AN ABSTRACT OF THE THESIS OF

PATRICIA ANN TESTER for the degree of MASTER OF SCIENCE

in _____ OCEANOGRAPHY _____ presented on _____ July 14, 1975 _____

Title: SIZE CLASSES, POPULATION STRUCTURE, GROWTH, SEX

RATIO, AND SIZE AND AGE AT MATURITY OF

CHIONOECETES TANNERI RATHBUN (BRACHYURA:

MAJIDAE) OFF THE OREGON COAST

Redacted for Privacy

Abstract approved: _____
Dr. Andrew G. Carey, Jr.

During eleven cruises conducted off the Oregon continental slope from April 1973 to March 1975, approximately 1600 specimens of the majid crab Chionoecetes tanneri Rathbun were collected. A time sequence of size frequency histograms and bivariate plots of allometric measurements were used to determine size classes, population structure, growth and age at maturity of C. tanneri from the Oregon coast. Adult sex ratios and sex ratios for each of the juvenile size classes were computed.

Bivariate plots of carapace width and cheliped length for males and carapace width and abdomen width for females defined nine size classes for juvenile males and eight size classes for juvenile females.

The morphogenic relationship between differential cheliped length and gonad maturity in males and differential abdomen width and gonad maturity in females (Watson, 1970a; Brown and Powell, 1972) allowed determination of minimum size at maturity of 118 mm carapace width for male C. tanneri and 85 mm carapace width for female C. tanneri. Mean carapace widths for adult males (142.7 mm) and adult females (102.5 mm) collected for this study compare well with those given by Pereyra (1972).

Mean carapace width increase for each molt for all juvenile size classes was computed to be 26.14%. When size classes were equated to molt groups a linear regression (Time = -2.94 + 0.81 (Carapace width)), based on progression of carapace width modes through time, predicts age at maturity to be from five to six years.

A highly significant departure from a 1:1 sex ratio for adults, of 2.41 females per 1 male, is consistent with reports for other members of the genus Chionoecetes (Hilsinger, 1975).

Size Classes, Population Structure, Growth, Sex Ratio, and Size
and Age at Maturity of
Chionoecetes tanneri Rathbun (Brachyura: Majidae)
Off the Oregon Coast

by

Patricia Ann Tester

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed July 1975

Commencement June 1976

APPROVED:

Redacted for Privacy

Associate Professor of Oceanography
in charge of major

Redacted for Privacy

Dean of School of Oceanography

Redacted for Privacy

Dean of Graduate School

Date thesis is presented ___July 14, 1975___

Typed by Suelynn Williams for Patricia Ann Tester

To B. L. T. and M.H.W.

ACKNOWLEDGMENTS

I extend special thanks and gratitude to Dr. A. G. Carey, Jr., my major professor, for suggesting this research and for allowing me the freedom to pursue it in my own manner. He has made a unique opportunity available to me.

Two members of my committee deserve special thanks. Dr. Howard Horton has provided much patient counsel. He has generously shared his time and knowledge and his editing ability has greatly improved this thesis. The interest shown by Dr. Charles B. Miller in a student other than his own is gratefully acknowledged. Charlie's ability to challenge and constructively criticize my thinking has helped clarify portions of this thesis.

I owe a debt of gratitude to those who helped in the extensive sampling program for this research. The Captain and crew of the "quick and maneuverable" R/V CAYUSE extended advice, friendship, and an extra measure of effort to help make sample collection possible regardless of weather. Brian Oliver, a co-worker on this project, deserves special mention. I had the benefit of the friendship and experience of Gene Ruff, John Dickinson, and Bob Carney for the first several cruises. Bob also interrupted his research to serve as Party Chief on the August 1974 cruise. To Bill Kopplin, Antoine Badan-Dangon, Chris VanderVelden, Gary and Sheri Sharp,

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES CONTINUED

LIST OF TABLES

SIZE CLASSES, POPULATION STRUCTURE, GROWTH, SEX RATIO, SIZE AND AGE AT MATURITY OF <u>CHIONOECETES TANNERI</u> RATHBUN (BRACHYURA: MAJIDAE) OFF THE OREGON COAST

I. INTRODUCTION AND BACKGROUND

The purpose of this research was to determine size classes, population structure, growth, sex ratio, and age at maturity, and to confirm size at maturity of <u>Chionoecetes tanneri</u> Rathbun from the continental shelf and slope off Oregon. Between April 1973 and March 1975 eleven cruises were conducted for this study. The findings of this research provide information on the biology of <u>C. tanneri</u> pertinent to the management of a prospective commercial fishery for this species. The feasibility of a fishery for <u>C. tanneri</u> is currently under study. Estimates of abundance and seasonal distribution patterns were determined by Oliver (1976) in a joint study.

The genus <u>Chionoecetes</u> Kroyer currently supports substantial commercial fisheries in the north Pacific basin and Atlantic maritime provinces of Canada. The U.S. fishery began in Alaska in 1968 as a supplemental fishery during closed king crab (<u>Paralithodes camtschatica</u>) season and has continued (Brown, 1971). The Department of Commerce Catch Statistics (Wheeland, 1972) record combined Alaskan landings in 1971 of 29 million pounds for the two shallow water species, <u>C. opilio</u> and <u>C. bairdi</u>; this is twice the previous high of

14.5 million pounds landed in 1970. The increased landings of
Chionoecetes sp. in Alaska are concurrent with declining catches of
king crab (Alaska Department of Fish and Game, 1972). Watson
(1970a) reports the landings from the Atlantic coast of Canada for C.
opilio increased from 1 million pounds in 1967 to 18 million pounds in
1969. The Japanese fishery for C. opilio elongatus, centered in the
Sea of Japan, peaked in 1968 with a catch of 136 million pounds (FAO,
1970). Since 1968 both Japanese and Russian fishermen have taken
increasing numbers of C. opilio from the Bering Sea. C. opilio and
C. bairdi are both shallow water species and to date little commercial
attention has been paid to the two deep water species, C. tanneri and
C. angulatus.

There is some interest in developing a commercial fishery along
the Oregon coast for C. tanneri (Pereyra, 1967). Of the four species
of the genus Chionoecetes reported in the eastern Pacific by Garth
(1958), C. tanneri is the only one occurring along the Oregon coast
in numbers large enough to suggest that a commercial fishery might
be feasible (Pereyra, 1972).

Even though species of the genus Chionoecetes constitute the
base of sizable commercial fisheries, little is known of their life
histories or population characteristics. Size frequency distributions
are available for the C. opilio stock in the Sea of Japan (Ito, 1970)
and other works have concentrated on the reproductive biology of

C. opilio (Ito, 1963, 1967; Watson, 1969, 1970a, b) and C. bairdi
(Hilsinger, 1975). Chionoecetes bairdi comprises approximately 95%
of the Alaskan catch (Brown, 1971), but as late as 1972, no size limit
existed for the C. bairdi fishery because size at maturity was not
known (Brown and Powell, 1972). Growth rates and population struc-
ture of the C. bairdi fishery are now being investigated by the Univer-
sity of Alaska, the Alaska Department of Fish and Game and the
National Marine Fisheries Service.

Accurate determinations of growth rates and age of a species
are of fundamental importance to any ecological research or resource
management study. Size measurements can be used to obtain informa-
tion on population structure, size at maturity, growth rates and age.
In the class Crustacea the discontinuous growth caused by the molting
process leaves no known permanent age indicator, and makes the
estimation of age and determination of growth rates difficult by use of
size measurements alone. This research resulted in a method based
on allometric measurements (Huxley, 1932) for determining size
classes and subsequently deriving population structure and growth for
Chionoecetes tanneri.

II. METHODS

Field Methods

Samples were collected with trawl gear on eleven cruises between April 1973, and March 1975. An effort was made to sample the same stations during each season of the year to determine seasonal differences of population characteristics. The dates, duration, and location of each cruise are given in Table I.

The continental shelf and slope area adjacent to Coos Bay, Oregon, was selected as the primary sampling site because of the local interest in a fishery for C. tanneri (personal communication William Barss, Fish Commission of Oregon, Charleston, Oregon, letters dated 23 October 1973, and 5 April 1974). Limited comparative sampling was conducted at Cape Blanco and along the northern Oregon coast and below the mouth of the Columbia River (Astoria location).

Two types of trawls were used for sampling. A 27-foot (8.22-m) semi-balloon Gulf of Mexico shrimp trawl was used during the first year. A 3-meter beam trawl (Carey and Heyamoto, 1972) was used at selected stations in addition to the shrimp trawl for the second year. The mesh for both trawl nets was 1.5-inch (3.81-cm) stretched dimension and each net was completely lined with 0.5-inch (1.27-cm) mesh.

Sampling was conducted along tracklines selected within depth

Table I. Collecting data for <u>Chionoecetes</u> <u>tanneri</u> taken on eleven cruises off the Oregon coast 1973-1975.

Cruise Number	Location	Date	Days at Sea	Trawl on Bottom Time in Minutes	Total Catch	Correction* Factor
1	Coos Bay	April 1973	5	828	136	9.85
2	Coos Bay	August 1973	6	945	268	17.02
3	Coos Bay	October 1973	6	945	226	14.35
4	Coos Bay	November 1973	5	700	137	11.74
5	Coos Bay	March 1974	5	690	122	10.60
6	Coos Bay	June 1974	10	1222	177	8.69
7	Coos Bay Cape Blanco	July 1974	10	1465	124	5.08
8	Coos Bay Astoria	August 1974	10	1940	163	5.04
9	Cape Blanco	September 1974	3	180	1	0.33
10	Coos Bay	January 1975	3	495	107	12.97
11	Coos Bay	March 1975	5	425	81	11.29

* Catch per hour used as a correction factor so data from each cruise could be compared.

intervals, but not selected at random. The topography of the continental shelf and slope in the Coos Bay region is uneven and tracklines selected completely at random within depth zones would have hampered trawl retrieval and precluded efficient use of time and effort. The standard tracklines for each sampling site are given by Oliver (1976). Since this research was not concerned with distribution or with absolute numbers, all specimens from all locations and those collected by both trawls were combined for each cruise.

Because of seasonal differences in weather conditions, bottom topography and differences in faunal abundance with depth, the tows were not of equal duration. A correction factor for effort, based on the calculated amount of time (in minutes) the trawl remained on bottom during each cruise, was used. Standardization to catch per 60 minutes allowed direct comparison of catch data between cruises. The correction factors for each cruise are listed in Table I. Estimates of the time the trawl was on bottom were determined as the interval between the time the wire was fully payed out until its retrieval commenced. A 3:1 scope was used for all trawls. Variation in the performance and speed of the trawls over different bottom topography caused unequal coverage of bottom areas. The extent of these variations and their distribution in time and space is not known. Therefore, no attempt was made to adjust for these errors and they are assumed to be random for the purpose of this study.

Laboratory Methods

All specimens were hand sorted aboard ship (except as noted), preserved in borax buffered, 5% Formalin, and returned to the laboratory.

Length and width measurements were taken for size frequency information. Because differential growth of body parts occurs at maturity in many brachyurans, cheliped length and width measurements were taken on all males, and abdomen width measurements were taken on all females to provide information on size at maturity. All measurements were made to the nearest 0.01 mm using vernier (dial) calipers.

Carapace width was measured at the widest part (across the mesobranchial region) exclusive of spines (Figure 1a). Carapace length was measured from the center of the rostrum to the back edge of the carapace, exclusive of spines (Figure 1a). The cheliped width was measured at the widest part of the manus so the caliper jaws were equidistant from the superior marginal spines (Figure 1b). Cheliped length was measured from the joint between the carpus and manus to the tip of the dactylus (Figure 1b). In females, abdomen width was measured at the widest part, the fifth segment (Figure 1c).

Observations made on each specimen included carapace hardness, general condition, attached fauna, and number of missing legs.
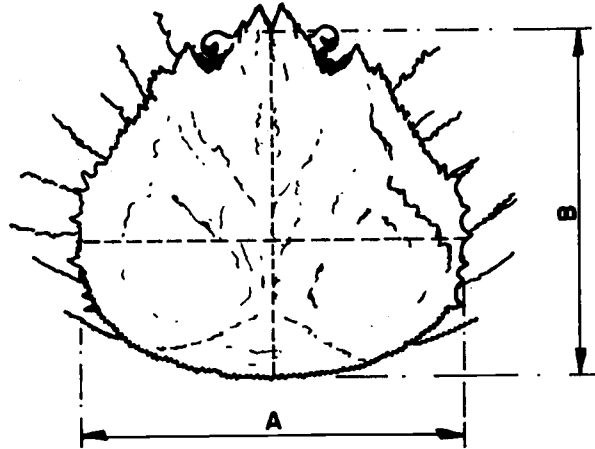
(a) Carapace measurements N = 1674: (a) width (♂ and ♀); (b) length (♂ and ♀).
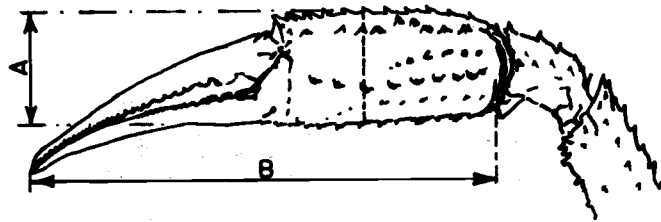
(b) Cheliped measurements N = 872: (a) width (♂); (b) length (♂).
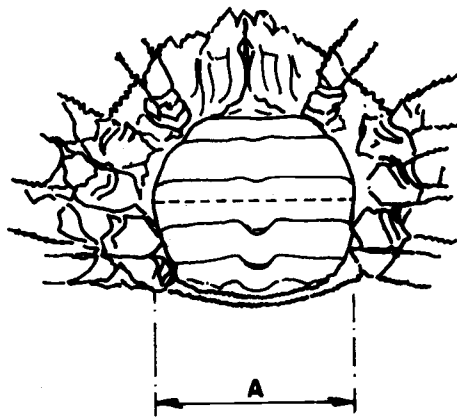
(c) Abdomen measurement N = 902: (a) width of fifth abdominal segment (♀).

Figure 1. Body dimensions of *Chionoecetes tanneri* measured for size frequency analysis.

Early in the sampling program, I noticed much of the adult population of C. tanneri, especially the females, was subject to carapace deterioration. Darkened and softened or weakened areas on the carapaces were similar to those reportedly caused by chitinoclastic bacteria (Bright, Durham, and Knudsen, 1960; Sindermann, 1970). The incidence of such carapace deterioration was recorded, and Dr. John Baross, Marine Microbiology, Oregon State University attempted to isolate and culture the bacteria responsible for the necrotic lesions and carapace darkening.

III. RESULTS

Size Frequency Distributions of Chionoecetes tanneri

Oliver (1976) lists numbers, sex, and depth of all specimens collected from each trawl during the eleven seasonal cruises. These data (except for one adult male collected September 1974) were corrected for effort and plotted as size (carapace width) frequency histograms (Figure 2). Examination of these histograms for modes indicative of size classes suggests that, if the various modes represent size classes, the size classes are both numerous and closely associated. Since adult C. tanneri are sexually dimorphic with respect to size (Pereyra, 1972), the data from the first year of sampling were plotted separately for each sex (Figures 3 and 4).

The modes for both juvenile males and females are coincident so none of the overlap in modes is due to differences in modal sizes between juvenile males and females. The pronounced modes between 85-110 mm and 130-160 mm carapace width represent the size classes for adult females and adult males respectively. Given that the modes in the size frequency histograms (Figure 2) were as clearly defined as possible, I tried to determine modes indicative of juvenile size classes.

The size frequency histograms (Figure 2) show certain persistent modes between 1-80 mm carapace width (i.e. modes centered
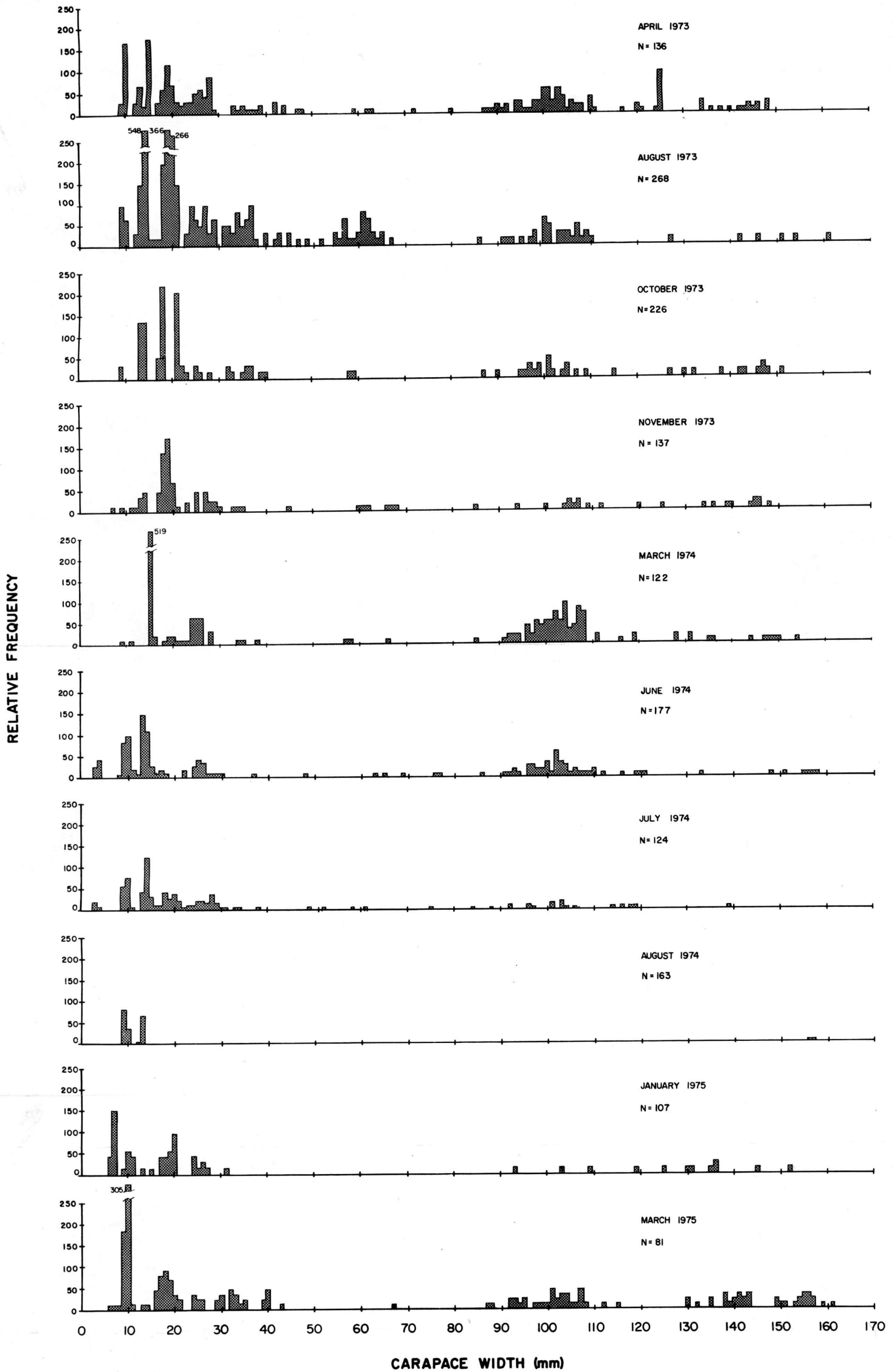
Figure 2. Size frequency histograms representing all specimens collected from ten cruises. These data have been corrected for effort.
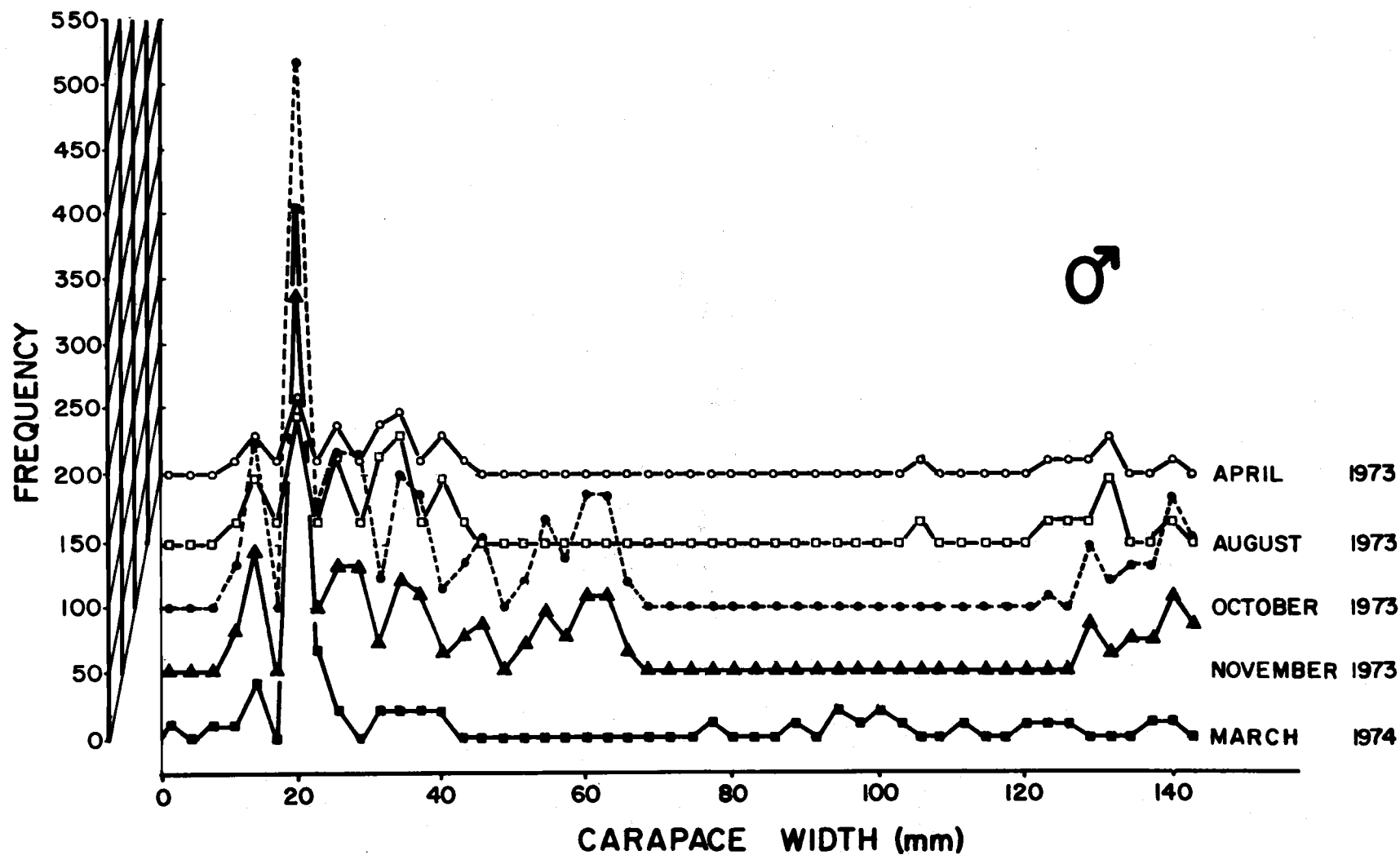
Figure 3.   Size frequency distribution for male <u>Chionoecetes tanneri</u>
collected during the first year of sampling off the Oregon
coast.
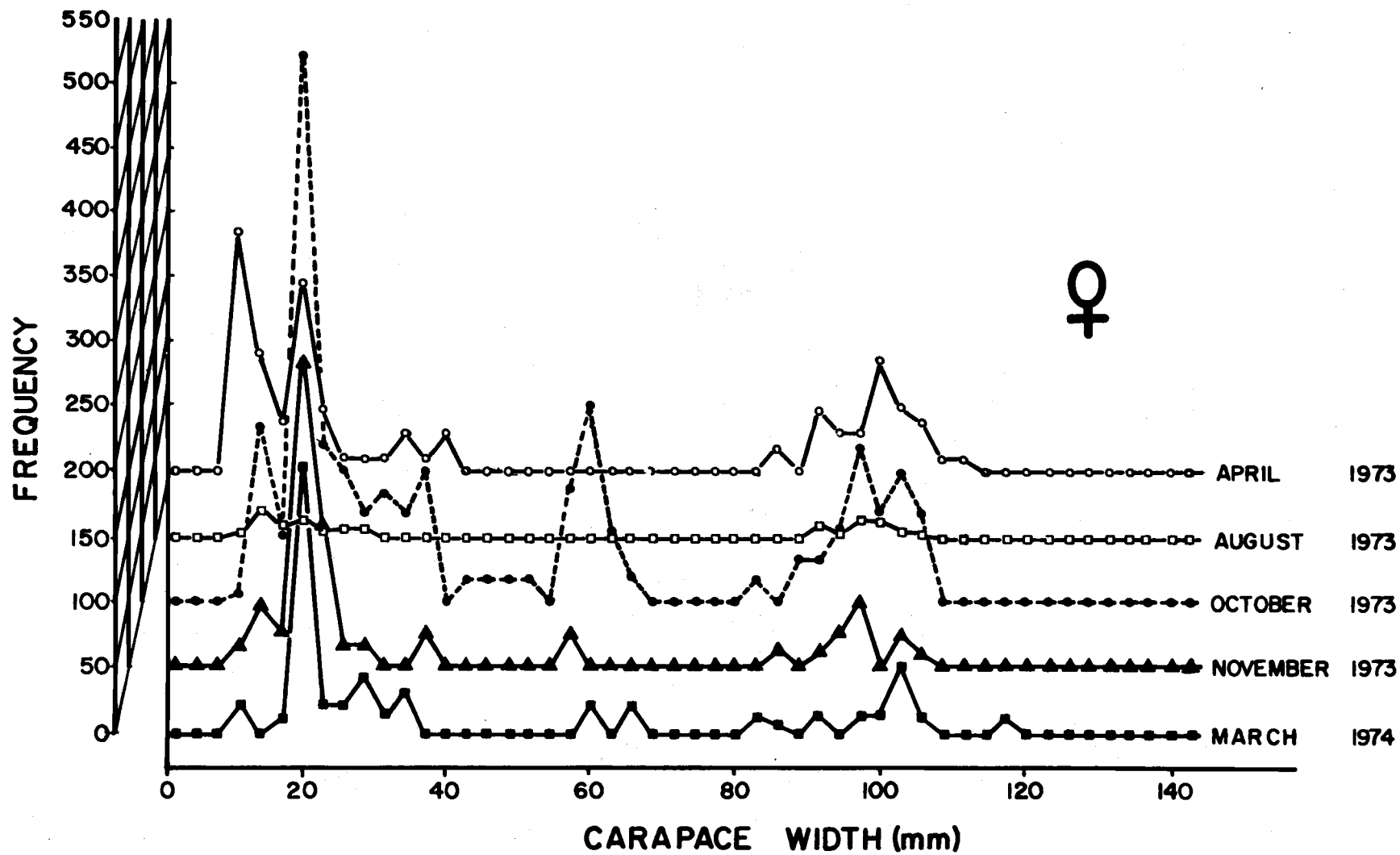
Figure 4. Size frequency distribution for female <u>Chionoecetes</u> <u>tanneri</u> collected during the first year of sampling off the Oregon coast.

13

around 10, 14, 19, 25, and 35 mm carapace width). These modes

are closely spaced on the carapace width axis yet distinguishable in

successive samples; the heights of these modes fluctuate with time

and no single mode (in the 1 to 80 mm carapace width range) is

significant during all times of the year. Therefore, it is assumed

the modes represent molt groups and the variance of size increase

per molt for these first five molt groups is small. This assumption

allows summation of the data over time.

Juvenile specimens in the size range from 1 to 120 mm carapace

width were summed over ten cruises and carapace width was plotted

against frequency (Figure 5). I reasoned that larger sample size

would allow clearer definition of juvenile size class modes and con-

sequently, their lower order moments. Five clear modes between

10 and 45 mm carapace width exist, but it is unclear if the specimens

below 10 mm represent one or two modes. Also, at carapace widths

greater than 70 mm, modes are difficult to define because of too few

specimens.

To help extract the component groups from this polymodal

frequency distribution (Figure 5), I tried using the method of Harding

(1949) as revised by Cassie (1954). The probability plot of the cumu-

lative frequency for each 1 mm carapace width interval and work

sheets of calculations for determining the lower order moments of

each distribution defined by this method are given in Appendix I.

15
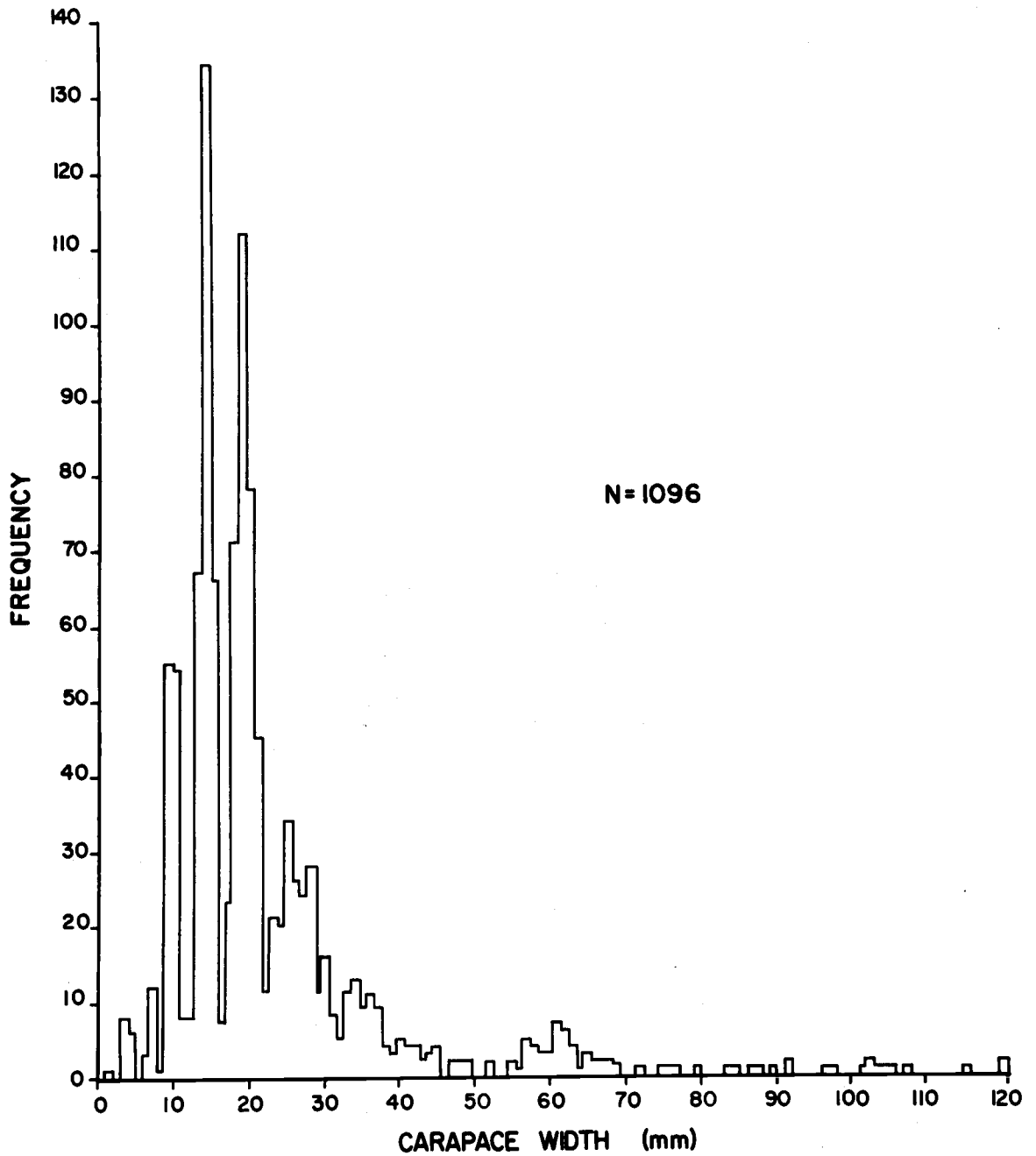
Figure 5. Size frequency distribution for juvenile *Chionoecetes tanneri* specimens collected during ten cruises off the Oregon coast 1973-1975.

The size frequency analyses were not adequate to resolve a complete series of size classes for juveniles from 1 to 120 mm carapace width. The sample size (N = 1096) generated by combining specimens from ten cruises was probably adequate in the 1 to 20+ mm carapace width range but not enough specimens of 20+ to 120 mm carapace width were collected to cause obvious inflections in a cumulative percent curve.

Because size frequency analyses were not adequate to define a complete series of size groups for juvenile C. tanneri, I examined bivariate plots of allometric measurements of C. tanneri for information on size at maturity.

Size at Maturity of Chionoecetes tanneri

Because certain morphogenic changes often accompany the maturity molt in brachyurans, the determination of size at maturity for C. tanneri was based on allometry. In females the abdomen differentially widens in relation to the carapace dimensions and the pleopods are modified in shape and develop hairs for holding egg masses at maturity; in males the chelae differentially enlarge with respect to the carapace dimensions at maturity (Carlisle and Knowles, 1959; Hartnoll, 1969; Watson, 1970a; Brown and Powell, 1972).

In two years of sampling measurements were taken on 421 males for cheliped length and carapace width and 689 females for

abdomen width and carapace width. These data are shown in Figures

6 and 7. As expected, there is a group of specimens with chelae

longer than 85 mm (corresponding to carapace widths greater than

118 mm) which are assumed to be sexually mature males (Figure 6),

based on the correlation between differential morphology and sexual

maturity. Those females with abdomen width greater than 50 mm

(corresponding to carapace widths greater than 85 mm) form a well

defined group and are assumed to be adults (Figure 7).

Size Classes of Chionoecetes tanneri

Upon closer examination of Figures 6 and 7, a series of size

groups (based on carapace width) can be detected. By use of expanded

scales one can visually define ten size groups for males and nine size

groups for females. These size groups are well defined, and although

generated by different measurements, are non-overlapping (except

for pre-Adult molt groups) and coincident (Table II and Figure 8).

The biological validity of the size class groupings can be tested

by calculating the percent increase in mean carapace width per molt

(Table III). The average increase in carapace width per molt for

juveniles is nearly constant and confirms the constant increase per

molt ratio reported by other workers (Newcombe, Campbell, and

Eckstine, 1949).

Most females of the genus Chionoecetes cease to molt after the
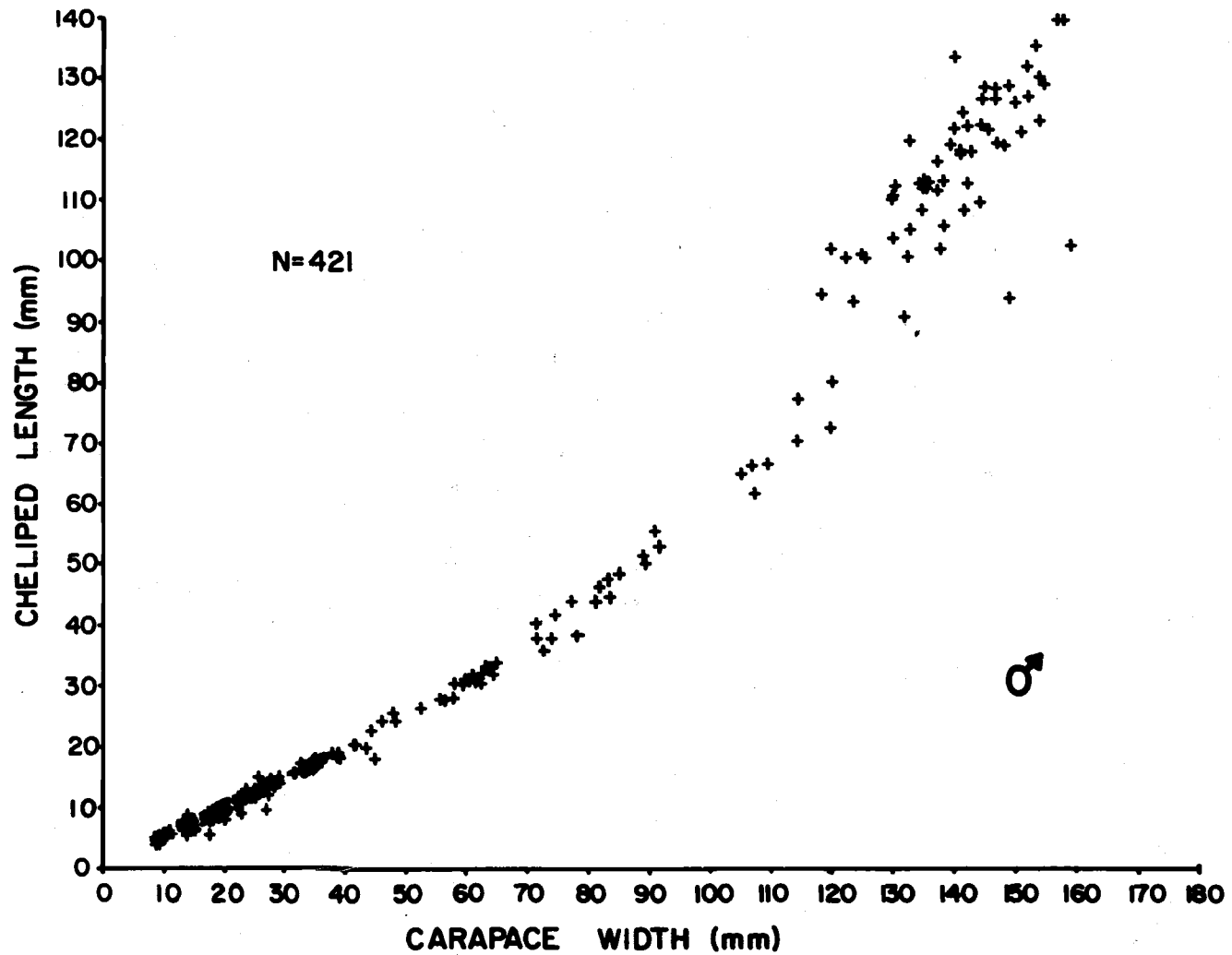
Figure 6. Allometric relationship of carapace width and cheliped length for male Chionoecetes
tanneri collected off the Oregon coast 1973-1975. Those specimens with cheliped
lengths greater than 85 mm and carapace widths greater than 118 are taken to be adults.
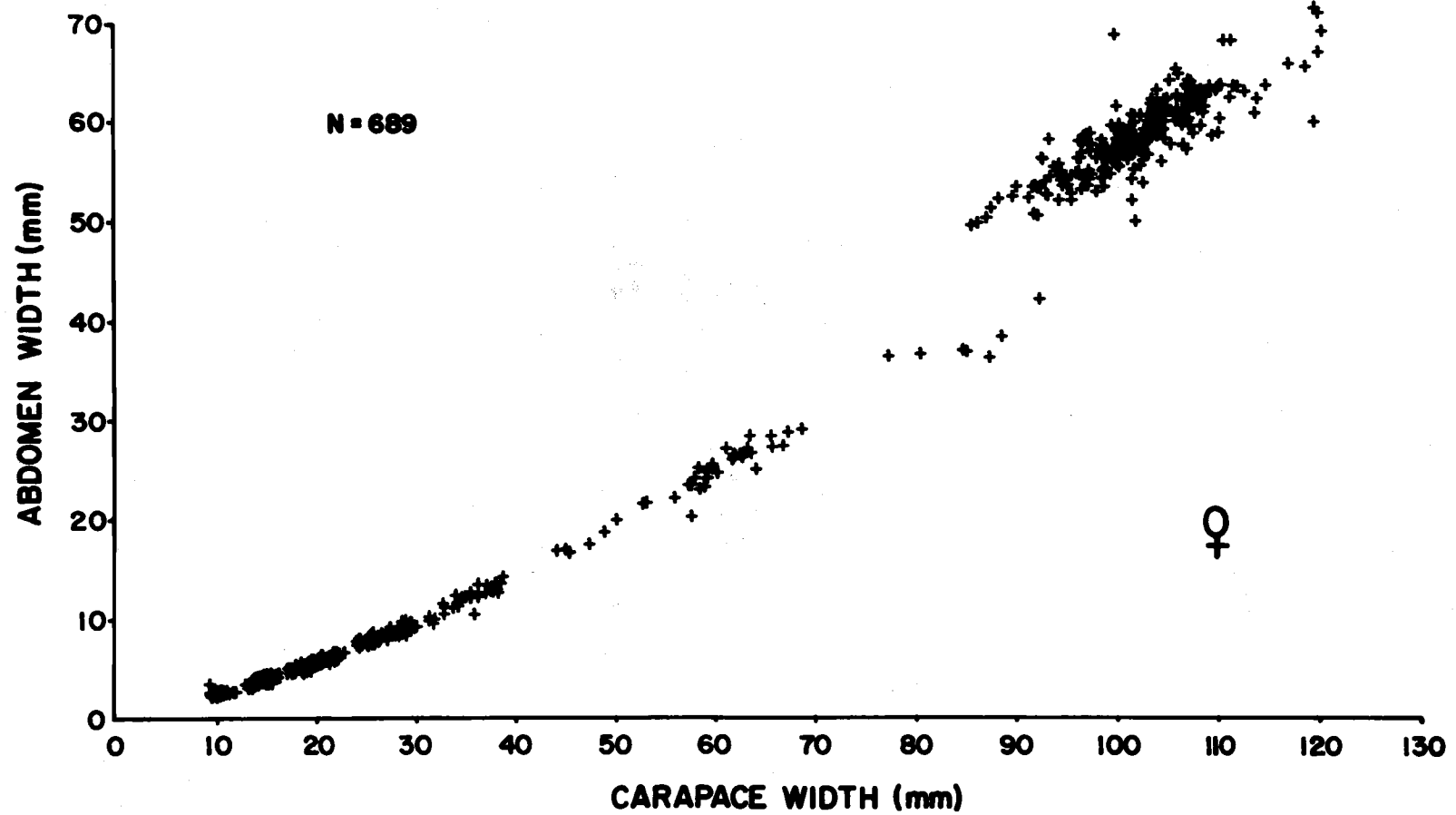
Figure 7. Allometric relationship of carapace width and abdomen width for female Chionoecetes tanneri collected off the Oregon coast 1973-1975. Those specimens with abdomen widths greater than 50 mm and carapace widths greater than 85 mm are taken to be adults.
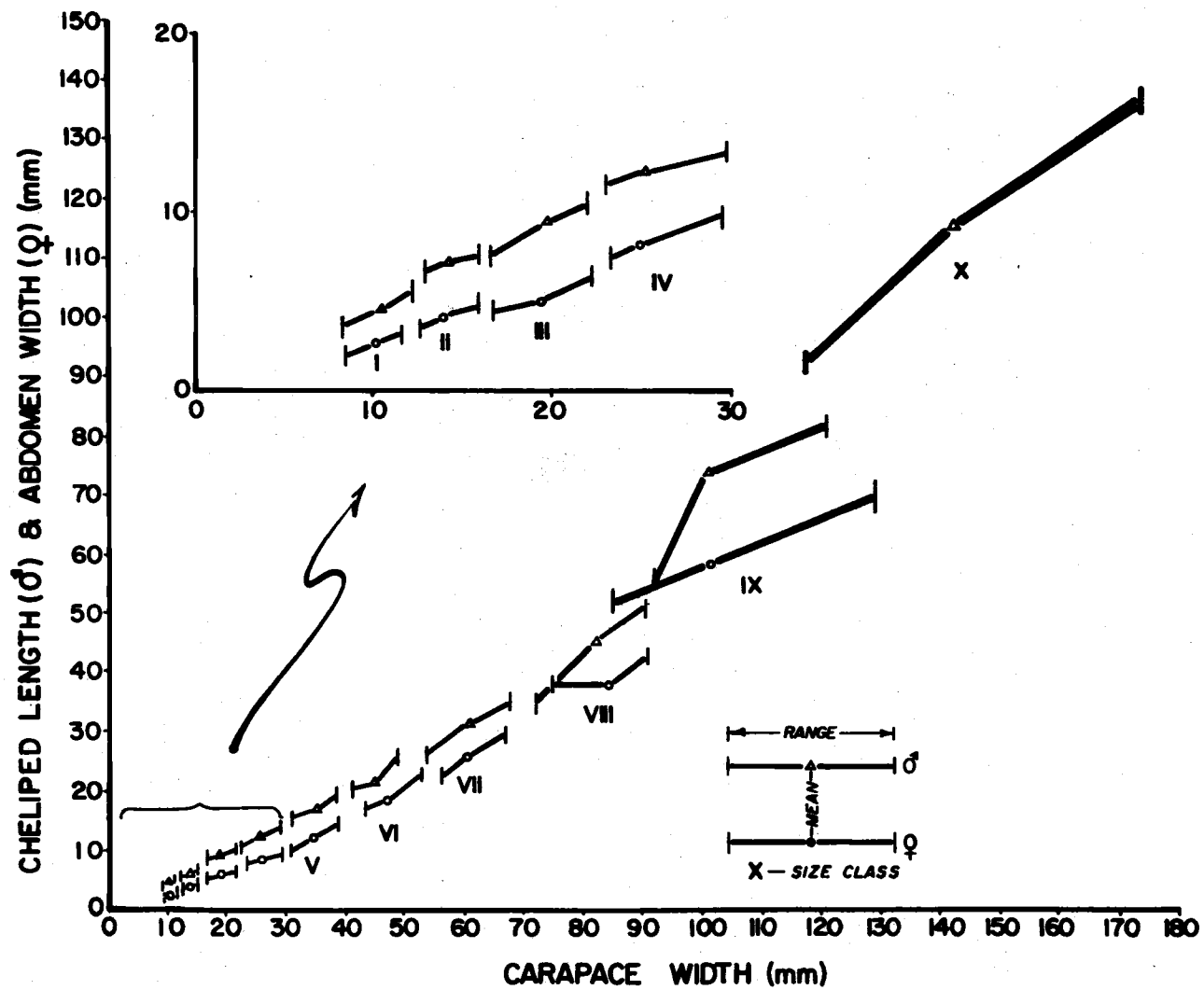
Figure 8. Male and female size classes of Chionoecetes tanneri as defined by allometric relationships of carapace width and cheliped length in males (△) and carapace width and abdomen width in females (○). Specimens were collected off the Oregon coast 1973-1975.

Table II. Size groups of Chionoecetes tanneri collected off the Oregon coast 1973-1975.

Size Group	Males				Females			
	Mean	N	Range	SD	Mean	N	Range	SD
1	10.11	33	3.2	.75	10.07	43	2.6	.58
2	14.48	90	2.86	.66	14.40	115	3.27	.67
3	19.63	106	5.60	1.27	19.73	145	5.92	1.19
4	26.46	62	7.90	1.85	26.28	60	6.02	1.77
5	35.74	25	7.67	2.26	35.01	28	7.44	2.46
6	46.51	8	11.05	3.52	47.77	8	8.99	3.38
7	61.98	16	9.40	2.81	61.29	29	12.70	3.26
8	83.24	7	28.30	10.55	85.01	6	15.05	5.05
9	113.16	9	18.62	6.66	102.27	246	34.94	6.15
10	142.70	120	39.30	9.61				

Table III. Increase in mean carapace width per molt for Chionoecetes tanneri collected off the Oregon coast 1973-1975.

Size Class	N	Mean Carapace Width (mm)		Increase in Mean Carapace Width (%)
1	76	10.09		
2	205	14.44		30
3	251	19.68		27
4	122	26.66		26
5	53	35.38		25
6	16	47.14		25
7	45	61.64		24
8	13	84.13		26
9	246	102.27	Adult ♀	18
9	9	113.16	Preadult ♂	
10	120	142.70	Adult ♂	26
				22

puberty molt (Carlisle, 1957; Hartnoll, 1969; Hilsinger, 1975). This is borne out by the observations on carapace condition. The adult female C. tanneri have much higher incidence of infection by chitinoclastic bacteria than adult males. Bright et al. (1960) indicate the chitinoclastic bacterial infection is not transferred to the new carapace after molting. Thus, the males by continuing to molt have a lower incidence of infection. The epifauna on the carapaces of adult females was also much more diverse and abundant than that found on the carapaces of adult males.

Population Structure of Chionoecetes tanneri

All specimens from the I through V size classes were combined to look at seasonal abundance on a relative scale. The percent of specimens in each size class (I-V) for each cruise was calculated and plotted (Figure 9). These data constitute approximately 85% of all juveniles. The significance of these data will be discussed in the following section.

Sex Ratio of Chionoecetes tanneri

The ability to detect changes in the sex ratio of a population may be an important management tool in a single sex fishery (Kingsbury and James, 1971) such as the Chionecetes fisheries. The sex ratio (male:female) for each size class by season and each size class

Figure 9.   Population structure of size classes I-V for all specimens of <u>Chionoecetes</u> <u>tanneri</u> collected off the Oregon coast 1973-1975.
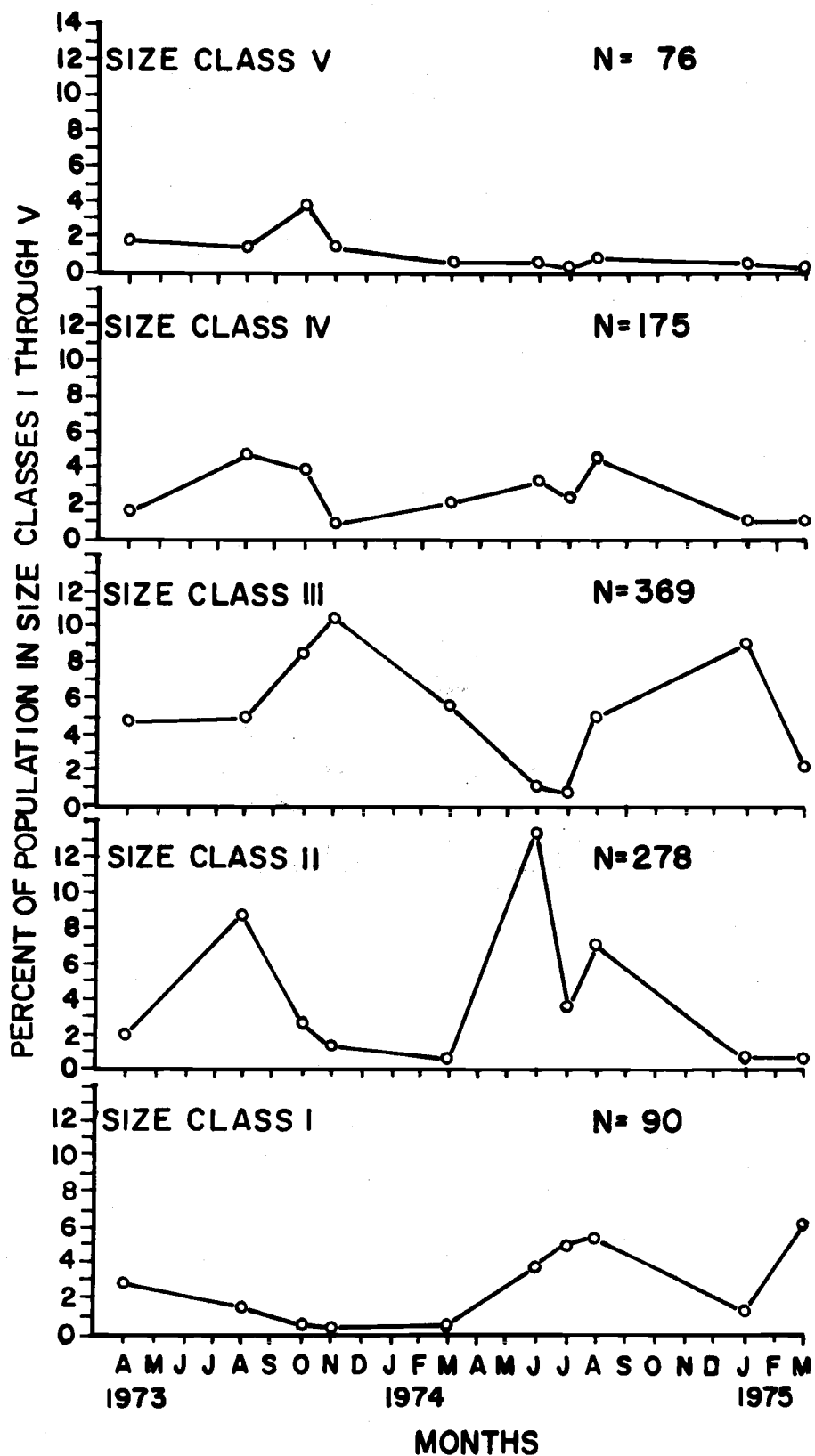
combined over ten cruises was computed and ranges from 0.42 to 1.5 (Table IV). The chi-square values for a test of a 1:1 sex ratio are given for each size class (Table IV). There is a highly significant departure from a 1:1 sex ratio only in the adults.

Table IV. Population structure and sex ratio for each size class for <u>Chionoecetes tanneri</u> 25
collected off the Oregon coast 1973-1975.

Cruise Date		I	II	III	IV	V	VI	VII	VIII	IX	Adults	Total
				Juveniles								
April 1973	a	1/19	3/11	9/24	6/3	9/4	3/1	0/1	0/0	0	9/33	40/96
	b	0.05	0.27	0.38	2.0	2.25	3.0	0	0	0	0.27	0.42
	c	20	14	33	9	13	4	1	0	0	42	136
August 1973	a	5/6	23/39	13/21	15/18	6/4	2/5	5/3	1/1	0	39/62	109/159
	b	0.83	0.59	0.62	0.83	1.5	0.4	1.67	1.0	0	0.63	0.69
	c	11	62	34	33	10	7	8	2	0	101	268
October 1973	a	2/1	8/9	27/34	16/11	11/16	7/5	17/17	0/0	0	16/29	104/122
	b	2.0	0.89	0.79	1.45	0.69	1.4	1.0	0	0	0.55	0.85
	c	3	17	61	27	27	12	34	0	0	45	226
November 1973	a	2/1	4/4	45/30	3/2	8/2	0/0	0/2	5/1	2	9/10	78/52
	b	2.0	1.0	1.5	1.5	4.0	0	0	5.0	0	0.90	1.50
	c	3	8	75	5	10	0	2	6	2	19	130
March 1974	a	0/3	0/0	19/19	7/8	0/2	0/1	4/0	0/6	0	12/10	42/49
	b	0	0	1.0	0.88	0	0	0	0	0	1.2	0.86
	c	3	0	38	15	2	1	4	6	0	22	91
June 1974	a	12/12	48/50	4/3	13/9	2/2	0/0	0/3	0/0	0	12/78	91/157
	b	1.0	0.96	1.33	1.44	1.0	0	0	0	0	0.15	0.58
	c	24	98	7	22	4	0	3	0	0	90	248
July 1974	a	18/13	9/15	4/1	7/9	0/1	1/0	3/1	3/1	3	13/46	61/87
	b	1.38	0.60	4.0	0.78	0	0	3.0	3.0	0	0.28	0.70
	c	31	24	5	16	1	1	4	4	3	59	148
August 1974	a	17/17	21/29	21/15	20/12	3/2	1/2	2/2	13/0	5	7/11	110/90
	b	1.0	0.72	1.4	1.67	1.5	0.50	1.0	0	0	0.64	1.22
	c	34	50	36	32	5	3	4	13	5	18	200
January 1975	a	4/2	2/1	33/30	6/2	2/1	0/0	0/0	1/0	1	1/7	50/43
	b	2.0	2.0	1.10	3.0	2.0	0	0	0	0	0.14	1.16
	c	6	3	63	8	3	0	0	1	1	8	93
March 1975	a	29/16	2/0	12/5	3/5	1/0	0/0	0/0	0/0	0	2/4	49/30
	b	1.81	0	2.4	0.60	0	0	0	0	0	0.50	1.63
	c	45	2	17	8	1	0	0	0	0	6	79
Total	a	$\frac{90}{90}$	$\frac{120}{158}$	$\frac{187}{182}$	$\frac{96}{79}$	$\frac{42}{34}$	$\frac{14}{14}$	$\frac{31}{29}$	$\frac{23}{9}$	11	$\frac{120}{290}$	$\frac{734}{885}$
	b	1.0	0.76	1.03	1.22	1.24	1.0	11.07	2.56	0	0.42	0.83
	c	180	278	369	175	76	28	60	32	11	410	1619
x^2		0	5.20*	0.07	1.75	0.84	0	0.06	6.12*†		70.48***	

a = male/female
b = sex ratio (male:female)
c = number in each size class
x^2 = significance value (P < 0.05) is 3.841

* = significant
*** = highly significant
† = size class IX consisted of males only

IV. DISCUSSION

Size at Maturity for Chionoecetes tanneri

A high degree of correlation between gonad maturity and external morphology has been shown for the genus Chionoecetes. Watson (1970a) based reproductive maturity of male C. opilio on examination of the vas deferentia and clearly demonstrated differential enlargement of the chelae with the onset of maturity. Watson (1970a), also, examined female C. opilio for ova and egg development and showed that differential widening of the abdomen coincided with gonad maturity. Similarly, Brown and Powell (1972) used reproductive tract weights to determine sexual maturity in male C. bairdi and found a high correlation of differentially enlarged chelae with sexual maturity. From this information and the data presented in Figures 6 and 7, male C. tanneri with chelipeds longer than 85 mm and female specimens with abdomen widths greater than 50 mm are considered mature. The minimum carapace widths recorded in this study for a mature male and female were 118 mm and 85 mm respectively.

The mean carapace width for adult males in this study was 142.7 mm and compares well with a mean carapace width of 148.9 mm given by Pereyra (1972) for adult male C. tanneri collected south of the Columbia River mouth (Astoria location). No significant difference (P < 0.001) occurs in mean carapace widths of adult males from

the data collected for this research and those collected by Pereyra (1972). The mean carapace width for adult females collected for this study was 102.3 mm and again, this compares well with the 102.5 mm mean carapace width given by Pereyra (1972) for adult female C. tanneri collected from the Astoria sampling site. Brown and Powell (1972) noted a similar correspondence in mean adult carapace widths for C. bairdi collected from different locations in Alaska.

Growth for Chionoecetes tanneri

In the early 1900's when the biometric study of growth began, the changes in proportions of various organs or relative growth of crustaceans was a favored topic (Huxley, 1932; Day, 1936; Huxley, 1936; Sandon, 1937; Grey and Newcombe, 1938). Numerous studies of allometric growth demonstrate that many of the brachyurans have differentially enlarging organs at maturity. Apparently no one, to this time, has looked at the allometry of the chelae in males or abdomen width in females at various growth stages in samples large enough to suggest allometry as a means of separating size classes. Sneath and Sokal (1973), in a discussion on growth and morphology suggest that, in theory, it should be possible to dissociate the growth stages of the same species on the basis of allometry. This appears to be true.

Separation of size classes on one axis as in size frequency distributions allows those size classes with large sample number and small standard deviation to be resolved. In cases where the sample number is not large enough to generate a normal distribution, or where the assumption of normal distribution of specimens in a size class is not valid, and where modes are closely spaced and numerous, the separation of size classes in two dimensions is necessary for resolution. For example, the 9th and 10th size classes in males and the 8th and 9th size classes in females overlap on the abcissa (Figures 6 and 7). The separation afforded by the second dimension defines these two groups as size classes separate from adults.

I originally hypothesized the few specimens comprising the 8th size class in females (N=9) and the 9th size class in males (N=11) were specimens which had not developed enlarged chelae or abdomens at maturity. Tessier (1960) notes that, in many crustaceans, two types of sexually mature animals are encountered. In one of these the secondary sex characteristics have reached full development, while in the other the individuals still have juvenile characters. Brown and Powell (1972) report that not all C. bairdi with mature reproductive tracts had undergone the molt to maturity and conversely not all crabs that had undergone the maturity molt had yet acquired mature reproductive tracts. These specimens represented approximately 3% of the adult population. But if the 9th size class in males (Figure 6) and the

8th size class in females (Figure 7) did not represent molt classes,
the molt to maturity would have to increase the average carapace size
in males from 83.24 mm to 142.70 mm (a 42% increase in mean cara-
pace width) and from 61.29 mm to 102.27 mm (a 40% increase in mean
carapace width) in females. Thus, size classes of C. tanneri are more
clearly defined by the allometric relationship of body parts than by
size frequency distributions.

Newcombe et al. (1949) report a 26% increase in carapace width
per molt for Callinectes sapidus. Donaldson (1974) reports up to a
30% increase in mean carapace width per molt for C. bairdi. The
average carapace width increase per molt for eight molts in juvenile
C. tanneri is 26.14% (a 1:1.26 ratio). This is approximately $\sqrt[3]{2}$
and corresponds to the relationship described by Brooks (1886) found
for Squilla mantis. This ratio was also reported by Przibram (1931).

Age at Maturity of Chionoecetes tanneri

Arguments have been made for number of molts and increase in
size per molt for C. tanneri. Because no time factor has yet been intro-
duced, no growth rate is known. Eighty five percent of all juveniles
collected were in size classes I through V. When the relative percent
of juveniles in each of these first five size classes was plotted (Figure
9) size class modes can be followed through time, and an estimate of
growth results. Size class I of April 1973, progresses to size class

II by fall of 1973, to size class III by winter of 1973-74, and to size

class IV by summer of 1974 (Figure 10). Size frequency distribu-

tions support this (Figure 11). The percent of juveniles in size class

V is relatively small so the recruitment of specimens to the 5th size

class is difficult to detect. The transition from size class IV to V is

about six months. The rate of growth appears to be from size class I

to size class IV in 12 to 15 months, and from size class IV to V in

six months (Figure 10). Using the progression of size class modes

to introduce a time factor, a regression equation based on size

classes I-IV was calculated.

$$\text{Time} = -2.94 + 0.81 \text{ (Carapace width)}$$

This equation predicts the growth rate to maturity as seen in Figure

12. A six month intermolt period between size classes IV and V is

predicted. After size class V, the intermolt period appears fixed

at approximately 12 months. The growth curve for C. tanneri proba-

bly slows after the maturity molt. This is not reflected (Figure 12)

because the regression assumes a linear relationship and the confidence

limits increase greatly beyond size class VIII. The age to size class

VIII for C. tanneri collected off the Oregon coast is estimated at 5.5

years and is consistent with the biology of large decapods (Weber

and Miyahara, 1962; Ito, 1970).

Adult females cease to molt after the molt to maturity and

determining the age of the adult female populations is difficult.
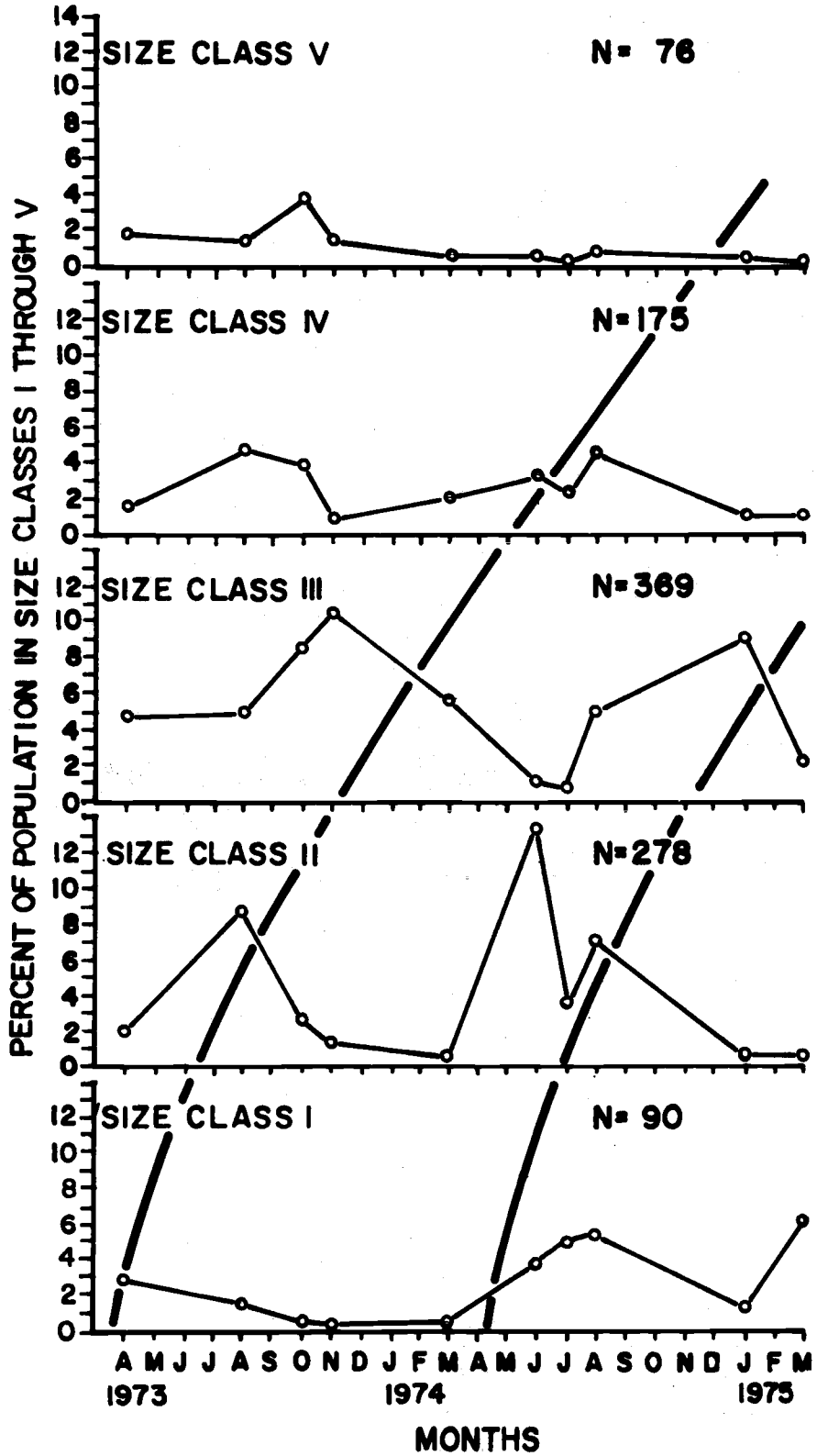
Figure 10. Relative abundance of specimens in size classes I-V
for <u>Chionoecetes</u> <u>tanneri</u> collected off the Oregon coast
1973-1975. Note the progression of size modes
through time.
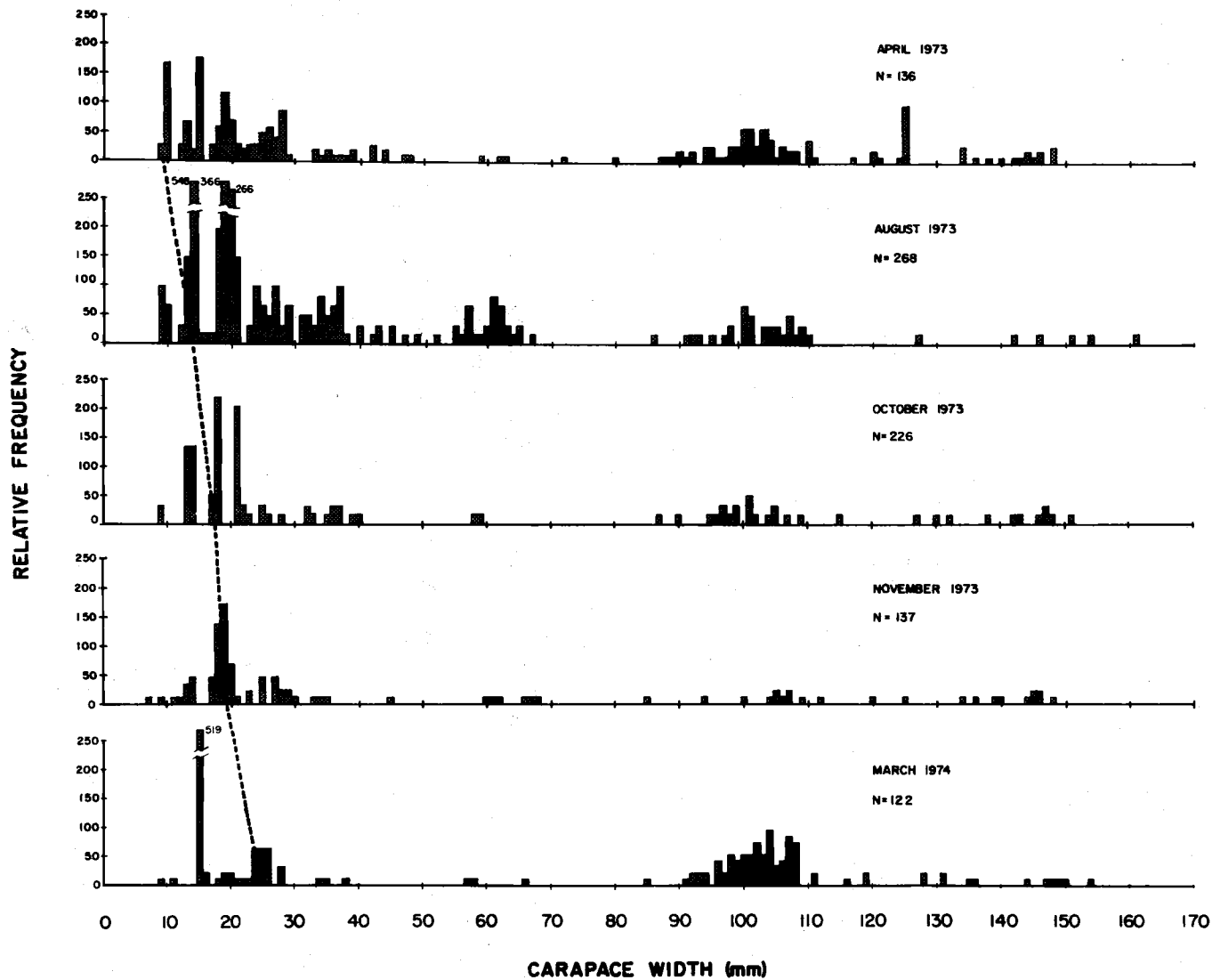
Figure 11. Size frequency distribution of <u>Chionoecetes</u> <u>tanneri</u> collected off the Oregon coast. The dashed line represents progression of size frequency modes through time.

Figure 12. Estimated growth rate for <u>Chionoecetes</u> <u>tanneri</u> for size classes I through VIII. Specimens collected off the Oregon coast 1973-1975.

34

Inspection of the carapace condition of C. bairdi and C. opilio

(personal communication spring 1975, J. F. Karinen, National

Marine Fisheries Service, Auke Bay, Alaska) indicated the females

remain in the adult population for at least 3 years. Ito (1970)

estimated that female C. bairdi lived from 3 to 4 years after maturing.

The adult males do continue to molt after the maturity molt, but no
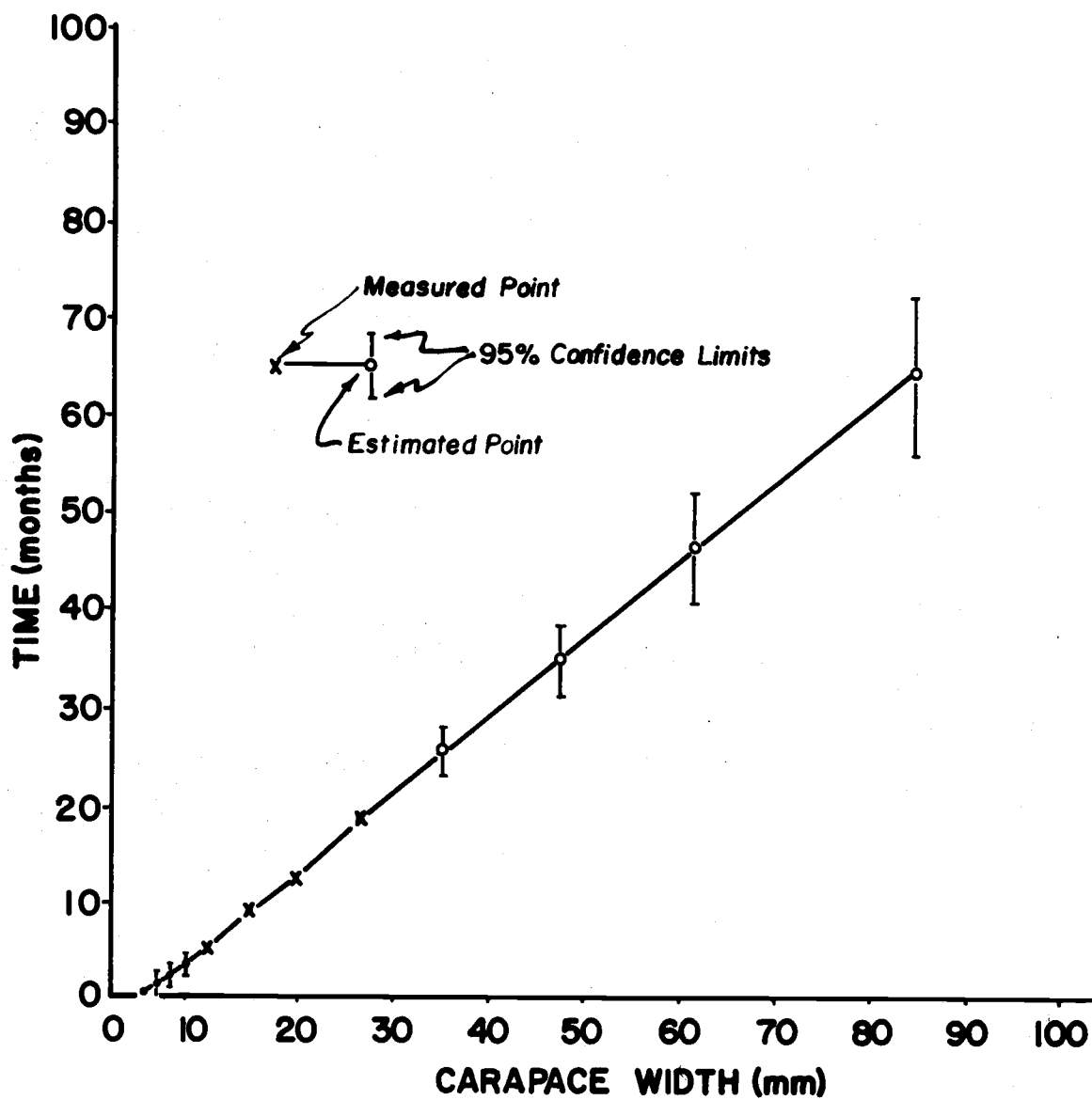
molt groups could be defined within the adult male size class. Both

Ito (1970) and Watson (1970b) indicate that molting is not necessarily

an annual occurrence in adult male C. opilio. Ito (1970) reports the

percent increase in carapace width per molt for males decreases

after maturity. Here, the assumption that size classes are equivalent

to molt groups may not be entirely valid and some smearing of the

size class groups would be expected. Observations on general cara-

pace condition and abundance of epifauna indicate that adult males

do molt frequently enough to maintain their carapaces relatively free

of epifauna. Ito (1970) estimated that male C. opilio remain in the

population for as long as 5 years after the maturity molt. Obser-

vations on the percent of the adult population infected by chitino-

clastic bacteria (Figure 13) indicate the lowest percent infection in

November 1973, and August 1974, suggesting a late summer-fall

molting period for adults of both sexes.

Pereyra (1972) noted that hatching of C. tanneri eggs occurred

predominantly in winter (January-March), and Lough (1974)
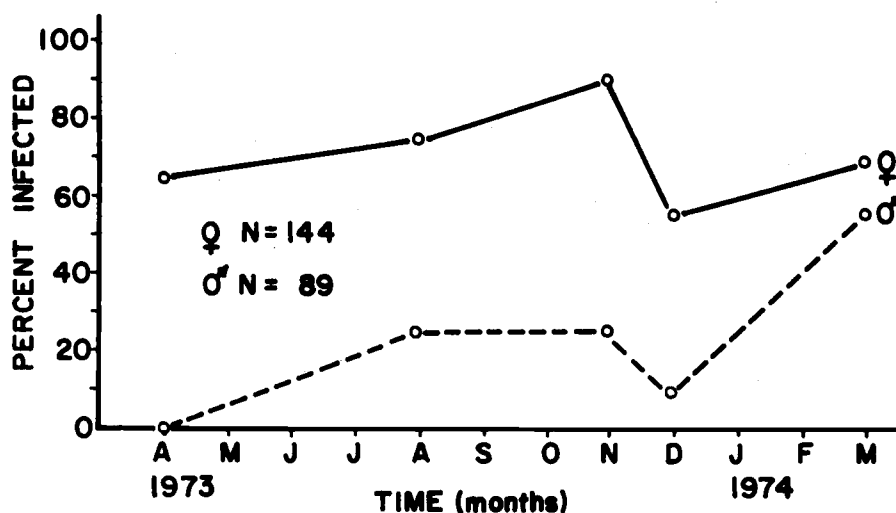
Figure 13.   Percent of the adult male and female of <u>Chionoecetes</u>
<u>tanneri</u> population infected with chitinoclastic bacteria.
Specimens collected off the Oregon coast.

estimated the total larval life of 80 days.   In 1974 recruitment of

juveniles to size class I occurred prior to April.   By August 1974,

most of the size class I specimens had molted to size class II

(Figure 11).   This agrees with the above postulates.   Yet, present

data suggest that hatching time may be more variable than observed

by Pereyra.   The group of juveniles near 5 mm carapace width in

June and July 1974, and those near 7 mm carapace width in January

1975, (Figure 2) are evidence of this.   The specimens in the 5 mm

carapace width range from June and July 1974.   Total samples from

these cruises were hand sorted under laboratory conditions.   These

specimens may have been represented in spring 1974 samples but

these were not hand sorted in the laboratory.   The January 1975

samples were sorted aboard ship. These specimens appear to be due to an early hatch. They developed at such a rate as to be recruited to size class I by March 1975 (Figure 2). Ito (1967) notes that in $\underline{C}$. opilio the year one adult females hatch their eggs six months out of phase with the older females. I do not know if this is true of $\underline{C}$. tanneri. Examination of egg masses and gonads of adult females (in progress) should provide this information.

The two size groups with modes centered about 5 mm and 7 mm carapace width are not predicted by the allometric relationship shown in Figures 6 and 7 but no cheliped lengths or abdomen widths were available for specimens this size. It is interesting to speculate on the number of molts from the megalopa to juveniles of 10 mm carapace width when they are first recruited to the gear. If the 1:1.26 ratio is assumed to hold, back extrapolation from the mean carapace width of size class I yields the following:

Size Class	Mean Carapace Width
I	10.09 mm
I-I	7.94 mm
I-II	6.30 mm
I-III	5.00 mm
I-IV	3.90 mm

Lough (1974) reports the carapace width of $\underline{C}$. tanneri megalopa as 3.6 mm. Back extrapolation to the megalopa stage predicts the carapace to within 10%. There are possibly three molt groups

before the juveniles are first recruited to the gear at 10 mm carapace width. The regression equation predicts a developmental time of 3.5 months for these three size classes. This is in agreement with rates predicted by known hatching times, length of larval life, and time of first recruitment to size class I.

Sex Ratio of Chionoecetes tanneri

Wenner (1972) found that the sex ratio in most marine crustaceans changes with increasing size due to differential mortality. He defined an anomalous pattern where a 1:1 sex ratio at birth is followed by differential mortality and growth causing first one sex and then the other to be most abundant. Such a pattern was cited for brachyurans, anomurans, amphipods, and herpacticoid copepods. Depending on the significance level of X^2 chosen, the juvenile size classes of C. tanneri do not vary greatly from the expected 1:1 sex ratio (Table IV). A highly significant departure from the 1:1 sex ratio is noted for adult C. tanneri; the adult female to male sex ratio is 2.41 to 1. This corresponds closely with the 2.5 to 1 sex ratio reported by Pereyra (1972) for adult C. tanneri population collected off the Columbia River. Hilsinger (1975) estimated a 2.1 to 1 sex ratio for adult C. bairdi in William Sound, Alaska.

There are several explanations for the skewed adult sex ratio. Differential avoidance of the trawls by adult males is a possibility.

Watson (1970b) observed $\underline{C}$. opilio partially buried in the sediment.
If differential avoidance was the major cause of a skewed adult sex
ratio, I would expect approximately the same ratio of females to
males during each cruise. The mating/molting season would be a
possible exception. The sex ratio of adults is shown to vary greatly
with time (Table IV). Mortality suffered by males because of contin-
ued molting after maturity is likely a contributing factor. Although
adult females are more highly infected with chitinoclastic bacteria
than are adult males (Figure 13), it does not appear that mortality
in adult females caused by chitnoclastic bacteria is as great as that
in males as a result of continued molts.

BIBLIOGRAPHY

Alaska Department of Fish and Game. 1972. Tanner crab
    research. Alaska Department of Fish and Game, Juneau.

Bright, D. B., F. E. Durham, and W. J. Knudsen. 1960. King
    crab investigations of Cook Inlet, Alaska. Allan Hancock
    Foundation Contract Report, Los Angeles. 369 p.

Brooks, W. K. 1886. Report on the stomatopoda collected by the
    H.M.S. Challenger during the years 1873-1876. Challenger
    Reports, 16, Zoological part XLV. 116 p.

Brown, R. B. 1971. The development of the Alaskan fishery for
    tanner crab, Chionoecetes species, with particular reference
    to the Kodiak area, 1967-1970. Alaska Department of Fish
    and Game, Juneau. 26 p.

Brown, R. B., and C. Powell. 1972. Size at maturity in the male
    Alaskan tanner crab, Chionoecetes bairdi, as determined by
    chela allometry, reproductive tract weights, and size or
    precopulatory males. Journal Fisheries Research Board of
    Canada 29: 423-427.

Carey, A. G., and H. Heyamoto. 1972. Techniques and equip-
    ment for sampling benthic organisms. Pages 378-421 in
    A. T. Pruter and D. L. Alverson, eds. Columbia River
    estuary and adjacent ocean waters: Bioenvironmental studies.
    University of Washington Press, Seattle.

Carlisle, D. B. 1957. On the hormonal inhibition of moulting in
    the decapod crustacean. II. The terminal anecdysis in crabs.
    Journal of the Biological Association of the United Kingdom
    46: 373-400.

Carlisle, D. B., and F. K. Knowles. 1959. Endocrine control in
    crustaceans. Cambridge University Press, Cambridge.
    103 p.

Cassie, R. M. 1954. Some uses of probability paper in the analy-
    sis of size frequency distributions. Australian Journal of
    Marine and Freshwater Research 5: 513-522.

Day, J. H. 1936. Growth gradients in the abdomen of the shore crab. Nature 137: 670-673.

Donaldson, W. E. 1974. Kodiak tanner crab research. Alaska Department of Fish and Game, Project No. 5-35-R Technical Report. 41 p.

Food and Agriculture Organization. 1970. F. A. O. yearbook of fisheries statistics Volume 30, 476 p.

Garth, J. S. 1958. Brachyura of the Pacific coast of America. Oxyrhyncha. Allen Hancock Pacific Expedition. Volume 21 Part 1. 499 p.

Gray, E. H., and C. L. Newcombe. 1938. The relative growth of parts in the blue crab Callinectes sapidus Rathbun. Growth 2: 235-246.

Harding, J. P. 1949. The use of probability paper for the graphical analysis of polymodal frequency distribution. Journal of the Marine Biological Association of the United Kingdom 28: 204-208.

Hartnoll, R. G. 1969. Mating in the brachyura. Crustaceana 16: 161-181.

Hilsinger, J. R. 1975. Aspects of the reproductive biology of female snow crabs, Chionoecetes bairdi, near Prince William Sound, Alaska. M. S. Thesis. Fairbanks, University of Alaska. 95 numbered leaves.

Huxley, J. S. 1932. Problems of relative growth. The Dial Press, New York. 276 pp.

Huxley, J. S. 1936. Growth gradients in the abdominal limbs of the shore crab. Nature 137: 668-670.

Ito, K. 1963. A few studies on the rpieness of eggs of zuwaigani, Chionoecetes opilio. Bulletin of the Japan Sea Regional Fisheries Research Laboratory 11: 65-76. Translation.

Ito, K. 1967. Ecological studies on the edible crab, Chionoecetes opilio O. Fabricius in the Japan Sea I. When do female crabs first spawn and how do they advance into the following reproductive stage? Bulletin of the Japan Sea Regional Fisheries Research Laboratory 17: 67-84. Translation.

Ito, K. 1970. Ecological studies on the edible crab, Chionoecetes opilio O. Fabricius in the Sea of Japan III. Age and growth as estimated on the basis of the seasonal changes in the carapace width frequencies and the carapace hardness. Bulletin of the Japan Sea Regional Fisheries Laboratory 22: 81-116. Translation.

Kingsbury, A., and K. James. 1971. Abundance and composition of king crabs in the Alitak and Kaguyak Bay areas during April and June 1970. Alaska Department of Fish and Game, Juneau. 34 p.

Lough, R. G. 1974. Dynamics of crab larvae (Anomura, Brachyura) off the central Oregon coast, 1969-1971. Ph. D. Thesis. Corvallis, Oregon State University. 299 numbered leaves.

Newcombe, C. L., F. Campbell, and A. M. Eckstine. 1949. A study of the form and growth of the blue crab Callinectes sapidus Rathbun. Growth 13: 71-96.

Oliver, B. L. 1976. The abundance, distribution, and ecology of the tanner crab Chionoecetes tanneri, on the southern Oregon continental slope. M. S. Thesis. Corvallis, Oregon State University. 75 numbered leaves.

Pereyra, W. T. 1967. Tanner crab - an untapped Pacific resource. National Fisherman 48: 16A.

Pereyra, W. T. 1972. Bathymetric and seasonal abundance and general ecology of the tanner crab, Chionoecetes tanneri Rathbun (Brachyura; Majidae), off the northern Oregon coast. Pages 538-582 in A. T. Pruter and D. L. Alverson, eds. Columbia River estuary and adjacent ocean waters: Bioenvironmental studies. University of Washington Press, Seattle.

Przibram, H. 1931. Connecting laws in animal morphology. London University Press. 62 p.

Sandon, H. 1937. Differential growth in the crab Ocypoda. Proceedings of the Zoological Society of London 107: 397-414.

Sinderman, C. J. 1970. Principal diseases of marine fish and shellfish. Academic Press, New York. 369 p.

Sneath, P. H. A., and R. R. Sokal. 1973. Numerical Taxonomy. W. H. Freeman and Company, San Francisco. 573 p.

Tessier, G. 1960. Relative growth. Pages 537-560 in T. Waterman, ed. The physiology of crustacea. Academic Press, New York. Volume I.

Watson, J. 1969. Biological investigations on the spider crab Chionoecetes opilio. Canadian Fisheries Reports 13: 24-47.

Watson, J. 1970a. Maturity, mating and egg laying in the spider crab, Chionoecetes opilio. Journal Fisheries Research Board of Canada 29: 447-449.

Watson, J. 1970b. Maturity, mating and egg laying in the spider crab, Chionoecetes opilio (O. Fabricius), in the Gaspe region of the Gulf of St. Lawrence. Journal Fisheries Research Board of Canada Technical Report No. 204. 16 p.

Weber, D. D., and T. Miyahara. 1962. Growth of the adult male king crab Paralithodes camtschatica (Tilesius). U. S. Fish and Wildlife Service Fisheries Bulletin No. 200, p. 53-75.

Wenner, A. M. 1972. Sex ratio as a function of size in marine crustacea. American Naturalist 106: 321-360.

Wheeland, H. A. 1972. U. S. Department of Commerce Current Fishery Statistics No. 6100; fisheries of the U. S. U. S. Government Printing Office, Washington, D.C. 101 p.

APPENDIX

APPENDIX I

Harding and Cassie Method of Size Frequency
Distribution Analysis

The graphical analysis of size frequency distributions outlined
by Harding (1949) and revised by Cassie (1954) was designed to sort
overlapping normal distributions. The purpose of using this method
on data from this research was to define modes on the carapace
width axis and equate these modes with size classes to determine
population structure and other population characteristics.

The method of Harding (1949) and Cassie (1954) uses probability
paper for defining polymodal frequency distributions. The use of
probability paper allows transformation of normal (distribution)
curves to straight lines. For this analysis, all juveniles (Figure 5)
were combined and the cumulative frequency of each 1 mm carapace
width interval was plotted on a probability scale (see page 44).
Because of the difficulty of detecting the inflection points (where the
second derivative of the cumulative percent function goes to infinity)
beyond the fourth inflection, it was not possible to define modes for
the size classes with carapace widths greater than 20+ mm (see work
sheet page 46).

The sample size (N = 1096) generated by combining specimens
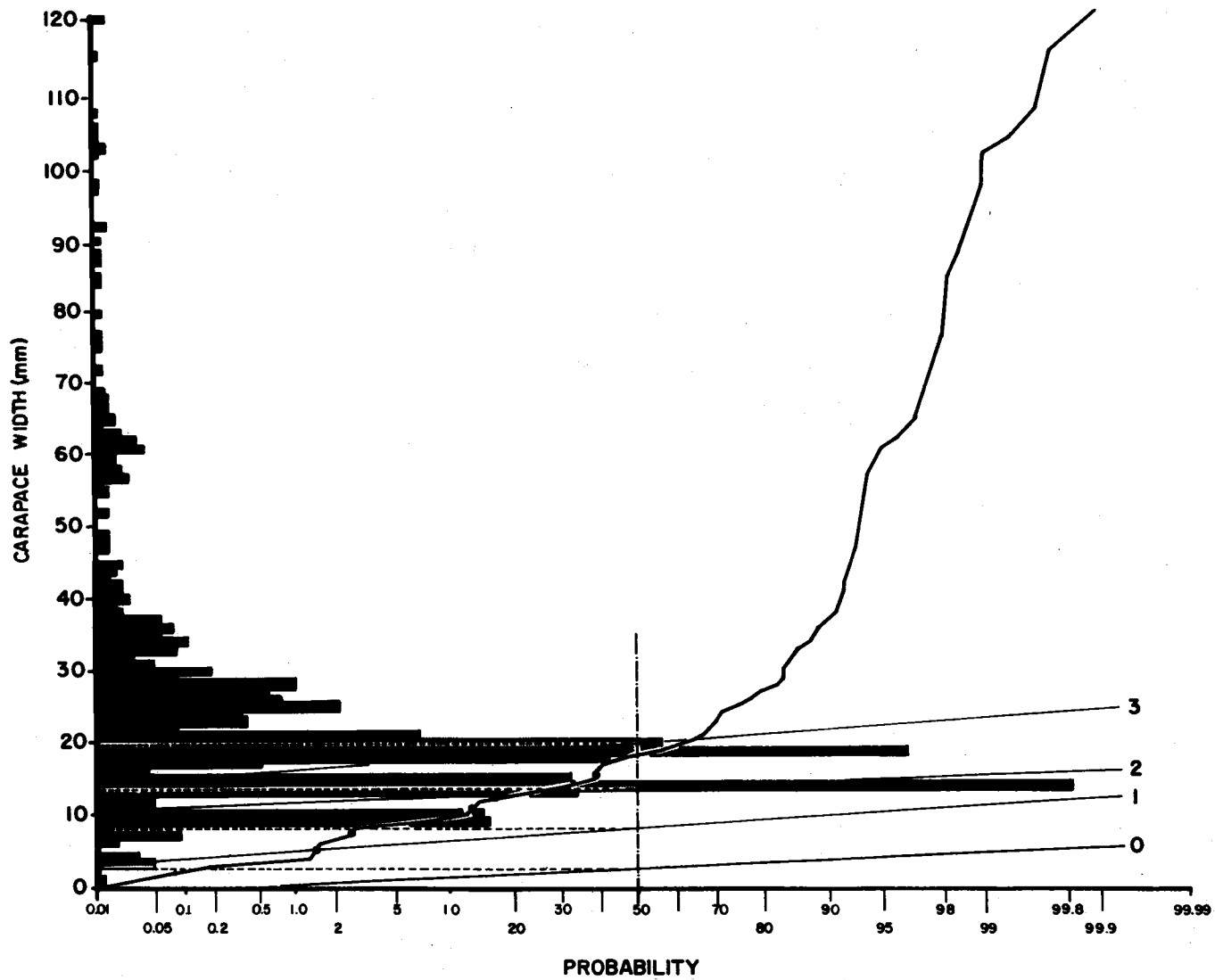from ten cruises was probably adequate in the 1 to 20+ mm carapace

Figure A1.   Size frequency distribution analysis after Harding (1949) and Cassie (1954).
(See text for explanation.)

width range but not enough specimens of 20 to 120 mm carapace width were collected to cause obvious inflection in a cumulative percent curve. Since the Harding (1949) and Cassie (1954) method depends on having a frequency distribution with fairly well separated modes and implies a need for large sample size (to generate the normal cruves and detect inflection points in a cumulative probability curve) the data from this research exceed the limitations of this method. Thus, the method of Harding and Cassie did not prove satisfactory for defining a complete series of size classes for Chionoecetes tanneri.

Work Sheet

The following are the calculations for determining the modes and means of the size frequency distribution in Figure A1. Inflection points at:

1.7%	5 mm
13.5%	11 mm
39.0%	16 mm
76.0%	25 mm

Assuming no great overlap.

Line "0"

$0.09 \times 100/1.5$	$= 5.99$	1 mm
$0.30 \times 100/1.5$	$= 19.99$	2 mm
$0.60 \times 100/1.5$	$= 39.99$	3 mm
$1.40 \times 100/1.5$	$= 93.30$	4 mm

Line "1"

$(1.6-1.5)\ (100/13.5-1.7)$	$= 8.47$	6 mm
$(4.0-1.5)\ (100/13.5-1.7)$	$= 21.19$	8 mm
$(8.0-1.5)\ (100/13.5-1.7)$	$= 55.08$	9 mm
$(12.5-1.5)\ (100/13.5-1.7)$	$= 93.22$	10 mm

Line "2"

$(15.0-13.5)\ (100/39-13.5)$	$= 5.88$	12 mm
$(20.0-13.5)\ (100/39-13.5)$	$= 25.49$	13 mm
$(32.0-13.5)\ (100/39-13.5)$	$= 72.55$	14 mm
$(38.0-13.5)\ (100/39-13.5)$	$= 96.08$	15 mm

Line "3"

$(40.0-39.0)\ (100/76-39)$	$= 2.70$	17 mm
$(47.0-39.0)\ (100/76-39)$	$= 21.62$	18 mm
$(56.0-39.0)\ (100/76-39)$	$= 45.95$	19 mm
$(65.0-39.0)\ (100/76-39)$	$= 70.28$	20 mm
$(69.0-39.0)\ (100/76-39)$	$= 81.09$	21 mm
$(73.0-39.0)\ (100/76-39)$	$= 95.90$	24 mm

A perpendicular from this line to the ordinate starting from the 50% cumulative probability line, defines the mean of the mode. The means defined by lines "0", "1", "2", and "3" are approximately 4 mm, 8.5 mm, 14 mm, and 20 mm respectively.