult fish were observed in the study area. The young of the year, from the time of birth, in early July, to mid-August, remain in relatively compact schools in and around the kelp beds. In mid-August the young of the year begin to move into deeper water off the reef faces and over the mud and sand flats. By mid-September the great majority of fish of this age group are to be found in depths below 50 feet.

By mid-October only small schools of young of the year were observed off the reef faces in depths below 80 feet. There were a scattered few individuals in the vicinity of the kelp beds. By the end of October no young of the year were observed in the study area.

Gill Net Data

The results obtained by the use of gill nets indicate that each age group, and both sexes, of <u>Cymatogaster</u> exhibit a relatively complex pattern of onshore and offshore movements that can vary seasonally.

No <u>Cymatogaster</u> were caught by gill nets in the month of May, the first being taken in the first week of June. At this time the great majority of fish within the areas sampled by the gill nets were yearlings (Figure 21). By the second week in June, the numbers of yearlings captured had decreased and adult <u>Cymatogaster</u> began to be taken in increasing numbers (Figure 21). The majority of the first

adult arrivals were sexually mature males (Figure 22), which were found in much shallower water than were most females (Figures 24 and 25). By the third week in June the numbers of adult males and females taken by the gill nets were roughly equal over the entire study area.

In the last week of June, just prior to the spawning period, there was a great increase in the number of both adult and yearling <u>Cymatogaster</u> caught by the gill nets. The majority of these fish were taken in the deep nets over the mud and sand flats outside the kelp beds (Figures 21 - 25).

In the first week of July, at the peak of the spawning season, the great majority of fish were taken in very shallow water over the beach (Figures 23 - 25). At this time the yearlings had again moved off the area sampled by the nets (Figure 21).

By the second week in July a great deal of spawning had taken place and most of the adult fish were concentrated in the vicinity of the kelp beds. The new born young of the year were also found almost exclusively in the region of the kelp beds in compact schools. From mid-July until they moved from the study area in early October, the numbers of adult <u>Cymatogaster</u> taken by gill nets in daylight hours remained at a relatively low level (Figure 22).

The number of yearlings taken over the study beach also remained at a low level from early July to the third week in September. In the last week of that month there was

Figure 21. Seasonal relative abundance of adult and yearling Cymatogaster.

Figure 22. Seasonal relative abundance of mature male and female <u>Cymatogaster</u>.

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Figure 23. Seasonal depth distributions and relative abundance of yearling <u>Cymatogaster</u>.

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Figure 24. Seasonal depth distributions and relative abundance of mature male Cymatogaster.

Figure 25. Seasonal depth distributions and relative abundance of mature female <u>Cymatogaster</u>.

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a great increase in the number of yearlings taken over the beach (Figure 23). The large schools of yearlings remained in shallow water only a short time before they again moved off the beach into deeper water.

Tagging Results

Diving observations, coupled with the fact that at certain times of the year the great majority of fish were taken on one particular side of the gill nets, indicated that <u>Cymatogaster</u> exhibited general tendencies of directional movement that varied seasonally. A limited tagging program was conducted to see if these observations were correct (Table VII).

A total of 983 fish were tagged, by a nylon thread inserted just anterior to the dorsal fin, and then released over the study beach between the two sets of gill nets. A total of 84 tagged fish were recovered (Table VIII).

Table IX shows that during the month of June, when the fish are first arriving in the study area, 25 of 29 tagged fish were recaptured in the gill net sets at the North-East corner of the beach. On June 12 the direction of flow of the tidal currents was from the South-West to the North-East. On June 25 the direction of flow was exactly opposite, from the North-East to the South-West. The tagging data indicates that in the spring of the year, regardless of the direction of flow of the tidal currents, Cyma-

	<u></u>		Number Released	Number Recovered	Position Recovered	
Date	Age Group	Age Group			N.E. Set	S.W. Set
- <b></b>						
June 12		Adult	59	7	6	L
		Yearling	62	4	4	0
		Young of Year	0	0	0	0
June 25		Adult	103	8	6	2
		Yearling	109	10	9	1
		Young of Year	0	0	0	0
August 30		Adu 1t	28	3	0	3
		Yearling	32	8	2	6
		Young of Year	40	2	1	1
September	5	Adult	61	7	2	5
	-	Yearling	95	9	0	9
		Young of Year	144	3	1	2
Sentember	20	Adult	20	0	0	0
September	_0	Vearling	50	2	0	2
		Young of Year	30	· 1	0	1
September	29	Adult	29	2	0	2
p • • • • • • • • • • • • • • • • • •		Yearling	41	6	2	4
		Young of Year	80	12	5	7

Table VII. Tag Recovery Results.

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togaster exhibits a general directional tendency of movement from the South-West to the North-East.

Table IX shows that in the fall (late August and September), 42 of 52 tagged fish were recaptured in the gill net sets at the South-West corner of the beach, despite varying directions of tidal current flow. The data indicates that in the fall <u>Cymatogaster</u> exhibits a directional tendency of movement, from the North-East to the South-West, that is directly opposite to that found in the spring.

In summary, based on information obtained by gill nets and Scuba diving observations, it may be stated that Cymatogaster exhibits a relatively complex pattern of seasonal movements that may vary with the time of year and with their age and sex. The first fish to appear in the study area are yearlings. The yearlings are closely followed by the adult males and then by the adult females. Over the beach area the numbers of both sexes of adult and yearling Cymatogaster remain at a fairly constant level from mid-June until just prior to the spawning period. At this time there is a great increase in the number of fish over the beach and in the vicinity of the kelp beds. During the actual period of spawning the adult fish move into very shallow water over the beach while the yearlings move out into deeper water off the reef faces. After spawning the adults also move out into deeper water off the reef faces and remain there until they leave the study area in early October. During daylight hours,

	Total Fish Released	Total Fish Recovered	Percent Recovered
Adult	300	27	9.00
Yearling	389	39	10.03
Young of Year	294	18	6.12
Totals	983	84	8.54

Table VIII. Total Percentage of Tag Recoveries.

Table IX. Position of Tagged Fish Recovered.

Time of Voor	Arra Crann	<b>Position</b> Recovered	
Time of Year	Age Group	N.E. Set S.W. Set	
Spring	Adult Yearling Young of Yoor	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	
Fall	Adult Yearling	2 10 2 21	
	Young of Year	6 11	

from mid-July until early October there are relatively few adults over the beach and in the vicinity of the kelp beds. Except for a sudden, but brief, increase in numbers at the end of September, there are very few yearlings present in shallow water from mid-July until they leave the study area in mid-October. The young of the year are born early in July and remain segregated in schools in the kelp beds until mid-August. At this time they start to move into deeper water and by the end of October they have left the study area.

#### Diurnal Movements

The data obtained from a series of gill net sets made over a 36 hour period, at 2 hour intervals, indicated that <u>Cymatogaster</u> exhibits a distinct pattern of diurnal movements that varies seasonally. Because of slight differences between the behavior of adults and yearlings, the results are given separately for the two groups. The collections were made in mid-June, July and August. The positions of the gill net sets in the study area are given by Figure 20.

# Adult Fish

Figures 26, 27 and 28 give the diurnal movement patterns of adult <u>Cymatogaster</u> in mid-June, July and August. Figure 26 shows that in mid-June there are relatively large

Figure 26. Diurnal movement patterns of mature Cymatogaster in June.

Figure 27. Diurnal movement patterns of mature Cymatogaster in July.

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Figure 28. Diurnal movement patterns of mature Cymatogaster in August.

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numbers of fish over the beach area during the daylight hours, from 0500 to 2100 hours. Between sunset and sunrise (2300 - 0300 hours), however, very few adults were taken by the gill nets. The pattern of diurnal movements during the pre-spawning period involves the migration of adults from over the beach and kelp beds into deeper water when there is a decrease in light intensity caused by sunset. With sunrise, and increasing light intensity, there is a movement onto the beach area of adult fish from deeper water.

The relatively high numbers of fish found over the study area during daylight hours correlates with data obtained from the study of seasonal movements. Figure 22 shows that during the entire pre-spawning period adults are taken in fair numbers in the vicinity of the kelp beds and over the beach.

In July and August there is complete reversal of the diurnal movement pattern exhibited by <u>Cymatogaster</u> in June (Figures 27 and 28). There are relatively few fish present over the study area during the daylight hours, but, with darkness, there is an onshore movement of large numbers of adult fish. The majority of fish are first caught by the deep nets, then later on in the evening they are taken in the shallow nets. As dawn approaches and the light intensity increased, the adults move into slightly deeper water and are caught by the deep nets again. With full daylight, very few adults are found in the study area.

The complete reversal of the pattern of diurnal movement between mid-June and July is probably associated with spawning activities. Before spawning the adults spend the daylight hours in relatively shallow water over the beach, after spawning they spend the daylight hours in deeper water (Figure 22). During the period of time when the reversal takes place, environmental factors such as water temperature, light duration and turbidity remain relatively constant.

Yearling Fish

Figures 29, 30 and 31 give the diurnal movement patterns in mid-June, July and August for yearling <u>Cymato-</u> <u>gaster</u>. Figure 29 indicates that the yearlings follow the same general pattern as the adults (Figure 26). They are in shallow water over the beach during the daylight hours, but in deeper water during darkness.

Figures 30 and 31 for July and August show the same reversal of diurnal movement patterns exhibited by adult <u>Cymatogaster</u> is also shown by the yearlings. With decreasing light intensity there is an onshore movement, with increasing intensity the yearlings move into deeper water.

Figure 30 shows the effect of bright moon light on the diurnal movement pattern of yearling fish. Just after dark the majority of fish were taken by the deep nets, by 2300 hours the fish were in shallower water and were Figure 29. Diurnal movement patterns of yearling <u>Cymatogaster</u> in June.

Figure 30. Diurnal movement patterns of yearling <u>Cymatogaster</u> in July.

Figure 31. Diurnal movement patterns of yearling <u>Cymatogaster</u> in August.

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caught by the shallow nets. Moonrise occured between 2300 and 0100 hours and the yearlings moved into deeper water. By 0300 hours they had returned to the shallows, and, with the dawn between 0300 and 0500 hours, the yearlings moved off the beach into deeper water. Figure 31 shows the diurnal movements of yearling on two cloudy nights. There was no increase in light intensity due to the moon and no corresponding movement of the fish into slightly deeper water. The fish were first taken by the deep nets, then between 2300 and 0100 hours they moved into the shallow beach area. By 0300 hours they were again moving into deeper water and by 0500 hours (after sunrise) there were very few yearlings taken by the gill nets over the study area.

It is suggested that light intensity is the primary factor governing the diurnal onshore and offshore movements of adult and yearling <u>Cymatogaster</u>. The cause of the reversal of the pattern of diurnal movement between mid-June and mid-July is not known.

## SEASONAL AND DIURNAL FEEDING HABITS AND FOOD PREFERENCES

### Seasonal Feeding Habits

A study was conducted to ascertain the feeding habits and food preferences of <u>Cymatogaster</u> during the period the fish are present in the Keates Island study area. The contents of the gastro-intestinal tracts of 217 fish, which had been taken at regular intervals from early June to the middle of October, were analysed. The contents of the entire tract were emptied into a small glass dissecting dish and then examined with a binocular microscope under magnifications varying from 6.3 to 40X.

Twelve fish from each collection made through the study period were selected for examination, three male and three female adults, and three male and three female yearlings. Before the contents of the gastro-intestinal tract were placed in the dissecting dish, a visual estimate was made of the percentage of the total volume of the tract that was taken up by food organisms. With the aid of the dissecting microscope, the food organisms were identified and placed under the general headings of mussels (<u>Mytilus edulus</u>), algae, and barnacles, which are associated with the ocean bottom, and zooplankton which are generally considered to be free floating organisms. The zooplankton were identified to Order or Sub-Class and placed under two general headings: the first being large zooplankton which included amphipods, isopods, mysids, chironomids, and large copepods. The second heading was small zooplankton under which were grouped small copepods and the cypris and nauplius stages of the life cycle of several crustaceans. After the food organisms had been identified and grouped, estimates were then made of the approximate percentage each group made up of the total food volume.

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Figure 32 shows the volume and percentage composition of the food organisms found in the gastro-intestinal tract of <u>Cymatogaster</u> at regular intervals from early June to mid-October. Figure 39 indicates that at times there are different feeding and food preferences exhibited by adult and yearling fish and slight differences between males and females as well as many similarities.

The total volume of food found in the stomachs of adults and yearlings varies throughout the time the fish are in the study area. At the time when <u>Cymatogaster</u> first move into the relatively shallow waters of the study area, the water temperatures are warming up and food organisms are becoming more abundant and available. Plankton blooms start occuring with increasing regularity (Hardy, 1956) and the young barnacles and mussles are beginning to settle and grow. An increase in water temperature may also cause an increase in the metabolic rates of the fish and, related to **th**is, an overall increase in activity including feeding (Brown, 1957).



Figure 32. Volume and composition of food organisms in the gastro-intestinal tract at regular intervals from June to October.

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In early spring the yearling fish feed primarily on planktonic organisms. The adult fish are also eating a substantial amount of zooplankton, but algae, barnacles, and mussels form an important segment of their diet. During the month of June the gastro-intestinal tracts of both adult and yearling Cymatogaster were rarely more than half full, but the great majority of fish had been feeding to some extent. In early July the yearlings begin to feed more intensively and their digestive tracts are usually found to be full. The adult fish, on the other hand, almost stop feeding entirely. This marked reduction in feeding by the adult fish corresponds to the period when the male testes are greatly enlarged and the embryos within the uterus of the female are taking up a considerable volume of the abdominal cavity.

Both sexes of yearling <u>Cymatogaster</u> maintain a relatively intensive rate of feeding from early July until just before they leave the study area in late September or early October. At this time there is a marked reduction in the amount of food found in the digestive tract.

The adult fish again begin to feed actively in early August and continue to eat intensively until the end of September when there is a marked reduction in the amount of food found in the gastro-intestinal tract.

The reduction of feeding intensity exhibited by both yearling and adult <u>Cymatogaster</u> just prior to their leaving the study area is probably associated with decreas-

ing water temperatures. As temperature levels decline, the metabolic rates and overall activity levels of the fish also decline. At this time of year both the adults and yearlings start to move out into deeper water where food organisms become less available. A decrease in feeding activity, associated with lower water temperatures, coupled with a reduction in the amount of food available presumably accounts for the reduction in the amount of food found in the digestive tracts of Cymatogaster in the late fall.

Adult and yearling <u>Cymatogaster</u> show many similarities in their preference of food organisms. By volume, mussels and algae make up the most important constituents of <u>Cymatogaster's</u> diet. Mussels were found in 44.5% of all digestive tracts examined and algae was found in 57.4%. Small copepods were the most frequently encountered food organism. They were present in 51.2% of the adults sampled and 94.2% of the yearlings. At different periods of the year barnacles appear to be an important constituent in the diet of <u>Cymatogaster</u> and were present in varying quantities in 25.3% of the digestive tracts examined. Large zooplankton were rarely an abundant item in <u>Cymatogaster's</u> diet, though they were present in limited quantities in 16.5% of the specimens examined.

Differences in food preferences are exhibited by adult and yearling <u>Cymatogaster</u> and there are also differences shown by male and female fish. Small zooplankton, mainly copepods, make up an important segment of the diet of year-

ling fish and were found in varying quantities in over 90% of the digestive tracts examined. Adult fish, although over 50% had taken some small zooplankton, ate far fewer individuals than did the yearling and the small zooplankton made up far less of the total volume of food eaten. When the yearlings first arrive in the study area, and through the month of June, small zooplankton make up the major portion of the total volume of food found in their digestive tracts. During this period the adults, however, although they do eat some small zooplankton, feed mainly on barnacles, mussels and algae. The digestive tract analysis showed that adult females tend to eat many more barnacles than do any other group of Cymatogaster, as this food organism was found in over 40% of the females sampled and only 11.4% of the other groups combined.

In summary it may be said that there is a great deal of similarity in the feeding habits and food preference of both sexes of adult and yearling <u>Cymatogaster</u>. Two types of food organisms, algae and small mussels, make up most of the total volume of food eaten by <u>Cymatogaster</u> during the time they are present in the study area. Small zooplankton, mainly copepods, are taken regularly by both adults and yearlings, though they are found in larger numbers and with greater frequency in the digestive tracts of the yearlings. Barnacles and large zooplankton may at times be important items in the diets of all groups of Cymatogaster, and mature

females tend to eat more barnacles than the other three groups combined.

In June, when they first move into the area, all groups of <u>Cymatogaster</u> are feeding actively though their digestive tracts are rarely more than half full. In early July the feeding intensity of the yearlings increases and at this time there is also a marked reduction of the feeding intensity exhibited by the adult fish. By early August the adults are actively feeding again and both adults and yearlings maintain a high rate of feeding activity through August and most of September. Just prior to the time when they leave the study area, both adults and yearlings exhibit a marked reduction in feeding.

Diurnal Feeding Habits

A study was conducted to ascertain the diurnal feeding habits and food preferences of <u>Cymatogaster</u>. Serial samples were taken at two hour intervals over thirty-six hour periods in mid-June, July, and August. The contents of the digestive tracts of 430 fish were examined by the same microscopic techniques as were applied in the seasonal feeding study and the individual food organisms were grouped under the same headings.

For each two hour interval two adult male and two adult females were examined as were two yearling males and two yearling females. The gastro-intestinal tract of each specimen was divided into four distinct sections (Figure 33). An estimate was made of the fraction of the total volume of each section that was occupied by food and then the contents of each section were examined separately.

Figure 34 gives a composite picture of the volume and composition of food organisms found in the four sections of the digestive tract of adult <u>Cymatogaster</u> males over 24 hour periods in mid-June, July and August. The two sets of data obtained from 2100 to 0500 hours in the 36 hour hauls were combined to give an overall picture for a 24 hour period. Figures 35, 36 and 37 give the same data for mature females, yearling males, and yearling females respectively.

Detailed examination of these figures can yield a great deal of information. The total volume of food and the percentage composition by volume of food organisms are given. These data are plotted over a 24 hour period at two hour intervals, thus estimates may be obtained of the time it takes for individual food items to pass through the gastro-intestinal tract. The times of the initiation and cessation of feeding may also be ascertained. All the above factors may then be compared on a seasonal basis as well as age and sex.

Figure 34 shows that in June, at 2100 hours there was very little food in the gastro-intestinal tract of the adult males, and this condition continued throughout the hours of darkness (2300-0300). Shortly after dawn, with the increase



# ENTRANCE TO STOMACH

Figure 33. The four sections of the gastro-intestinal tract of <u>Cymatogaster</u>.







Figure 34. Volume and composition of food organisms in the four sections of the gastro-intestinal tract of mature male <u>Cymatogaster</u> over 24 hour periods in June, July, and August.

in light intensity, the males began to feed on large zooplankton (copepods). By 0700 the first section of the gut was full and there were some food organisms in the second and third sections, and by 0900 there was food in all four sections. The adult males stopped feeding between the hours of 0900 and 1100 and as time passes the successive reduction of the volume of food can be seen in sections one to four of the gastro-intestinal tract, until by 2100 hours there were only traces of food organisms to be found in section four.

In July, the adult males appear to feed at a lower overall intensity as their stomachs were never full, but they must feed constantly from dawn to dark (0700 to 2100) as there was usually always some food in the first section of the digestive tract. At this period of the season the fish fed mainly on algae and mytilus. As in June, light intensity seemed to govern the initiation of feeding.

The feeding habits and food preferences exhibited by mature male <u>Cymatogaster</u> in August were quite similar to those of July except that the feeding intensity had increased to some extent as was illustrated by the full gastro-intestinal tract, and the fish stopped feeding by 1700 hours. Again feeding seemed to be initiated with the increased light intensity associated with sunrise.

Figure 35 shows that by 2100 hours in June the mature females have stopped actively feeding and that there was no feeding throughout the hours of darkness. With sun-







Figure 35. Volume and composition of food organisms in the four sections of the gastrointestinal tract of mature female <u>Cymatogaster</u> over 24 hour periods in June, July, and August.

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rise (0500 hours) they started eating large zooplankton (copepods), and by 0700 hours many of the plankton have reached the second section of the gut. After the initial feeding on copepods the females started to feed on mytilus and algae between 0700 and 0900 hours and continued to do so until 1900 hours when, with decreasing light intensity, they ceased feeding.

In the mid-July sample, which was taken just following the peak of the spawning period, the mature females almost ceased feeding entirely. Throughout the entire 24 hour period there were only traces of food organisms found in the gastro-intestinal tract.

In August, the mature females were actively feeding again. They started to eat with the increase in light intensity and continued until around 1700 hours when feeding ceased. During this period most digestive tracts were full which indicates that the fish were feeding quite intensively. Progressively less food was found in the gut during the hours of darkness.

In mid-June, at the time of sampling, the yearling males (Figure 36) were mainly feeding on large copepods. Like the mature males, they started eating after sunrise (0500) and continued feeding until around 1300 hours when all feeding activity stopped.

In July, the yearling males again started feeding with the sunrise and continued to eat actively until darkness







Figure 36. Volume and composition of food organisms in the four sections of the gastro-intestinal tract of yearling male <u>Cymatogaster</u> over 24 hour periods in June, July, and August.

(2100 hours). At this time of year the fish feed actively all day long as is evidenced by the full digestive tracts. Their diet consists mainly of <u>Mytilus</u> and algae with some small zooplankton.

In August the yearling males again start feeding with the dawn, eat intensively until around 1700 hours, when food intake is reduced, and then cease to feed with darkness. In August, similar to July, their main dietary constituents were Mytilus and algae, with some small copepods and barnacles.

The feeding habits and food preferences of yearling females (Figure 37) are very similar to those of yearling males throughout the sampling period, except that in June the females continue feeding until 1900 hours instead of 1300 hours.

Estimates were made of the time it took food to pass from the first section of the gastro-intestinal tract through to the last section (four) by noting the time of the first appearance of food in section one (just after sunrise) and the first appearance of the same type of food in section four. Estimates were also made of the time it took for the gut to become empty after feeding had ceased.

In June, when the fish were eating large copepods, it took approximately four hours for these food organisms to pass from section one to section four in the mature fish for both males and females. In the digestive tracts of the yearling male and female <u>Cymatogaster</u>, it took food items eight to ten hours to move from section one to section four.







Figure 37. Volume and composition of food organisms in the four sections of the gastro-intestinal tract of yearling female Cymatogaster over 24 hour periods in June, July, and August.

During this period of the year it took approximately eight hours for the stomachs of both adults and yearlings to empty.

In July, when the main dietary items were mytilus and algae, it took approximately six hours for food to pass through to section four in the mature males and ten hours in the mature females. It took approximately four hours to make the same passage in both male and female yearlings. It took six to eight hours for the stomachs of the adults and yearlings to become empty.

In August, with the diet very similar to that found in July, it still took approximately six hours for food to reach section four in the mature males, but only four hours in the females. It also required about four hours in the yearling males and females. The time required for the stomachs to become empty was again from six to eight hours.

The feeding habits, food preferences, and digestive rates of <u>Cymatogaster</u> may vary with season, age and sex. One feature, however, was exhibited by all four groups throughout the study period, and this was that feeding seemed to be initiated by the increased light intensity associated with sunrise.

During the pre-spawning period in June, the mature and yearling fish of both sexes started feeding with sunrise, but the males fed only until early afternoon while the females continued until evening. During this period of the year, the time it took for food organisms to pass from the first sec-

tion of the gastro-intestinal tract to the last differed greatly between adults and yearlings, requiring at least twice as long in the yearlings. The digestive rates, or the time it takes for a stomach to empty itself after feeding had ceased, were approximately the same (8 hours) for both adults and yearlings.

In mid-July, just after the peak of the spawning period, the intensity of feeding of the mature fish was greatly reduced, in fact the females had almost entirely stopped feeding. At this time the males started feeding at dawn and may continue to eat small amounts of food until late evening. The females may take in a few food organisms anytime of the day or night. At this time of year the rate of passage of food through the gut also decreased in the mature fish, taking in the males approximately six hours and the females around ten hours instead of four. The digestive rates appeared to remain at around eight hours. Both sexes of the yearlings, however, increased their rate of feeding in July and the food passed much more quickly through the gastro-intestinal tract than it did in June (about one half The digestive rates remained approximately the the time). The yearlings started to feed with sunrise and consame. tinued eating until late evening.

By mid-August the mature fish of both sexes were actively feeding again and the yearlings continued to feed at an intensive rate. Feeding was initiated with increased

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light intensity and continued until evening. The rate of passage through the digestive tract of food remained approximately the same for the mature males and both sexes of yearlings, but was greatly increased in the mature females. The digestive rates again remained the same.

In summary it may be stated that the feeding habits, food preferences, rate of passage of food through the digestive tract and the digestive rates of <u>Cymatogaster</u> may vary with time of year, age and sex.

### DISCUSSION

<u>Cymatogaster</u> exhibits relatively complex patterns of seasonal and diurnal movements that may vary with the time of year and with the age and sex of the individual fish.

Most authors have been able to correlate various environmental factors such as light, temperature, food preferences or a combination of these factors with diurnal movements and seasonal depth preferences. Throughout the present study, <u>Cymatogaster</u> seemed to be influenced more by light than by any other aspect of their physical environment.

In the marine environment, studies by Hickling (1927), Richardson (1952), and Nomura (1958) have demonstrated that the diurnal migrations exhibited by hake, sardines, herring, and pilchards are related to underwater light Studies in the freshwater environment have also intensity. shown that in some cases light intensity may be important. Bryon and Howell (1946), Carlander and Cleary (1949), Hasler and Wisley (1958) observed that vertical distribution of the fishes under observation was related to the intensity of illumination at various depths. However, Dendy (1945) observed that the vertical distribution of game fish in a resevoir showed no relation to light intensity. Also, in some instances, a species' reaction to light intensity may vary from year to year. Lorz (1962) found that in 1961 kokanee were not present in areas where the light intensity

was above a certain value, but in 1959 their presence was noted through all ranges of light intensity.

Studies have shown that under natural conditions pelagic fishes of both the marine and fresh water habitats may keep within a given range of light intensity by making vertical migrations. In most instances these diurnal migrations have involved the movement of fish from deep to shallow water with the falling light intensity associated with evening, and the return to deeper water with the increase in illumination at dawn. Reverse migrations are also known. However, there are no instances in the literature that involve the sudden reversal of diurnal movement pattern such as is exhibited by Cymatogaster. The cause of this sudden reversal is unknown. The environmental factors such as water temperature and illumination, as well as feeding habits and food preferences, remain relatively similar over the period of change, perhaps indicating that the basis of the reversal is physiological rather than environmental.

There seems to be little doubt that the diurnal migrations observed for both mature and yearling <u>Cymatogaster</u> are governed by changes in light intensity. In June, very few fish are found in shallow water after sunset, but there is a great increase in numbers after the light intensity increases at sunrise. After the reversal, in July and August, Cymatogaster become much more abundant in shallow water after sunset, and move back into deeper water with the

dawn. As further evidence of the importance of light intensity, in July the increased illumination associated with moonrise caused yearling fish to move into deeper water. The effect of light is also very evident in the data obtained from the study of diurnal feeding habits. Regardless of the period of sampling, the initiation of feeding was invariably associated with an increase of light intensity after a period of darkness. Also, with rare exceptions, no feeding occurred during the hours of darkness.

In the freshwater environment, it has been suggested that temperature may play an important role in governing the spatial distribution of fishes (Fry, 1937, Hile and Juday, 1941, Dendy, 1945, and Ferguson, 1958). However, Lorz (1962) found that the vertical distribution of kokanee could not have been controlled directly by temperature. In Nicola Lake, regardless of thermal structure, kokanee undertook diel vertical movements.

The marine environment where the present study was undertaken, in the Strait of Georgia and the southern inlets which enter into it, is characterized by stable thermal stratification of the surface layer due to summer heating. Surface temperatures usually range from  $10^{\circ}$  to  $18^{\circ}$  C. during the warmer seasons; the deeper layers below the thermocline range from  $5^{\circ}$  to  $8.5^{\circ}$  C. throughout the year. During winter months, when stratification breaks down, temperatures for the entire water mass usually range from  $5^{\circ}$  to  $8.5^{\circ}$  C. (Pickard,

1961).

There are indications that there may be a relationship between the seasonal migrations and depth preferences of <u>Cymatogaster</u> and changes in water temperature. In spring, when the surface water temperatures are rising the fish first appear in the study area, and in fall, when water temperatures are falling, the fish leave the area. The diurnal movements of <u>Cymatogaster</u>, however, do not seem to be directly related to temperature. The fish moved freely through the thermocline during all periods of the day and night during the study period. Also, there was very little difference between the surface and deeper water temperatures of June and July when the reversal of the diurnal movement pattern occurred.

Perhaps temperature may play some role in the vertical distribution of <u>Cymatogaster</u> on a seasonal basis, but it is likely that temperature is acting in combination with other environmental factors. Ferguson (1958) states "... temperature, if acting alone, can determine the distribution of fish in laboratory apparatus. Factors such as light, conditioned response related to feeding routines, and social behaviour can interfere with expression of the response to temperature."

Several authors have found that feeding habits and food preferences may have an effect on the vertical distributions of some fishes. Fry (1937) found that cisco remained

in the epilimnion in the summer for some time to feed upon emerging mayflies, even if temperature conditions became unfavorable. Martin (1952) showed that lake trout came up through the thermocline to feed on perch concentrated in the warmer water. Lorz (1962) found that the vertical distribution of kokanee in some years appeared to be related to diet in the early spring and summer.

The present study indicates that there is probably little relationship between the seasonal and diurnal food preferences and feeding habits of Cymatogaster and seasonal and diurnal movements and depth preferences. Principal food items, such as Mytilus, algae, and barnacles, are found both in the upper sub-tidal and inter-tidal environments, and are available to the fish regardless of the level of the tide or the temperature of the water. Both large and small zooplankton are also found throughout the depths frequented by Cyma-Since the primary food items are available to the togaster. fish throughout the depths frequented by the species, and the stomach contents of fish taken from different depths have contained similar food items, it seems unlikely that food preferences and feeding habits have much effect on seasonal and diurnal depth distributions of Cymatogaster.

Correlation of Age and Growth, Movement, and Stomach Content Analysis Data

After formation of the annulus in early spring (around mid-April) Cymatogaster probably starts to feed at a higher intensity as the water temperature begins to rise. The increase in rate of feeding may be due to several factors. Rise in water temperatures probably causes an increase in metabolic rates and also apparently causes fish to become more active (Brown, 1957). An increase in water temperature may cause plankton blooms (Hardy, 1956) thus increasing the availability of food organisms. Also, as the fish start to move into shallower water they will come into increasingly greater concentrations of some of their most important food items, algae, barnacles and mussels. An increase in metabolic rates, coupled with the availability of more food, should cause an increase in the growth rate. This expected increase in instantaneous daily growth rate in the spring and early summer months is shown by Figure 15.

In early June, with warming of the surface waters, <u>Cymatogaster</u> started to move into the study area at Keates Island from the south-west. The first fish to appear were yearlings, followed by adult males and then by adult females. The relative numbers of both sexes of adult and yearling <u>Cymatogaster</u> remained at a fairly constant level from mid-June until just prior to the spawning period. During June the yearling and adult fish exhibited a pattern of diurnal movement, which involved migration of fish from over the beach and kelp beds into deeper water with the decrease in light intensity associated with sunset, and then the return to shallow water with sunrise.

In early June, when the first specimens became available for examination, the stomachs of both adult and yearling <u>Cymatogaster</u> were rarely more than half full, but all fish had been eating to some extent. The yearlings were feeding predominantly on small zooplankton while adult fish tended to feed on mussels and algae. The fish started feeding at sunrise, the males ceasing to feed by early afternoon while the females continued until evening.

Just prior to spawning, at the end of June, there was a great increase in the number of both adult and yearling fish over the beach and in the vicinity of the kelp beds. During the period of actual spawning, in early July, the adult fish moved into very shallow water over the beach while the yearlings moved back into deeper water off the reef faces. After spawning the adults also moved into deeper water.

By mid-July a complete reversal of the diurnal movement pattern exhibited by <u>Cymatogaster</u> in June had occurred. There were relatively few fish present over the study area during the daylight hours, but, with darkness, there was an onshore movement of large numbers of adult and yearling fish. The feeding activity of the yearling fish increased in early July, while the adult fish, particularly the females, almost entirely stopped eating. This lowering of the rate of feeding of adult fish was probably associated with reproduction, the testes of the male were large and ripe and the embryos within the female took up a large volume of the abdominal cavity. The average instantaneous monthly growth rate of the mature males remained relatively constant in June and July, while that of the mature female was noticeably reduced. This phenomenon was probably due to a much greater reduction in the intake of food by females than by males. Why there was a decrease in the growth rate of yearlings from June to July is not known at present.

By early August the adult fish had begun actively feeding again and their rate of growth increased. The yearlings continued to feed at an intensive rate. During August the pattern of diurnal movement was similar to that of July for both yearlings and adults, and, as in July, feeding was initiated at dawn and ceased before total darkness. It was also during the month of August that the majority of fish formed a spawning check. Since the yearling fish, as well as the adults, formed the check, and since the yearlings actively fed during the entire time they are in the study area, it was assumed that the formation of a spawning check was related to some physiological stress associated with reproduction and not to the amount of food eaten.

Cymatogaster continued to feed actively until the end of September when food intake was reduced. At this time of year the surface water was cooling down and the fish started to move into deeper water. Although there was no 36 hour diurnal sample taken then, the seasonal netting data indicated that the fish remained in deeper water during the day, following the same pattern as July and August. By the end of September the great majority of fish had formed a spawning check. There are indications that when the fish move out of the study area into deeper, colder water, growth and probably feeding almost cease. In the study of age and growth it was noted that the average distance from the last annulus to the leading edge of the scale was almost as great as the average distance from that annulus to the one that will be formed in the coming winter. The average instantaneous monthly growth rate was also demonstrated to be much less during the eight month period between the formation of a spawning check and the following annulus, than during the four month period between the formation of an annulus and the following spawning check.

#### SUMMARY

- Regression lines plotted for the body length scale relationship show that <u>Cymatogaster</u> exhibits a relatively constant relationship between scale growth and increment of body length throughout its life history.
- 2. The scale of <u>Cymatogaster</u> may have up? to three different checks, birth checks or metamorphic annuli, spawning checks, and annuli. By observing the time of formation of a check, by studying the physical features of a check, and by taking the average distance from the focus of the scale to a check and comparing it with the average distance, the nature of a particular check can be determined accurately.
- 3. By plotting the regression lines for body length on anterior scale radius, and measuring the distance from the focus of a scale to a particular point on the scale, the body length of the fish at any previous stage in its life history may easily be back-calculated.
- In the sample of <u>Cymatogaster</u> studied, Lee's phenomenon is not apparent.
- 5. Virtually all yearling <u>Cymatogaster</u> males were sexually mature in the spring of the year. No yearling female examined contained embryos but virtually all the 2 year old females did.
- 6. The highest levels of instantaneous growth rates occur

between the formation of an annulus and the following spawning check. The lowest level of instantaneous growth rates occur between the formation of a spawning check and the following annulus.

- 7. In the spring the first fish to appear in the study area moving into shallower water were yearling males, followed by adult males, then adult females.
- 8. At the time of spawning there was a great increase in the number of adult <u>Cymatogaster</u> over the study area and at the same time the yearlings moved out into deeper water during the day.
- After spawning the adult fish returned to deeper water during the day.
- 10. In June, before spawning, <u>Cymatogaster</u> exhibited a pattern of diurnal movement that involved the movement from deep to shallow water during the day, and from shallow to deeper water at night. After spawning there was a complete reversal of the diurnal movement pattern.
- 11. Light intensity appeared to be very important in governing onshore and offshore movements of <u>Cymatogaster</u>. Other factors such as temperature and feeding habits seemed to have little effect on diurnal movement or seasonal movement patterns.
- 12. Yearling <u>Cymatogaster</u> actively feed throughout the time they are present in the study area. Adult <u>Cymatogaster</u> exhibited a marked reduction of feeding activity before,

during, and after spawning.

- 13. By volume, mussels and algae were the most important items in the diet of <u>Cymatogaster</u>, but barnacles and zooplankton were sometimes eaten in large quantities. The feeding habits and food preferences of adults and yearlings were very similar.
- 14. The rate of passage of food through the digestive tract varied between adults and yearling <u>Cymatogaster</u>, and the rate also varied with the season of the year. The digestive rates of adults and yearlings were approximately the same and they did not vary seasonally.

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