ASPECTS OF THE BIOLOGY OF THE SEPIOLID SQUID *ROSSIA PACIFICA* BERRY

by

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ABSTRACT

Aspects of the biology of the sepiolid squid *Rossia pacifica* Berry were studied from specimens obtained by otter trawling at Cape Lazo Gully and Saanich Inlet, British Columbia. Temperature, salinity, and sediment size at Cape Lazo Gully varied from 7.18°C to 11.00°C, 28.01 °/$_{oo}$ to 30.21 °/$_{oo}$, and from less than 100µd to over 250µd respectively. Living specimens in the laboratory exhibited color changes from dark red-brown to opalescent grey-green. They did not mimic the color of the substrate. Comparisons of the morphometric indices of *R. pacifica* with other species of this genus showed differences in some indices but not in others. The arm formula is inconsistent, the most common being 3>2>4>1 and 3>2=4>1. The lower beak differs from that of *R. macrosoma* by having a "tooth" on its shoulder. In an aquarium *Rossia* spent most of its time resting on the bottom either in a horizontal position or with the anterior end elevated. The squid usually formed a depression in the sandy bottom to rest in. In some instances they threw sand onto their backs. Fish were caught with the tentacles and held with the arms while being eaten. Stomach analysis revealed that crustacea were present in 86.6% of the stomachs that contained food,while fish were present in

16.6%. Shrimp formed the largest portion of the crustacea in the diet. Bivalve molluscs, squid, and ostracods were occasionally found. Proportions of crustacea to fish in the diet were higher in smaller squid and decreased in larger animals. Seasonal variations in the diet were correlated with the biomass of shrimp in the area where the squid were collected; when a low biomass of shrimp was present the squid had a higher proportion of fish in their diet. The female *R. pacifica* are slightly larger than the males of the same age and grow to a larger size than do the males. The male and female reproductive systems are described. Gonad indices show that the ovaries and nidamental glands begin to mature when the females have a dorsal mantle length of approximately 24.0 mm. Spermatophores were not found in males smaller than 22 mm mantle length. The proportion of males containing spermatophores was 9% at 22 mm and increased through 17% at 24 mm, 50% at 26 mm to 90% at 28 mm. During mating the male attaches to the female from below by means of his second, third, and fourth pairs of arms. Spermatophores are transferred into the dorsal region of the female's pallial cavity by his dorsal, hectocotylized arms. The sex ratio of males to females found at Cape Lazo Gully was 1.2:1.0. Spawning occurs in the fall with the most active period occurring from August through October.

This may be correlated with an increase in the water temperature during this time. The squid have a life span of one year,at the end of which they mate, spawn, and die.

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INTRODUCTION

Rossia pacifica Berry is one of the common species of squid on the Pacific Coast of North America (Berry, 1912). In spite of its abundance, very little is known about its biology. The species was described from this coast by Berry (1912). Sasaki (1920 and 1929), Kondakov (1941), and Akimushkin (1963) extended its range to the western Pacific Ocean. There are no published accounts concerning the life history of this species.

The purpose of this study is to extend present knowledge through investigations of some aspects of its biology. These aspects include taxonomy, morphometry, behaviour, foods and feeding, population dynamics, and reproductive biology.

The genus *Rossia* includes ten species that together have a nearly world-wide distribution. The members of this genus are typically coastal, shallow water, nektobenthic forms with no known representatives occurring in the open oceans.

SAMPLING AREAS AND COLLECTING METHODS

Study Areas and Collecting Methods

Specimens of *R. pacifica* were obtained from Cape Lazo Gully and Saanich Inlet, British Columbia, Canada (Fig. 1). Those from Cape Lazo Gully were used for studies of taxonomy, morphometry, stomach contents, reproductive biology, and population dynamics; those from Saanich Inlet for studies of behaviour.

Study Areas

Cape Lazo Gully (Fig. 2) is located on the east central coast of Vancouver Island, B.C. It is bordered by Cape Lazo on the north, Baynes Sound and Denman Island on the west, Hornby Island on the south, and is separated from the Strait of Georgia on the east by a shallow sill. The gully is a north-south trough approximately eight miles long and two miles wide with a maximum depth of 53-55 fathoms. The bathymetry of the gully is shown in Figure 2.

Saanich Inlet is located on the south east coast of Vancouver Island (Fig. 1).

Collecting Methods

The Cape Lazo population was sampled seven times from August, 1968 to October, 1969 in conjunction with the Crustacea Investigation carried out by the Fisheries Research Board of Canada, Biological

Figure 1. Collecting areas. Cape Lazo Gully (1) and Saanich Inlet (2).

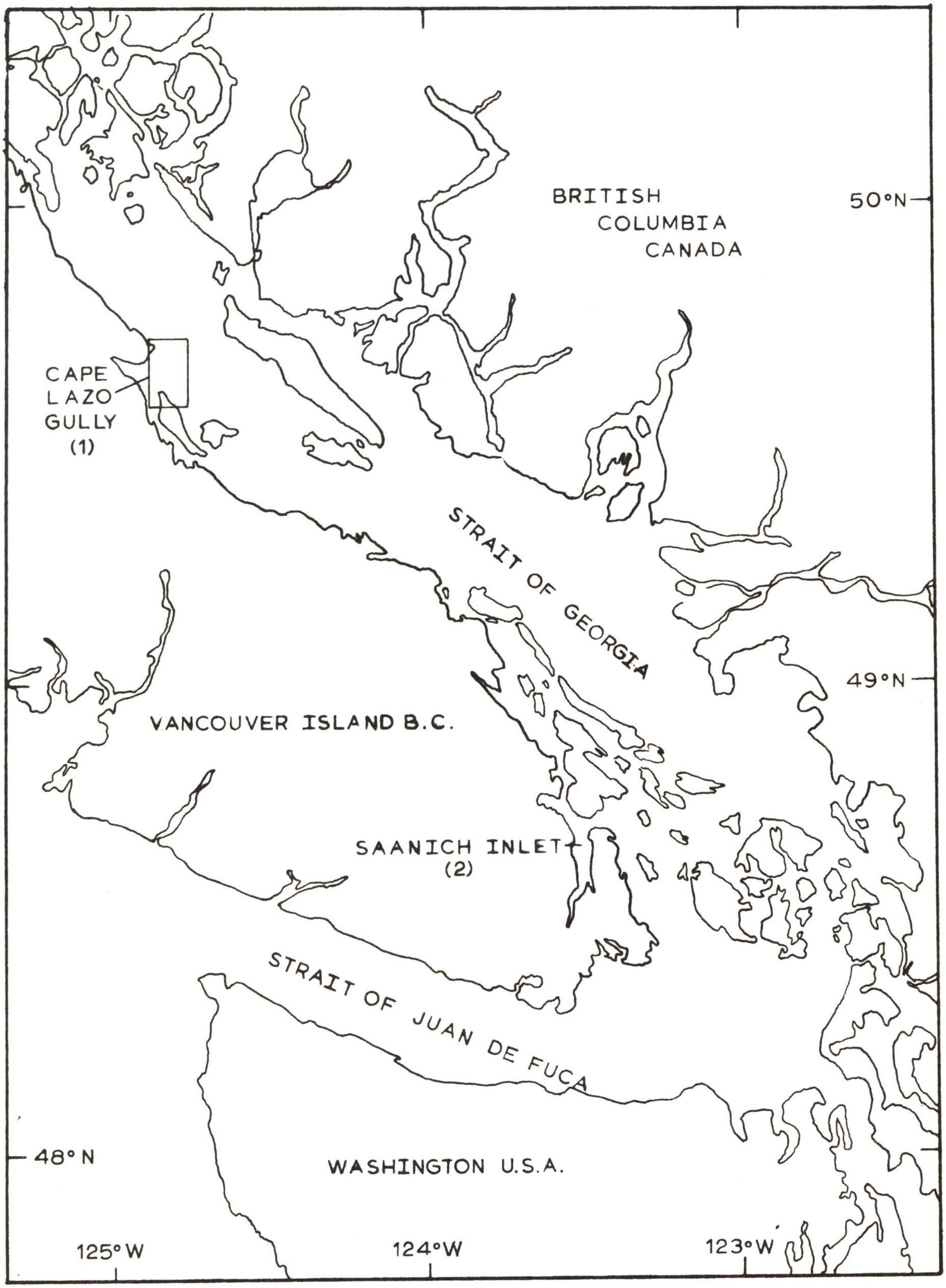
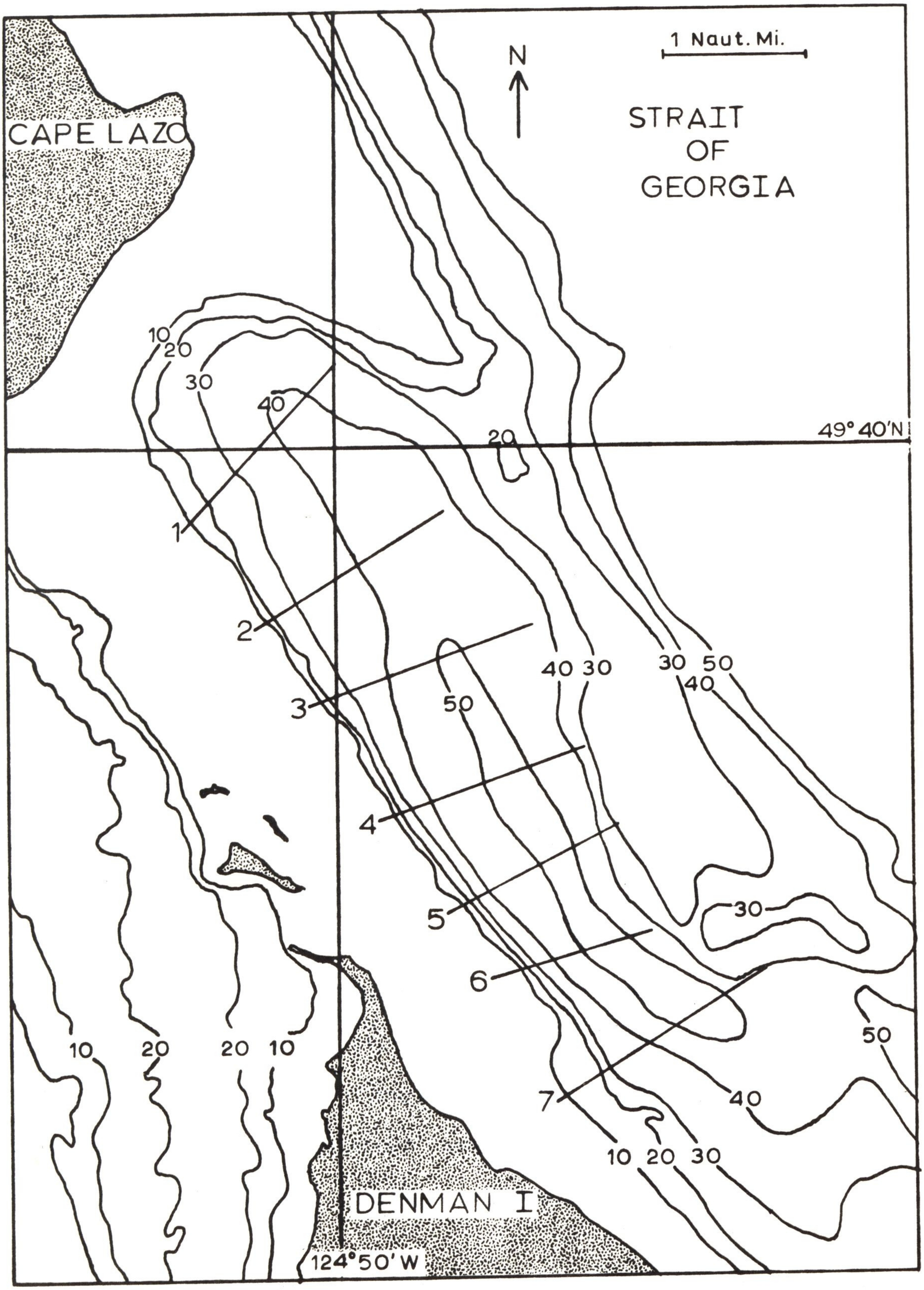

BRITISH
COLUMBIA
CANADA
50°N
CAPE
LAZO
GULLY
(1)
STRAIT OF GEORGIA
49°N
VANCOUVER ISLAND B.C.
SAANICH INLET
(2)
STRAIT OF JUAN DE FUCA
48° N
WASHINGTON U.S.A.
125° W
124°W
123°W

Figure 2. Map of Cape Lazo Gully showing bathymetry and transects. (Isopleths are in fathoms).


1 Naut. Mi.
N
STRAIT
OF
GEORGIA
CAPE LAZO
DENMAN I
49° 40'N
124°50' W
10
20
30
40
20
1
2
3
50
40 30
30 50
40
4
5
30
6
50
7
40
10 20 30
10
20
20 10

Station, Nanaimo, British Columbia. The dates, sections occupied, and the number of tows made for each collecting trip are listed in Table 1. The gully was divided by seven transects (Fig. 2). Tows, each of ten minute duration, were made along isopleths with the center of each tow crossing a transect. Tows were made at five fathom intervals between 30 fathoms and the deepest part of each transect. The sampling gear consisted of a commercial otter trawl that was towed from the stern of the Investigator I, a 56 foot fisheries vessel (except in January, 1969, when the CSS Parizeau, a 211 foot Canadian Hydrographic Research Vessel, was used). Contents of the trawl were emptied into a sorting box after each tow and the *Rossia* removed. Most specimens were preserved immediately in 10% neutral formalin and later transferred to 80% ethyl alcohol after being rinsed in running water. Some specimens were kept alive and brought to the aquarium at the University of Victoria.

Temperature and salinity data were collected near the bottom at selected depths on each transect using a Nansen bottle with a pair of reversing thermometers. The temperature and salinity determinations were made by the Biological Station at Nanaimo.

Rossia were collected at regular intervals from Saanich Inlet using the Department of Transport launch CSS Vancouver II to tow a try net (a small otter trawl). Pertinent dimensions of the commercial

TABLE 1

Cape Lazo Sampling Information

Date	Ship	Transects Occupied	Number of trawls Sampled
Aug. 27-Sept. 6, 1968	Investigator I	1-7	32
Oct. 21-Nov. 1	Investigator I	1-7	31
Jan. 14-17, 1969	CSS Parizeau	Gully northward of transect 3	25
Feb. 6-11	Investigator I	1-7	34
March 25-April 2	Investigator I	1-2, 4, 6-7	25
May 25-30	Investigator I	1-2, 4-5, 7	11
Oct. 7-9	Investigator I	1-7	32

TABLE 2

Trawl Dimensions

Trawl	Length of Footrope	Mesh Size in Body and Wing	Mesh Size in Cod End	Mesh Size in Liner
Commercial Otter Trawl	47.3 ft. (14.2 m.)	1.5 in. (3.8 cm.)	1.5 in. (3.8 cm.)	0.5 in. (1.3 cm.)
Try net	13.5 ft. (4.0 m.)	1.5 in. (3.8 cm.)	1.5 in. (3.8 cm.)	0.25 in. (0.63 cm.)

otter trawl and the try net are given in Table 2.

Sampling Limitations

Ricker (1958) states that if only one sampling technique (or mesh size) is used an unrepresentative sample will be obtained. Parish (1958) points out that in addition to mesh size the selectivity of the sampling method is affected by (1) method of rigging the cover (chaffing gear), (2) catch size, (3) towing speed and time, (4) net material, and (5) amount of escapement through the different parts of the net.

These factors were taken into account during the Cape Lazo sampling to assure that the samples would be as consistent as possible. Rigging was the same throughout. Small catch size during the brief tows did not affect sampling efficiency. The tows were consistently of ten minute duration (the period that the net was on the bottom). Towing speed of the net was as uniform as possible, and sufficiently fast to keep the net from digging into the bottom. The same net was used throughout the study.

No data are available concerning the escape success of *Rossia* from the trawl mouth; however, because of the large frontal area of the trawl in relation to the small size of the squid it seems unlikely that the escape rate would be high except possibly near the edges of the trawl path. The females because of their larger size may be more successful in escaping the trawl than the males. The mesh size in the cod end of the trawl may have possibly permitted escapement of small

squid. The smallest squid taken in the commercial trawl had a dorsal mantle length of 11.0 mm; smaller squid either passed through the net or they were absent from the Cape Lazo grounds.

TAXONOMY AND MORPHOMETRY

Historical

Rossia pacifica was briefly described by Berry (1911) from specimens collected on the Albatross Expedition. In 1912, Berry published a complete original description of *R. pacifica*.

The taxonomic position of *R. pacifica* is:

Phylum - Mollusca, Cuvier 1798
  Class - Cephalopoda, Schneider 1784
    Subclass - Coleoidea, E.W. Berry 1928
      Order - Sepioidea, Naef 1912
        Family - Sepiolidae, Leach 1817
          Subfamily - Rossinae, Hoyle 1904
            Genus - Rossia, Owen 1834
              Species - *Rossia pacifica* Berry 1911

The genus *Rossia* was previously included under the Order Myopsida (Orbigny 1839) by Berry (1911 and 1912), Akimushkin (1963), and Voss (1955) and under the Division Myopsida by Sasaki (1929). Under the system of classification proposed by Naef (1912) the sepioid squid are removed from the former Order Myopsida and placed in a new Order, the Sepioidea; the remaining Myopsida become a suborder under the Order Teuthoidea. This system has been adopted since "there seems to be little justification for the classical treatment as proposed by Orbigny (1839) and while certain aspects of the present classification ... [followed here] are not entirely cleared up, it is felt that the change will be beneficial and give a truer picture of the relationships found within the higher categories" (Voss, 1956).

Berry's Original Description of *Rossia pacifica*

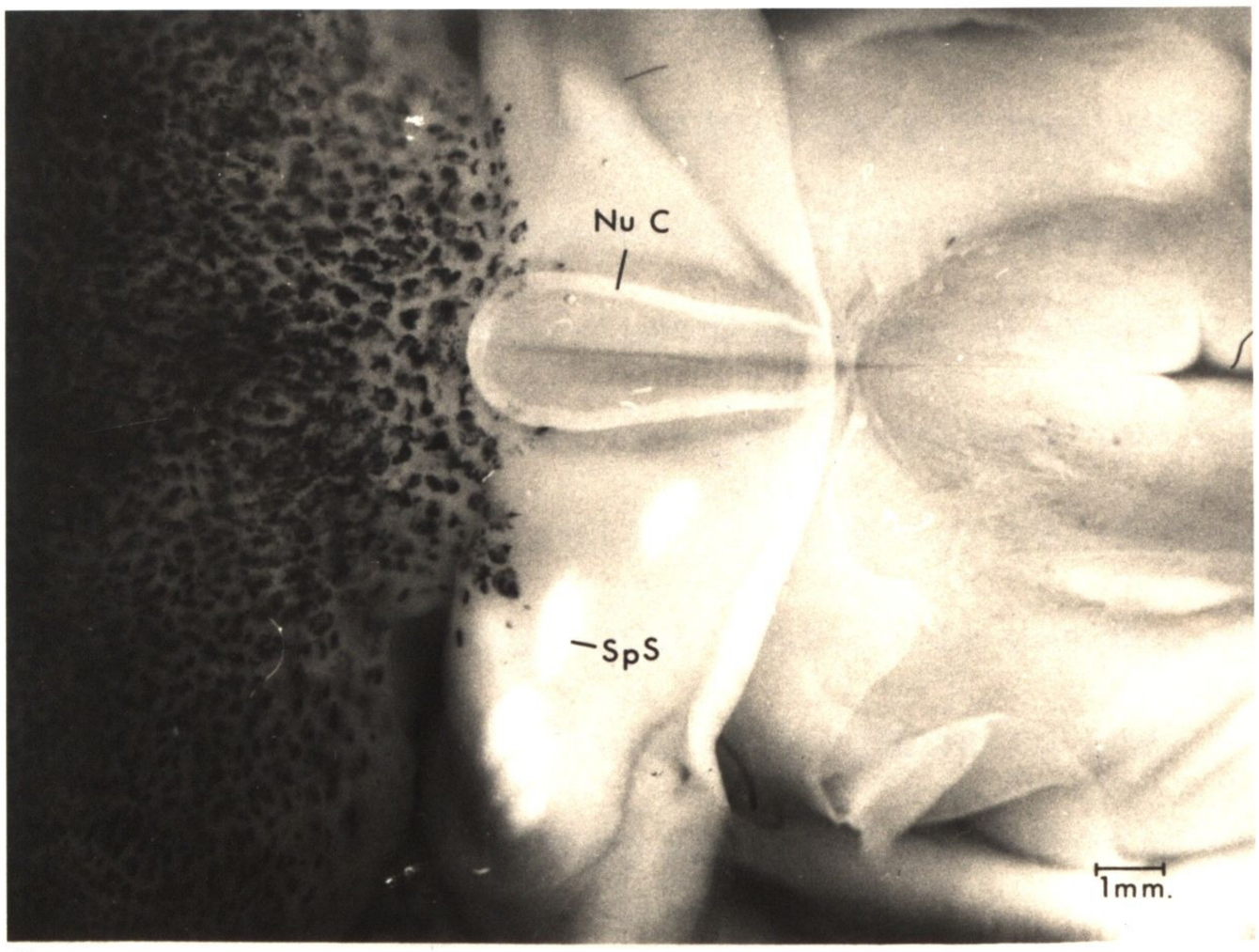
Berry's 1912 complete original description is quoted here so that it may again become widely available:

"Body smooth, sepioliform, moderately large; the mantle full, somewhat flattened above and below; rounded behind; some specimens relatively short, others more slender. Fins large, subcordate, with a free anterior lobe, their attachment more or less oblique to the general plane of the body. Mantle margin free all round, articulating with the head by an elliptical cartilage in the nuchal region, [Fig. 3] and a deep elongate groove with a prominent raised margin on either side of the base of the funnel [Fig. 4]; the ridges corresponding to the latter on the inner surface of the mantle nearly straight and notably long and heavy.

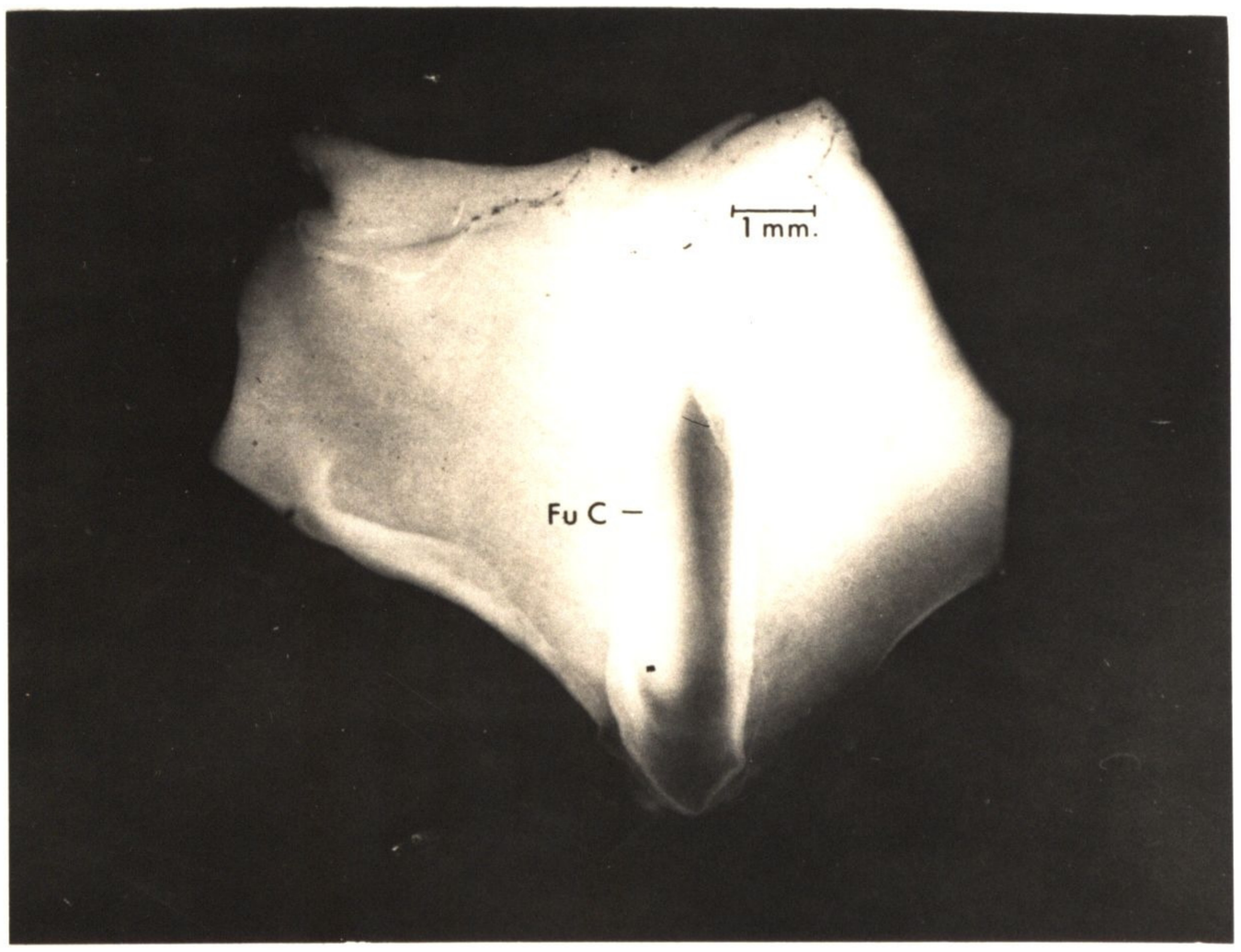
"Head very large, as wide as or wider than the body, and much flattened. Eyes large, the lower lids free. Funnel short, conical, broad at the base, the extremity truncate; interior capacious, transversely plicate, finely striate longitudinally; a delicate, rounded, flaplike valve on the dorsal wall near the tip. Funnel organ prominent, comprising a large median liver-shaped pad and two elongate-pyriform, flattened pads laterally placed on the interior surface of the ventral wall; the latter broad and curving inward at the base, the margins slightly raised, and the center apt to be occupied by a somewhat sunken triangular area.

Figure 3. Dorsal view of the female showing (A) nuchal cartilage, NuC, and (B) spermatophoric sperm sacs, SpS, in the nuchal valve pocket.

Figure 4. Right funnel cartilage, FuC.



3



4

"Arms stout, thick, rather short, unequal, the order of length 3, 4=2, 1; third pair joined with the fourth by a well developed web, functioning as a sheath for the tentacles; slight rudiments of an umbrella also to be detected between all the arms except the ventral pair; obscure carinations or keels present along the outer surfaces of all the arms in some specimens, but prominent only on the third pair. Suckers spherical, oblique; in two rows at the base and tip of all the arms, but in the adult often extremely crowded along the middle, where they are apparently ranked in three to four rows; indications of this condition always present, at least in fully grown individuals, but in a few specimens (notably a female from Albatross station 4457) the two-rowed condition persists over all except a very small portion of the arm; sucker openings circular, minute; horny rings well developed, with entire margins.

"The detailed structure of the arms in the two sexes differs greatly. In the female, the arrangement of the suckers on none of the arms is essentially unlike that on the others, and the suckers occupying analogous positions in the different rows differ very little, if any in form or size. The males present a greatly modified condition. Here both dorsal arms are hectocotylized; strongly recurved, their suckers greatly reduced; the latter usually in two rows until just before the tip is reached, when they become increased to four for a small space, then reduced to two again at the extremity; bases of the sucker pedicels (especially those of the outer row) much enlarged and transversely compressed to form a prominent series of transverse

folds or ridges very similar to those already described by Steenstrup and others as obtaining in *R. macrosoma*. There is a narrow marginal membrane on the inner side of these arms and a much wider and more prominent one along the outer margin. Above the latter and constructed parallel with it so as to form a deep fossa is a second membrane extending distally from the base of the arms for more than half their length. The suckers of the remaining arms are much enlarged, but otherwise much as in the female; those of the second and third pairs best developed and most densely placed; largest at the middle of the arm, gradually decreasing in size toward the tips, but subequal in all the rows at the same point on the arm. In young males the suckers are two-rowed and very irregularly unequal in size.

"Tentacles variable; sometimes longer than the body, but often completely retracted; stout, the inner surfaces flattened and with a distinct median groove. Tentacular club elongate, but little expanded; the sucker bearing area bordered by a narrow marginal membrane, outside of which dorsally and parallel is a second much larger and wider membrane, the latter when expended nearly half as wide as the club itself. Suckers small, unequal; largest dorsally at the base, thence gradually decreasing in size ventrally and toward the tip; in but two or three rows at the extreme base, but thence multiplying to as many as seven or eight near the middle; cup-shaped, with wide apertures, moderately long peduncles, and horny rings furnished with numerous small blunt teeth.

"Gladius slender, lanceolate, shorter than the mantle, very thin and delicate posteriorly.

"Skin everywhere smooth, without papillae, although some specimens show a number of definite but more or less obscure grooves or plicae running longitudinally on the dorsal surface of the mantle.

"Colour in life unknown; in alcohol reduced to the usual brownish buff, heavily punctate above and in less degree below with purplish chromatophores, which extend even over the fins, though fewer on their under surfaces and margins."

Additions to the original description

Color

Adequate color descriptions of the living animal are not given by Berry (1912), Sasaki (1929), or Akimushkin (1963). The following descriptions were made from *Rossia* kept in an aquarium at the University of Victoria.

Rossia pacifica are capable of rapid and varied color changes by the expansion and contraction of chromatophores. These are distributed more densely on the dorsal surface, their numbers gradually decreasing to become sparse ventrally. The squid are dark red-brown when resting undisturbed on the bottom of the aquarium and do not tend to take on a camouflage coloration as many other benthic cephalopods do. When disturbed or excited *R. pacifica* exhibits rapid waves of color change, from dark red-brown to a light opalescent grey-green. Actively swimming animals may show either the reddish brown or the grey-green coloration.

The red-brown color pattern exhibits countershading, the squid being dark on the dorsal surface and almost white ventrally. This tends to make the squid inconspicuous in its environment when it is off the bottom actively hunting for food or avoiding predators.

Occasionally *Rossia* displays iridescent blue and green colors. The iridescence is produced by reflecting cells, iridocytes, that lie beneath the chromatophores (Nicol, 1968).

Morphometrics

The identification and taxonomic evaluation of closely related species of cephalopods has been greatly facilitated through the use of proportional indices (Voss, 1963). These indices consist of measurements of various body parts related to one another or to the dorsal mantle length as a ratio or percentage. The greatest disadvantage of such a system is that cephalopods are soft bodied and tend to change in shape when preserved. This is especially the case in those species that have a reduced pen as *Rossia*, or no pen as the octopods.

Specimens of *R. pacifica* were measured fresh then preserved in 10% formalin and sea water, transferred to 80% ethyl alcohol and later remeasured. Shrinkage in length varied from 3.5% in the fin at the plane of attachment to 24.1% in the tentacles (Table 3). Haefner (1964) noted 5% shrinkage in the tentacles of specimens of *Loligo pealei* and *Lolliguncula brevis* after preservation in 5% formalin. Variations in shrinkage are due to tissue differences in the various parts.

TABLE 3.

Average Percentage Shrinkage of Various Parts

of 20 *R. pacifica* After Preservation

Measurement	Fresh Specimens	Preserved Specimens	Difference	Percentage Shrinkage
TL	85.7 mm.	70.0 mm.	15.7 mm.	18.3
ML	35.0	30.9	4.1	11.7
MW	28.0	23.0	5.0	17.9
HW	25.8	22.1	3.7	14.3
FW	53.5	42.3	11.2	20.9
FL	22.6	20.2	2.4	10.6
FLA	17.1	16.5	0.6	3.5
AL	35.9	32.3	3.6	10.2
T	87.0	65.9	21.1	24.1

Thirteen morphometric characters from each of 39 preserved and 62 fresh specimens were measured with Vernier calipers to the nearest tenth of a millimeter. Indices were calculated from these data (Appendices 1 and 2). Indices were also derived from Berry's table of the "Measurements of *Rossia pacifica*" (Appendix 3) and averaged with those of the 39 preserved specimens in the present study. The head width index was calculated from 100 specimens from the May, 1969 Cape Lazo sample. Spermatophore and sperm reservoir lengths were measured from the spermatophores of 178 male specimens. When less than 20 spermatophores were present all were measured; when more, 20 were randomly chosen and measured. Average spermatophore length and sperm reservoir length were calculated for each squid. The spermatophore length and sperm reservoir indices were then derived from these average values and averaged for each mm size class on the Y axis of the appropriate figure.

The following measurements and indices were listed by Voss (1954), with the exception of tentacle length and index, and length of the fins at their plane of attachment to the body which were originally used by Berry (1912) in his description of *R. pacifica;* the author devised the fin length index for this measurement.

Measurements

TL - total length of the specimen from tip of sessile arms to posterior end of mantle, exclusive of the tentacles.

ML - dorsal length of the mantle from the anterior margin to the posterior end. In octopods this measurement is from a point between the eyes to the posterior end of the mantle.

T - tentacle length from the base of the tentacle to its distal tip.

Arms I, II, III, IV - length of the sessile arms, dorsal, dorso-lateral ventro-lateral and ventral, respectively, measured from the first basal sucker to the distal extremity of the arm (in octopods from the mouth to the distal end).

MW - greatest width of the mantle.

HW - width of the head measured across the eyes.

FW - greatest distance across both fins.

FL - maximum length of the fin.

FLA - length of the fin at its plane of attachment to the body.

SpL - length of spermatophore.

SpR - length of sperm reservoir.

Indices

TLI - length of the tentacles expressed as a percentage of the mantle length.

MAI - length of the longest arm expressed as a percentage of the mantle length.

ALI - length of the longest arm expressed as a percentage of the total length.

MWI - width of the mantle expressed as a percentage of the mantle length.

HWI - width of the head expressed as a percentage of the mantle length.

FWI - width across both fins expressed as a percentage of the mantle length.

FLI - length of the fins expressed as a percentage of the mantle length.

FLAI - length of the fin at the plane of attachment expressed as a percentage of the mantle length.

SpLI - length of the spermatophore expressed as a percentage of the mantle length.

SpRI - length of the sperm reservoir expressed as a percentage of the spermatophore length.

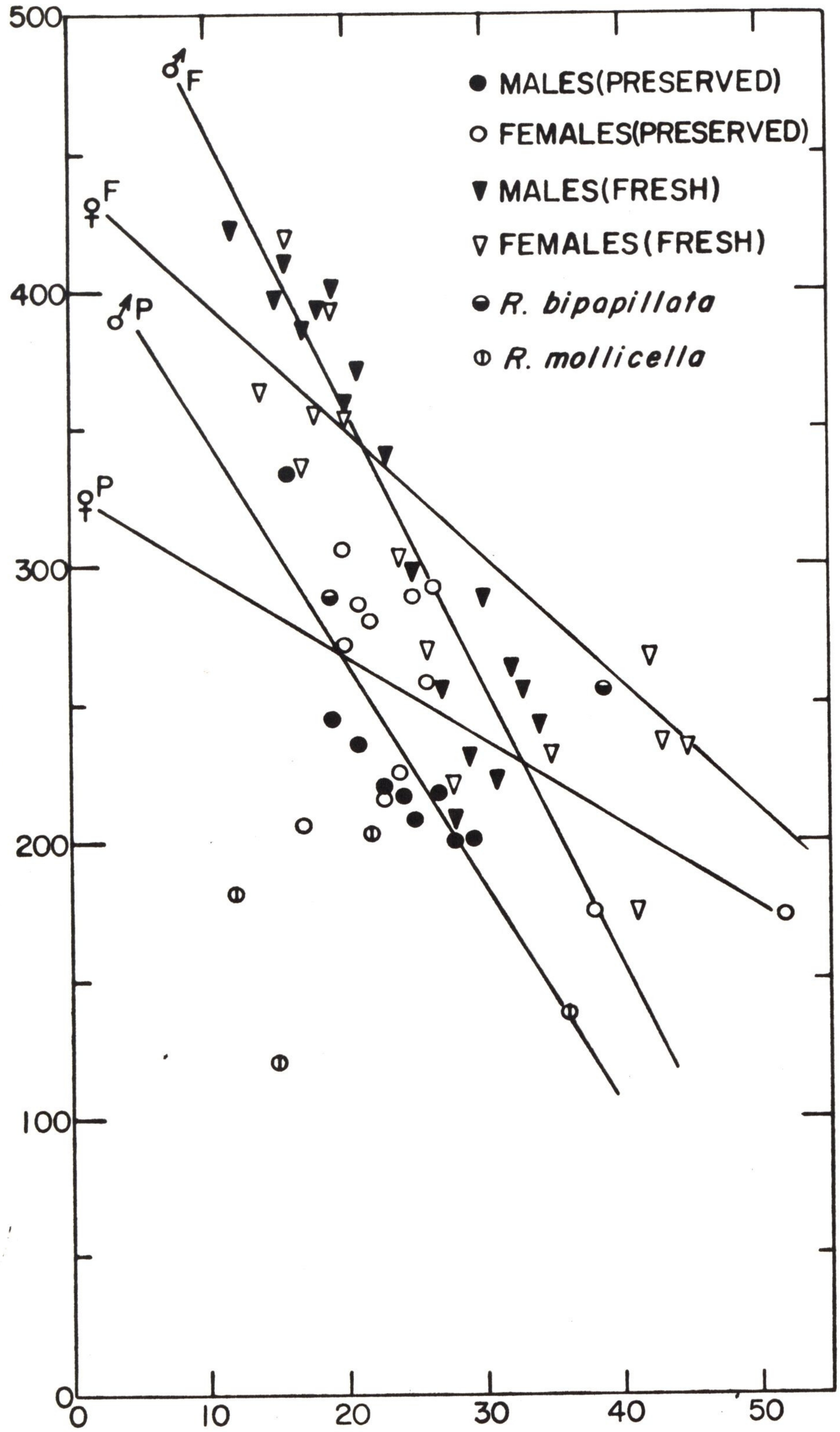
In the figures accompanying the discussion of the morphometric indices the average indices for fresh and for preserved male and female specimens are plotted for each millimeter size class on the Y axis of each graph. This was done in order to detect differences between the indices due to preservation or to sex. Regression lines were calculated and plotted on the figures, where applicable, in order to show the trends. The confidence levels and the regression equations are listed in Appendices IV and V respectively.

In those cases where data were available separate figures showing the relationship between the index values of preserved *R. pacifica* and those available from other species were drawn. Index values for *R. equalis*, *R. tenera*, *R. bullisi*, *R. tortugaensis*, and *R. antillensis* are from Voss (1956); for *R. bipapillata* from Voss (1963);and for *R. mollicella* from Sasaki (1929).

Tentacle Length Index (TLI)

The tentacle length indices of both fresh and preserved specimens (Fig. 5) decrease rapidly with increasing mantle length, indicating allometric growth in which the tentacles grow at a slower rate than the mantle. The tentacle length indices tend to be higher in the fresh than in preserved specimens. This is due to a greater relative shrinkage of the tentacles upon preservation (Table 3). The tentacle length indices of the males decrease with increasing mantle length at a faster rate than do those of the females.

Figure 5. Tentacle Length Index: The relationship of tentacle length to mantle length in fresh and preserved males and females. Each point represents the mean TLI of animals of that mantle length.


500
400
300
200
100
0
TENTACLE LENGTH INDEX
♂F
♀F
♂P
♀P
● MALES(PRESERVED)
○ FEMALES(PRESERVED)
▼ MALES(FRESH)
▽ FEMALES(FRESH)
● R. bipapillata
Φ R. mollicella
0
10
20
30
40
50
DORSAL MANTLE LENGTH (mm)

A comparison between the tentacle length indices of *R. pacifica* and *R. bipapillata* shows no definite differences. The tentacle length indices of *R. mollicella* tend to be lower than those of *R. pacifica*.

Mantle Arm Index (MAI)

The mantle arm index (Fig. 6A) decreases with increasing mantle length, showing an allometric growth relationship. The arms, particularly in the females, are thus growing at a slower rate than the mantle length. There are no significant differences between mantle arm indices of fresh and preserved specimens of either sex.

The species comparison (Fig. 6B) shows the same range of values for all the species except *R. bipapillata*. Two females of that species (not shown in Fig. 6B) have mantle arm indices of 552.6 and 256.4 and respective mantle lengths of 19.0 and 39.0 mm. These mantle arm indices are considerably higher than any found for *R. pacifica* and therefore appear to be valid criteria for separating these two species.

Arm Length Index (ALI)

The arm length index (Fig. 7) expresses the arm length in relation to the total length exclusive of the tentacles. The indices of the preserved males and females decreases somewhat with increasing total length. The arm length indices of fresh material show slight continuous increases with growth of the animal, indicating an allometric growth relationship in which the arms grow at a relatively faster rate than does

Figure 6. Mantle Arm Index: The relationship of arm length to mantle length. (A) In fresh and preserved males and females. (B) Species comparison of preserved animals. Each point represents the mean MAI for animals at that mantle length.

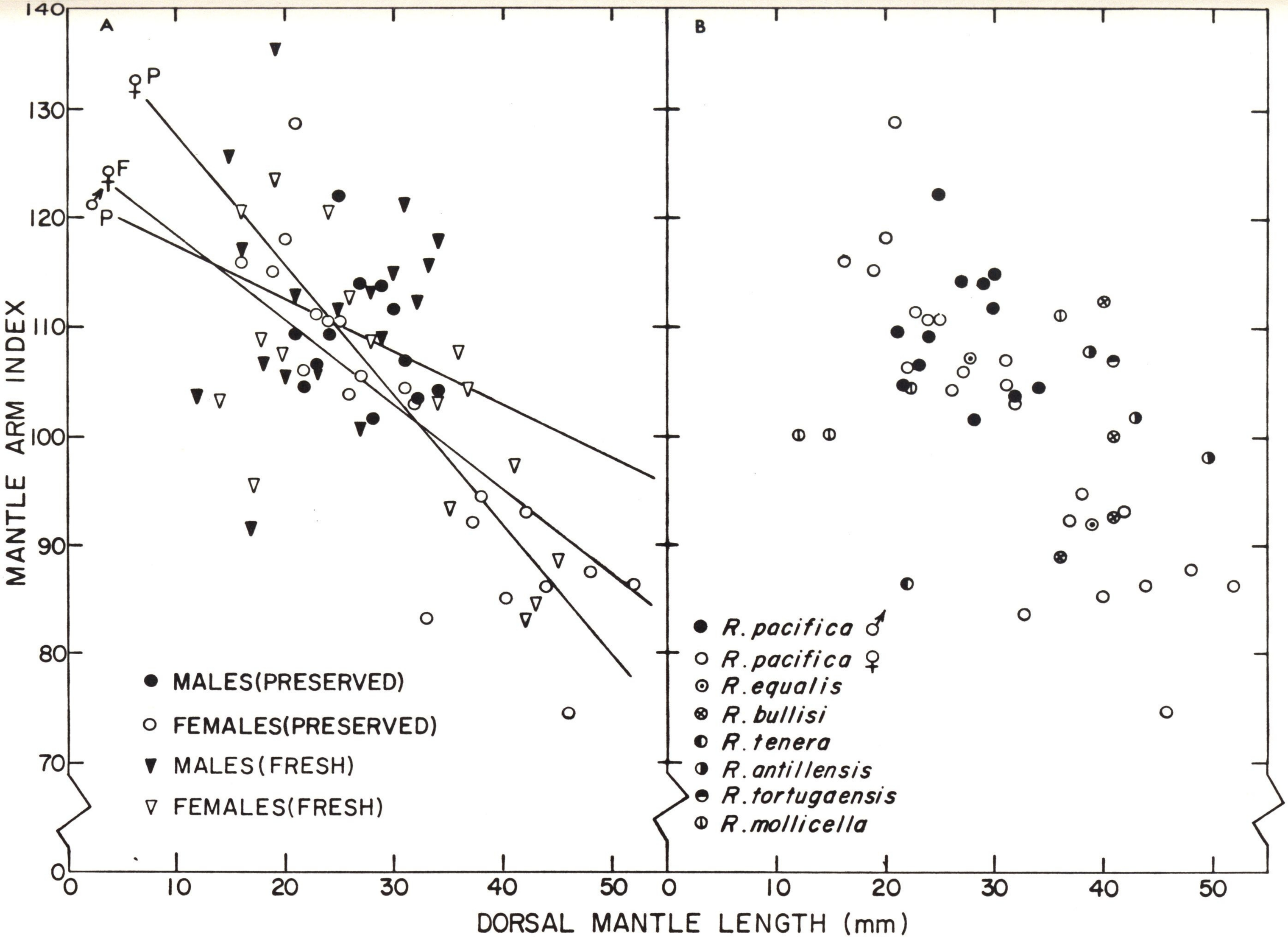
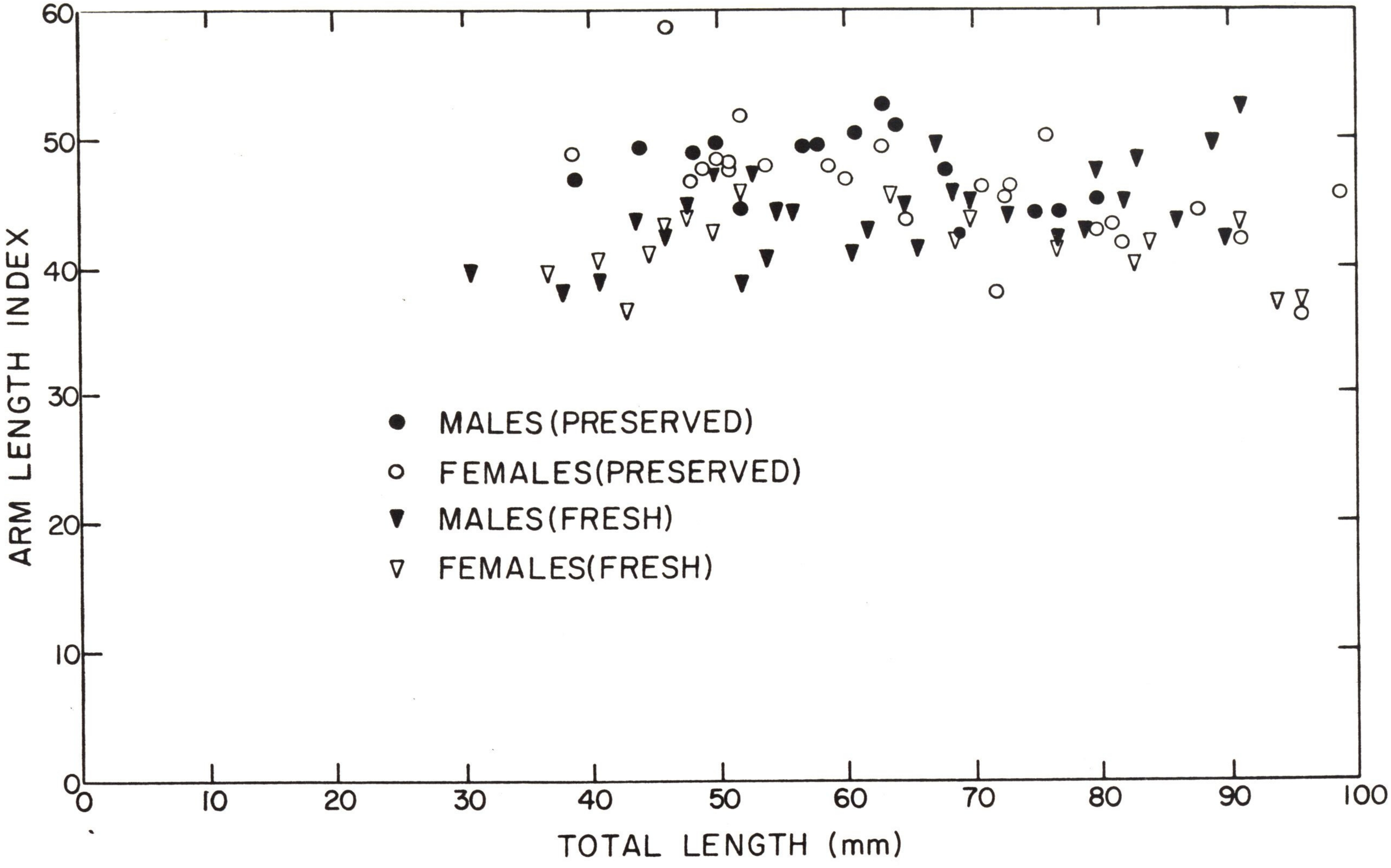

A
B
♀P
♀F
♂P
MANTLE ARM INDEX
DORSAL MANTLE LENGTH (mm)
MALES(PRESERVED)
FEMALES(PRESERVED)
MALES(FRESH)
FEMALES(FRESH)
R. pacifica ♂
R. pacifica ♀
R. equalis
R. bullisi
R. tenera
R. antillensis
R. tortugaensis
R. mollicella

Figure 7. Arm Length Index: The relationship of the arm length to total length in fresh and preserved males and females. Each point represents the mean ALI for animals at that mantle length.


ARM LENGTH INDEX
TOTAL LENGTH (mm)
0
10
20
30
40
50
60
70
80
90
100
MALES (PRESERVED)
FEMALES(PRESERVED)
MALES(FRESH)
FEMALES(FRESH)

the total length. This reversal of the mantle-arm growth relationship implies that the head length increases more slowly than does either the arm or the mantle length. The arm length indices of the preserved specimens are higher than those of the fresh specimens up to 70 mm total length.

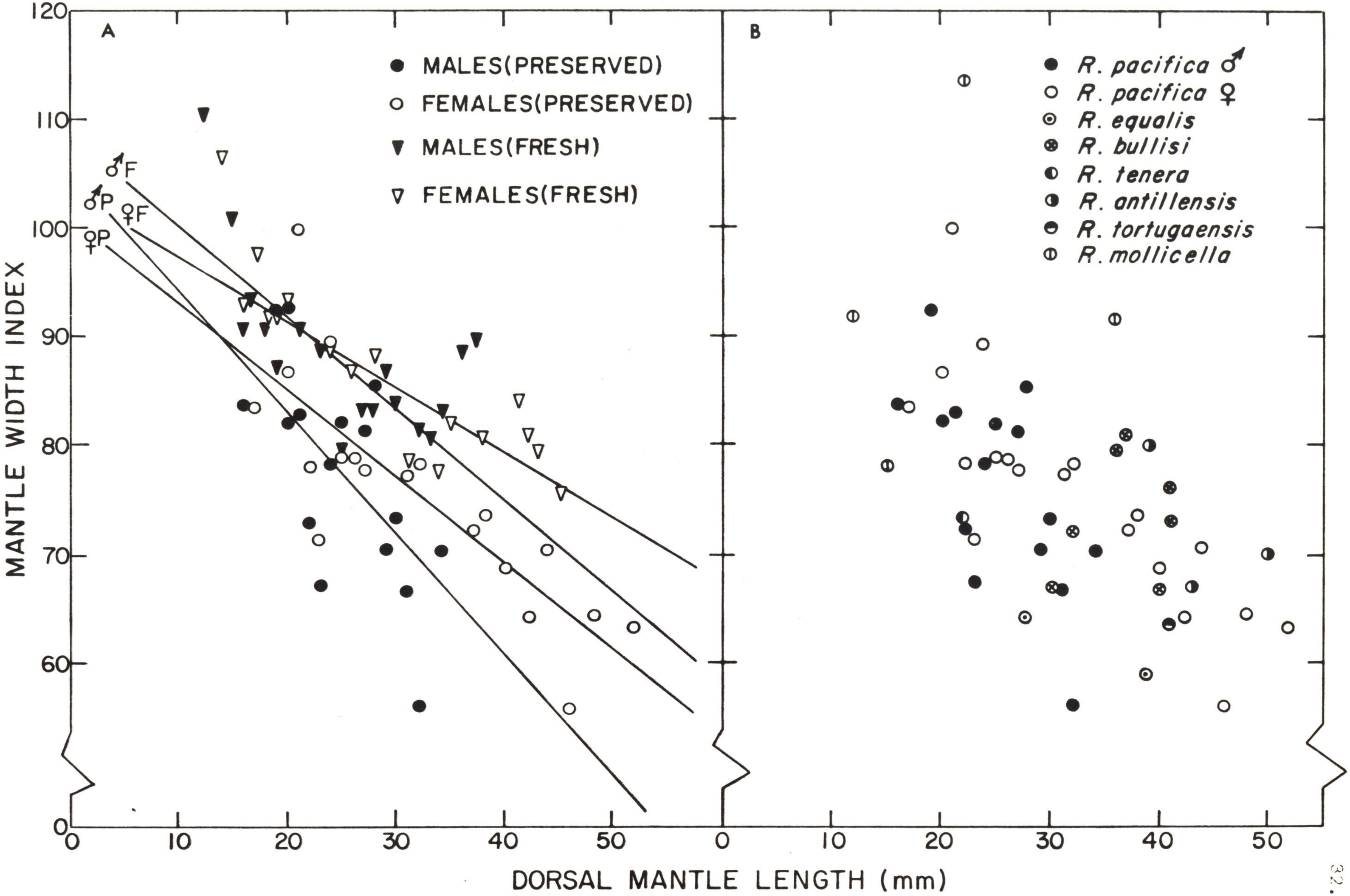
In preserved specimens the mantle and arms shrink 11.7 and 10.2 per cent respectively while the total length shrinks 18.3 per cent (Table 3). This greater shrinkage of the total length may be due to contraction of the head retractor muscles causing the head to be pulled back into the mantle cavity. Because of the complex relationship between arm length, mantle length, total length, and head retraction, the arm length index appears to be of little value for comparative purposes. There were no arm length indices available from other species for comparison.

Mantle Width Index (MWI)

The mantle width index of fresh specimens (Fig. 8A) decreases with increasing mantle length, expressing allometric growth in which mantle length increases at a greater rate than mantle width. Mantle width indices of preserved specimens tend to be lower than those of fresh animals due to the greater relative shrinkage of mantle width than mantle length (Table 3).

Species comparisons (Fig. 8B) show no significant differences between mantle width indices of *R. pacifica* and of other species, except those of three specimens of *R. mollicella* which are higher.

Figure 8. Mantle Width Index: The relationship of mantle width to mantle length. (A) In fresh and preserved males and females. (B) Species comparison of preserved animals. Each point represents the mean MWI for animals at that mantle length.


A
B
MALES(PRESERVED)
FEMALES(PRESERVED)
MALES(FRESH)
FEMALES(FRESH)
♂F
♂P
♀F
♀P
R. pacifica ♂
R. pacifica ♀
R. equalis
R. bullisi
R. tenera
R. antillensis
R. tortugaensis
R. mollicella
MANTLE WIDTH INDEX
DORSAL MANTLE LENGTH (mm)
0
60
70
80
90
100
110
120
10
20
30
40
50

Head Width Index (HWI)

Head width indices for fresh female specimens decrease rapidly with increasing mantle length (Fig. 9A) indicating allometric growth in which head width grows less quickly than mantle length. The slope of the regression line for the fresh male specimens is strongly influenced by animals less than 16 mm mantle length (Fig. 9A). Animals of larger size, however, show a relatively isometric growth relationship between head width and mantle length. This disparate growth between the sexes is comparable to that found in *Loligo opalescens* (Fields, 1965).

The regression lines indicate that head width indices of preserved specimens are slightly lower than those of fresh. This is due to a relatively higher shrinkage of head width than of mantle length (Table 3).

A species comparison (Fig. 9B) shows that definitely higher head width indices are found in *R. bullisi*, *R. antillensis*, *R. bipapillata*, *R. mollicella* and *R. tortugaensis* while lower head width indices are found in *R. equalis*. The head width indices therefore appear to be valid taxonomic criteria for separating *R. pacifica* except from *R. tenera*.

Fin Width Index (FWI)

The fin width index for fresh specimens (Fig. 10A) decreases rapidly with increasing mantle length indicating allometric growth in which the fin width increases at a slower rate than the mantle length.

Figure 9. Head Width Index: The relationship of head width to mantle length. (A) In fresh and preserved males and females. (B) Species comparison of preserved animals. Each point represents the mean HWI for animals at that mantle length.

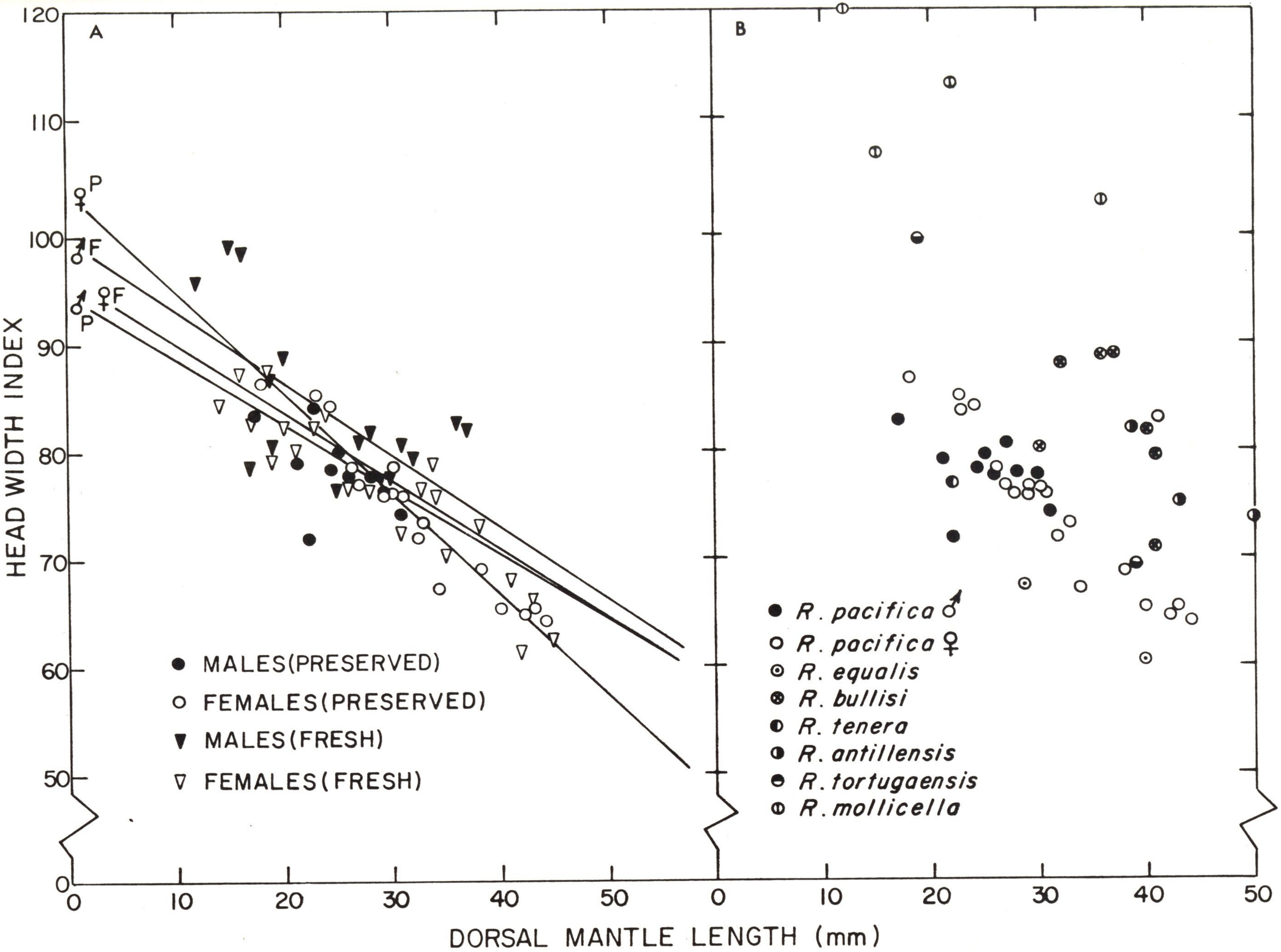
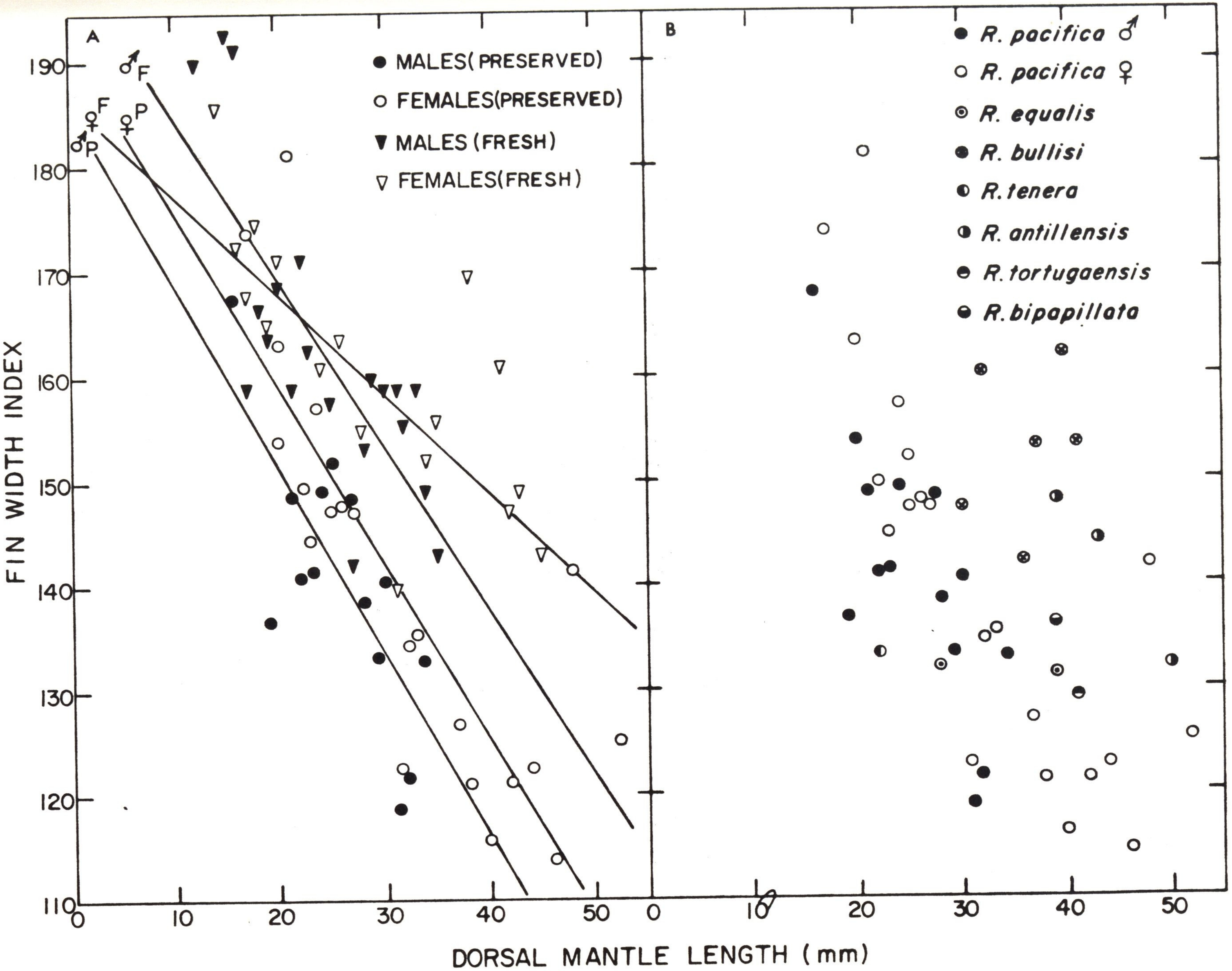

A
B
HEAD WIDTH INDEX
DORSAL MANTLE LENGTH (mm)
♀P
♂F
♀F
♂P
MALES(PRESERVED)
FEMALES(PRESERVED)
MALES(FRESH)
FEMALES(FRESH)
R. pacifica ♂
R. pacifica ♀
R. equalis
R. bullisi
R. tenera
R. antillensis
R. tortugaensis
R. mollicella

Figure 10. Fin Width Index: The relationship of fin width to mantle length. (A) In fresh and preserved males and females. (B) Species comparison of preserved animals. Each point represents the mean FWI for animals at that mantle length.


A
B
MALES(PRESERVED)
FEMALES(PRESERVED)
MALES (FRESH)
FEMALES(FRESH)
♂F
♀F
♀P
♂P
R. pacifica ♂
R. pacifica ♀
R. equalis
R. bullisi
R. tenera
R. antillensis
R. tortugaensis
R. bipapillata
FIN WIDTH INDEX
190
180
170
160
150
140
130
120
110
0
10
20
30
40
50
DORSAL MANTLE LENGTH (mm)

Fin width indices for preserved specimens tend to be lower than for fresh.

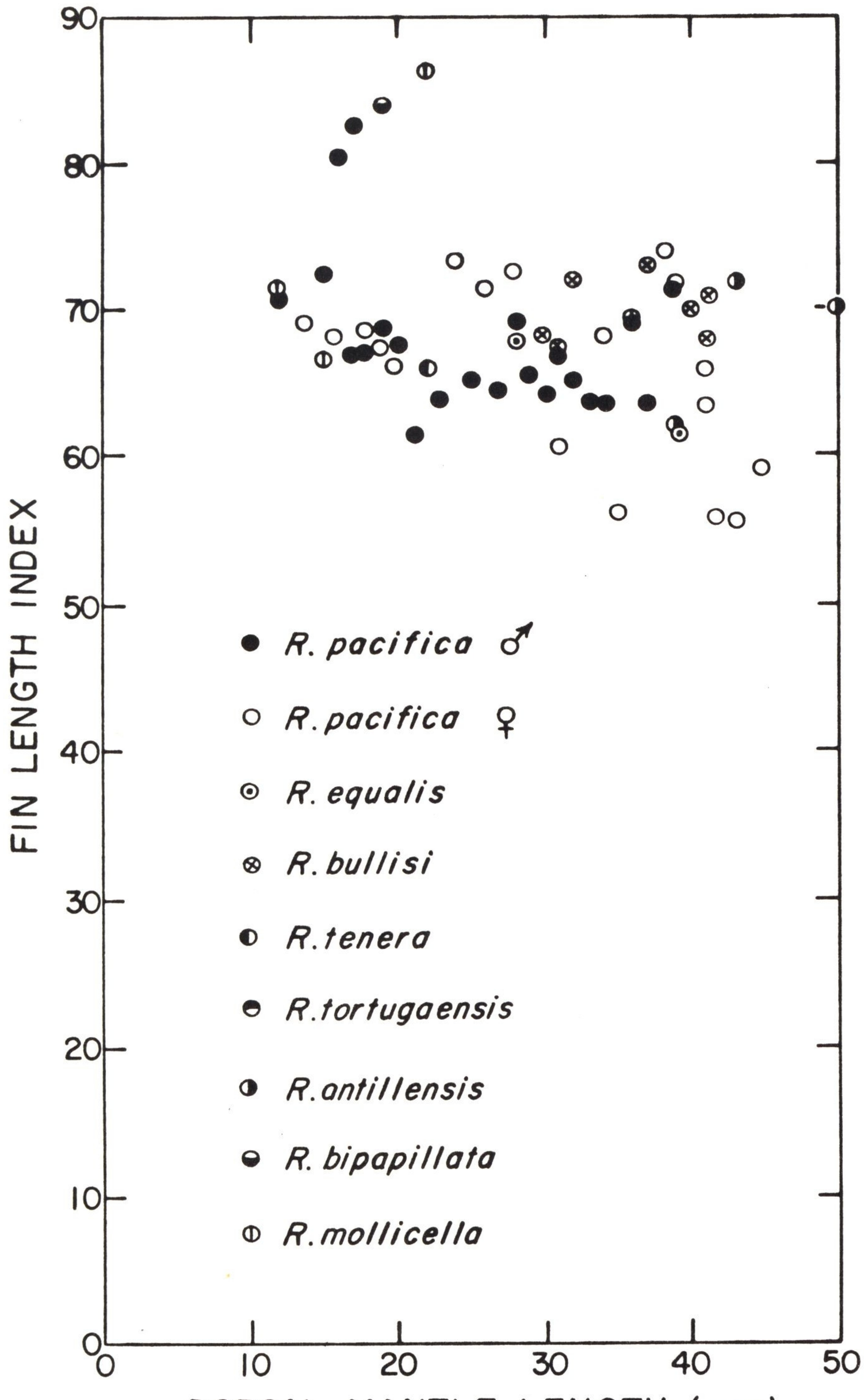
The slope of the regression line for fresh females is less than for preserved. The fresh females contain many eggs that apparently maintain an extended mantle girth. Mantle contraction due to preservation must compress and redistribute the mantle contents to establish a regression slope similar to that of the males.

Species comparisons (Fig. 10B) indicate that the fin width indices of *R. bullisi*, *R. bipapillata*, and *R. antillensis* are higher than those of *R. pacifica* except for an unusually high value for one 48 mm female *R. pacifica*. The fin width indices of *R. equalis* and *R. tortugaensis* fall within the range of *R. pacifica* while that of *R. tenera* is slightly lower. The fin width indices of four specimens of *R. mollicella* (not shown in Fig. 10B) are considerably below those of any *R. pacifica*, being 72.2, 75.0, 54.2, and 46.7. The fin width index would appear to be a useful taxonomic criterion for separating *R. pacifica* from any of the above species except *R. equalis* and *R. tortugaensis*.

Fin Length Index (FLI)

The fin length index of fresh specimens (Fig. 11) decreases slightly with increasing mantle length, showing an allometric growth relationship where the mantle is increasing at a somewhat faster rate than the fin length. The fin length indices of males and females fall within the same range of values.

Figure 11. Fin Length Index: The relationship of fin length to mantle length. In fresh male and female *R. pacifica*, and comparisons to other *Rossia* species. Each point represents the mean FLI for animals at that mantle length.


FIN LENGTH INDEX
DORSAL MANTLE LENGTH (mm)
0
10
20
30
40
50
60
70
80
90
R. pacifica ♂
R. pacifica ♀
R. equalis
R. bullisi
R. tenera
R. tortugaensis
R. antillensis
R. bipapillata
R. mollicella

A species comparison (Fig. 11) shows that the fin length indices of *R. bipapillata*, *R. bullisi*, *R. tortugaensis*, and *R. antillensis* tend to be higher than those of *R. pacifica* while those of *R. equalis*, *R. mollicella*, and *R. tenera* show no appreciable differences. It should be noted that the fin length indices of *R. pacifica* used in the above comparison are from fresh specimens. These, however, are very close to indices of preserved specimens because mantle and fin lengths shrink almost equally upon preservation (i.e. 11.7% and 10.5% respectively, see Table 3).

Fin Length Attachment Index (FLAI)

The fin length attachment index (Fig. 12), with increasing mantle length, remains constant in fresh males but increases slightly in fresh females showing allometric growth in the latter. This suggests differentially greater growth, in the female, of the posterior region of the mantle to which the fins are attached and within which the great bulk of the female sex products are maturing.

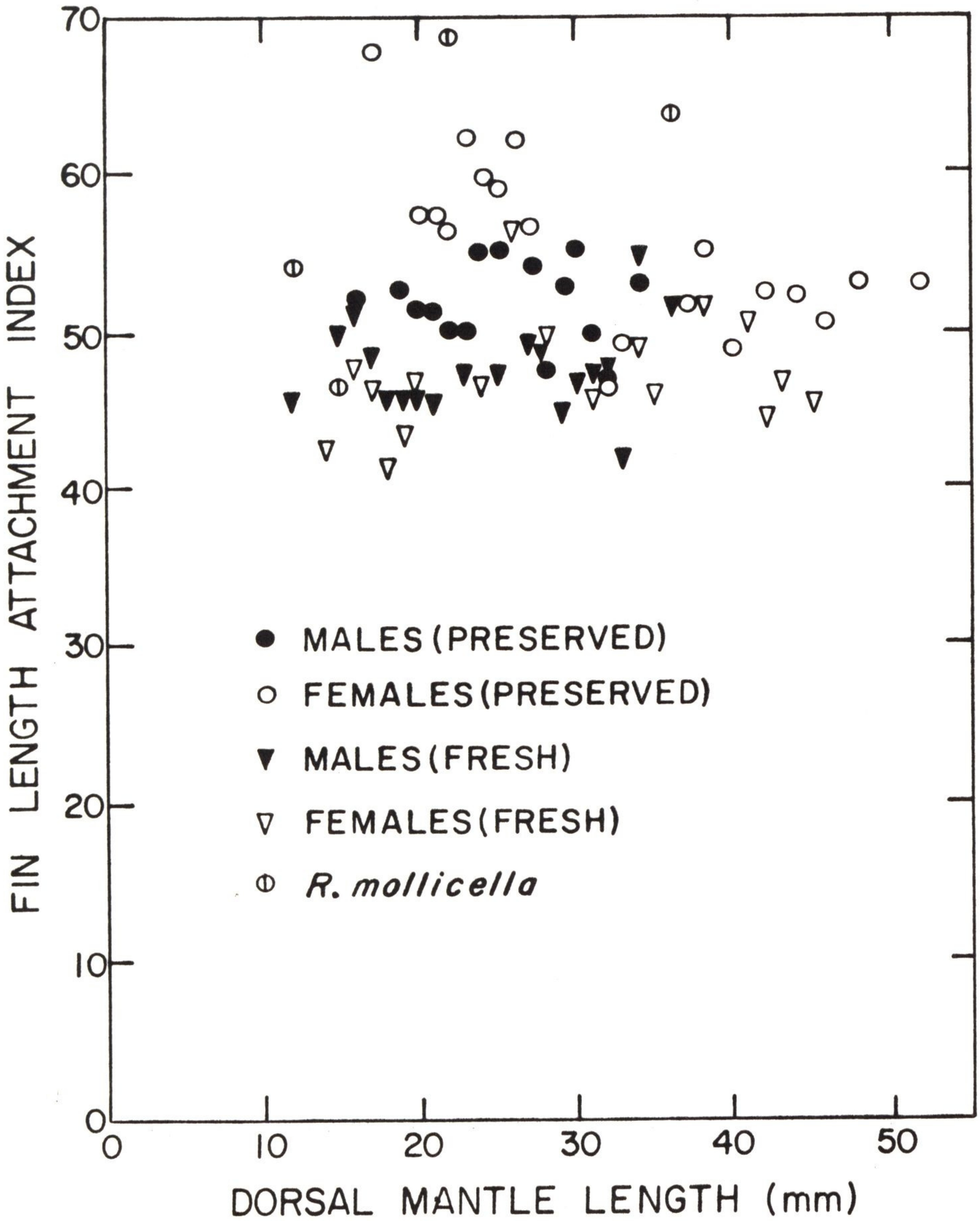
The fin length attachment indices for preserved animals are higher because the cartilage support in the base of the fin prevents as great a shrinkage as the mantle, (i.e., 3.5% and 11.7% respectively; Table 3).

The only indices available for comparison were from *R. mollicella* (Fig. 12). These tend to be somewhat higher than those of *R. pacifica*.

Conclusions From Morphometric Studies

These morphometric indices show relative growth rates of different

Figure 12. Fin Length Attachment Index: The relationship of fin length at the plane of attachment to mantle length. Each point represents the mean FLAI for the animals at that mantle length.


FIN LENGTH ATTACHMENT INDEX
70
60
50
40
30
20
10
0
0
10
20
30
40
50
DORSAL MANTLE LENGTH (mm)
● MALES (PRESERVED)
○ FEMALES (PRESERVED)
▼ MALES (FRESH)
▽ FEMALES (FRESH)
Φ R. mollicella

parts of the body. Mantle length shows relatively faster growth than other body parts, making larger animals somewhat more elongate. The resulting increased space within the mantle serves to accommodate the maturing gonads and accessory structures. This is especially true in the larger females where the ovary and ova occupy a very large volume in the posterior of the mantle cavity.

Comparisons of morphometric indices of *Rossia* species show significant differences in many cases. These differences would be of considerable value in preparing a key to the species of the genus. However, larger samples of other *Rossia* species must be measured before the full extent of taxonomic usefulness of these morphometric indices can be determined.

Arm Formulas

Arm formulas were constructed for 101 specimens in the present study and for the specimens in Berry's 1912 table of the "Measurements of *Rossia pacifica*". The arm formula is a comparison of the relative arm lengths of a cephalopod where the arm lengths are expressed numerically according to decreasing length. The numbers 1,2,3, and 4 represent respectively the dorsal, dorso-lateral, ventro-lateral, and ventral pairs of arms. Arms whose differences were less than 1 mm were considered to be equal.

Berry (1929) states the arm formula for *R. pacifica* to be 3>2=4>1. In the present study the arm formulas 3>2>4>1 and 3>2=4>1 prevailed in 23.0% and 17.7% respectively of the specimens examined. The

average differences between the dorso-lateral and ventral arms in those specimens with the arm formula 3>2>4>1 was 2 mm. The remaining 59.3% of the specimens had various other arm formulas. The dorsal pair of arms were the shortest or one of the shortest pairs in 92.1% and the ventro-lateral pair were the longest or one of the longest pairs in 93.1% of the specimens examined. The inconsistency of the arm formulas is due primarily to variability in the lengths of the dorso-lateral and ventral pairs of arms. Akimushkin (1963) and Sasaki (1929) both found similar inconsistencies in the arm formulas of *R. pacifica*.

Description of the Beaks and Radula

The radula and beaks of squid have proven to be reliable taxonomic criteria for the identification of squid families and, in some cases, for more specific identification (Clarke, 1962). Because of their non-digestible nature the beaks of squid are often found among the stomach contents of marine predatory animals. They are thus a valuable aid in identification of squid remains.

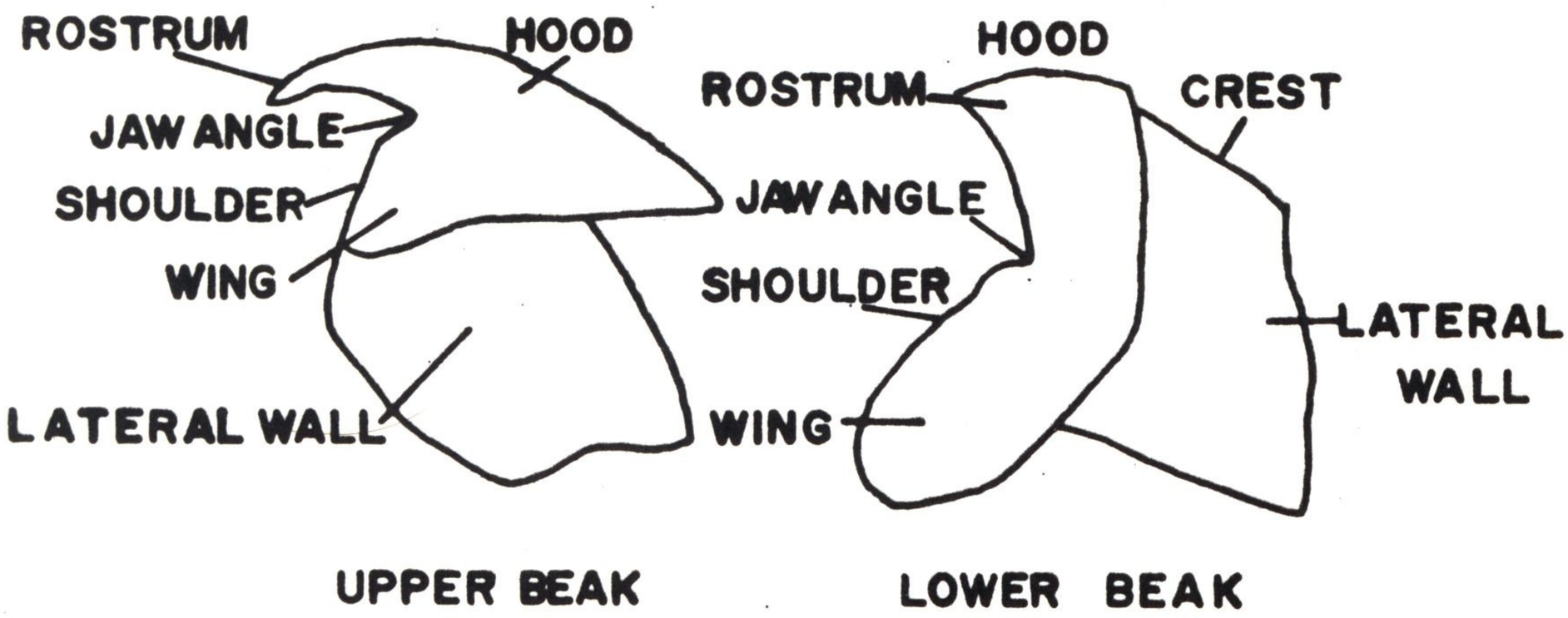
The morphological regions of a typical squid beak are shown in Figure 13. The nomenclature used here is that proposed by Clarke (1962).

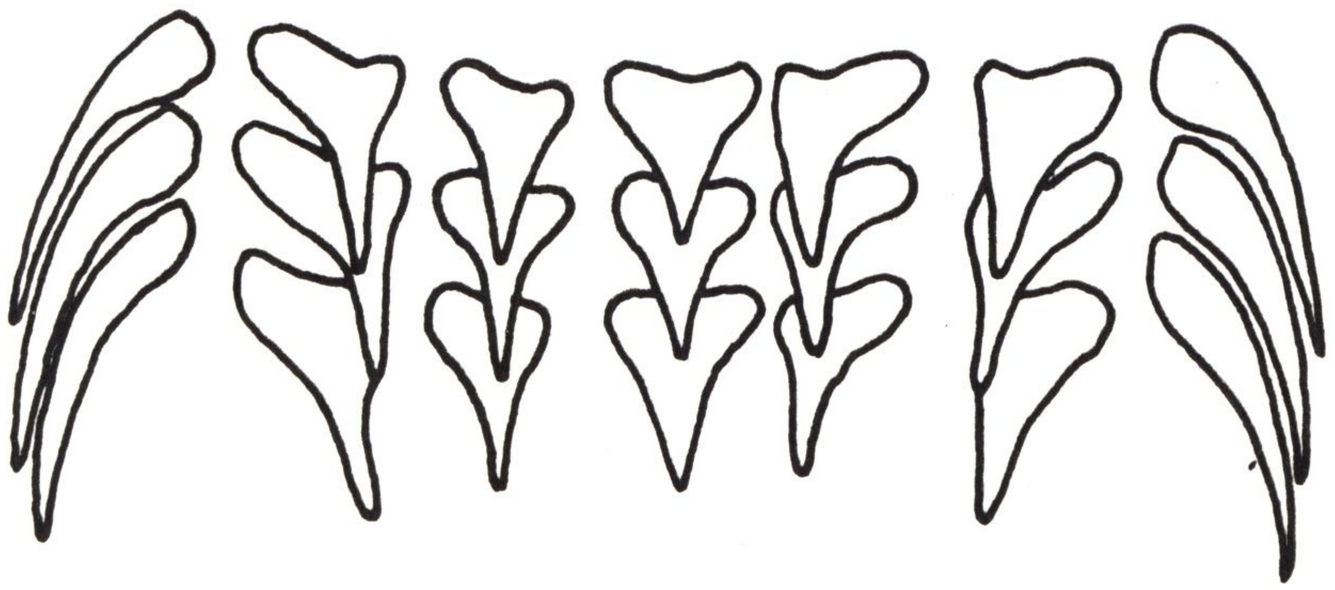
Radula

The radula (Fig. 14) is of the taenioglossan type and consists of seven series of unidenticulate teeth. The distal ends of the median

Figure 13. Parts of generalized upper and lower cephalopod beaks. (Modified from Clarke, 1962).

Figure 14. Radula: Three transverse rows of radular teeth showing denticulation and arrangement of the teeth. 50x natural size.


ROSTRUM
HOOD
JAW ANGLE
SHOULDER
WING
LATERAL WALL
HOOD
ROSTRUM
CREST
JAW ANGLE
SHOULDER
LATERAL WALL
WING
UPPER BEAK
LOWER BEAK



and inner lateral teeth are somewhat more slender than the corresponding parts of the outer lateral and marginal teeth.

Upper Beak (Figs. 15A and B)

The angle of the jaw is recessed. The shoulder is smooth with minor indentations. There is a marginal indentation on the posterior margin of the lateral wall. Rostral length is slightly less than one third the hood length. Rostrum and hood are black without transparent edges. The large crest is black anteriorly, fading to brown and then becoming transparent posteriorly. The upper beak is similar to that described for *R. macrosoma* by Clarke (1962).

Lower Beak (Figs. 15C and D)

The jaw angle is obtuse and the shoulder has a convex area or "tooth" (T). The rostral length is approximately one-seventh the hood length. The rostrum and hood are black; the median part of the wing and the anterior part of the lateral wall and crest are transparent. The lower beak of *R. pacifica* differs from that of *R. macrosoma* in that the shoulder of *R. pacifica* has a "tooth" while that of *R. macrosoma* does not.

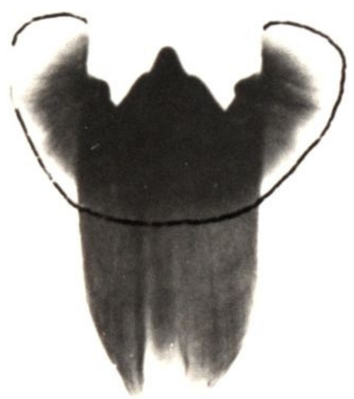
Figure 15. The beaks of *R. pacifica*. (A) Front view of the upper beak (the beak is lying on its side). (B) Side view of the upper beak. (C) Front view of the lower beak. (D) Side view of the lower beak. (4x natural size).



15A



15B



15C



15D

Distribution

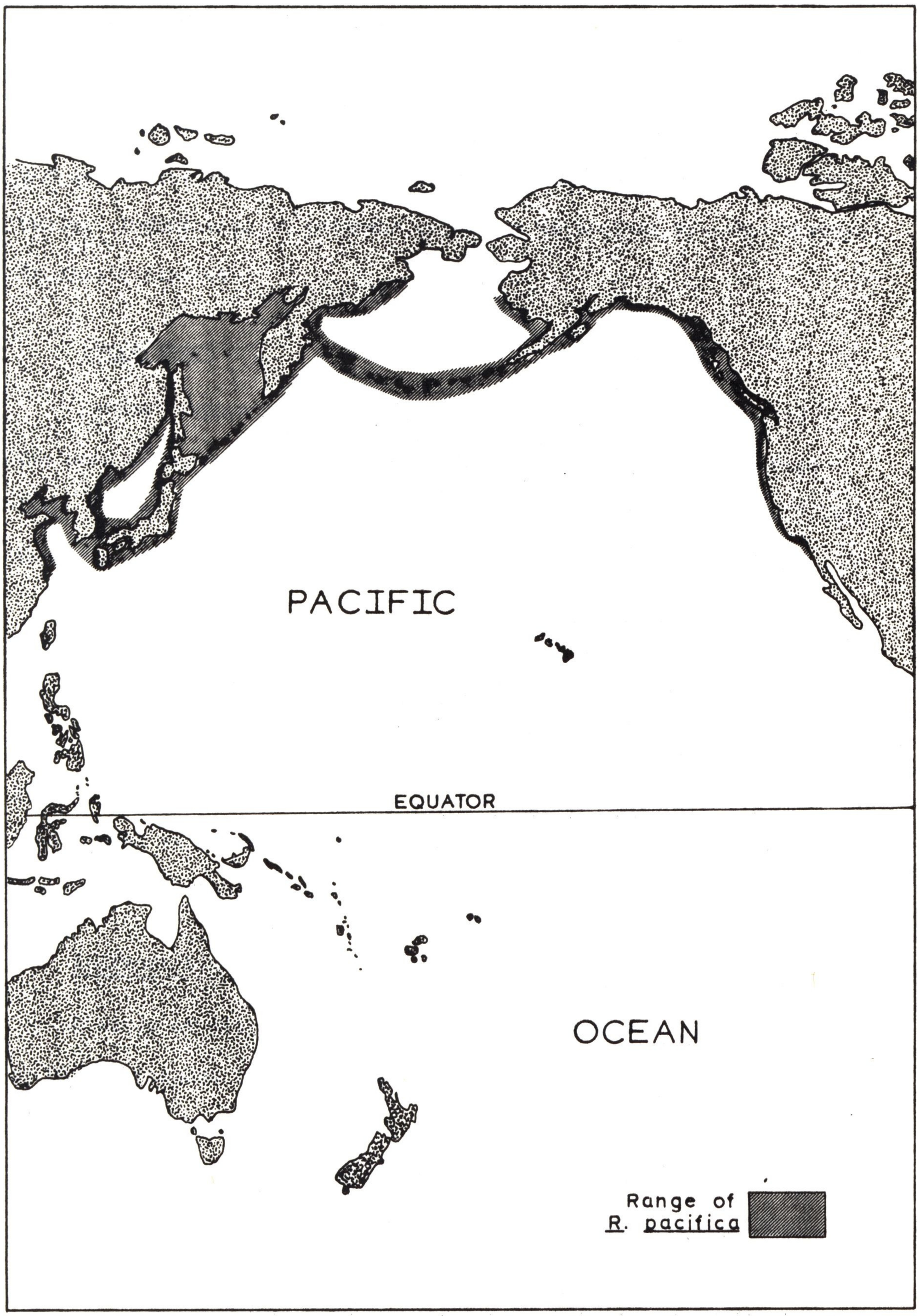
Rossia pacifica is a nektobenthic species that is known only from coastal waters. It is widely distributed in the North Pacific having been reported from the following localities: Southern California to Southern Alaska (Berry, 1911 and 1912); Aleutian Islands (Sasaki, 1929); the Bering Sea, the Sea of Okhotsk, the Kurile Islands, and south-eastern Kamchatka (Kondakov, 1941; Akimushkin, 1963); and along the east coast of Japan and the entire coast of the Sea of Japan (Sasaki, 1920 and 1929; Kondakov, 1941; Akimushkin, 1963). The geographic distribution of *R. pacifica* is shown in Figure 16.

Sasaki (1929) reports taking specimens to a depth of 200 fathoms. Berry (1912) reports the Albatross Expedition to have collected them from depths ranging from 9 to 142 fathoms. Specimens have been collected with otter trawls at a depth of 125 fathoms off the west coast of Vancouver Island, B.C. (Scrivener, 1968) and off its east coast by the author at depths of 10 to 50 fathoms. The bathymetric distribution may be extended when more investigations are carried out on the benthic fauna at greater depths.

Habitat

Although knowledge of an animal's environment is very important in any study of its biology there are no published records of physical

Figure 16. Geographic distribution of *R. pacifica*.


PACIFIC
EQUATOR
OCEAN
Range of
R. pacifica

parameters of habitats in which any species of *Rossia* have been found. In order to assess the habitat of *R. pacifica* bottom temperatures and salinities were taken in conjunction with sampling at Cape Lazo Gully. Information on sediment types, as determined by other workers, is also discussed.

Temperature

Bottom temperatures ranged between 6.89° and 11.00°C (Table 4). The mean of bottom temperatures recorded for each sampling period (Fig. 17 and Table 4) decreased from 9.47°C in August, 1968 to 7.54°C in March 1969 then increased to 8.27°C in May 1969.

Salinity

The minimum recorded salinity of the bottom water was 28.01 °/₀₀ and the maximum was 30.21 °/₀₀. The means of bottom salinities recorded remained relatively constant throughout (Fig. 17 and Table 4). The lowest mean salinity was 29.46 °/₀₀ in August, 1968 and the highest was 29.60 in October, 1968.

Sediment Sizes

A study of distribution of sediment types in the gully was done by Dr. R. Sheldon in August, 1966. The sediment types were classified according to their modal grain diameters in microns, μd, by using a Coulter counter(Sheldon and Parsons, 1966). The results of this study (Fig. 18) as shown by Levings (1967) indicate sediment types

Figure 17. Mean bottom temperatures and salinities of Cape Lazo Gully during sampling periods.

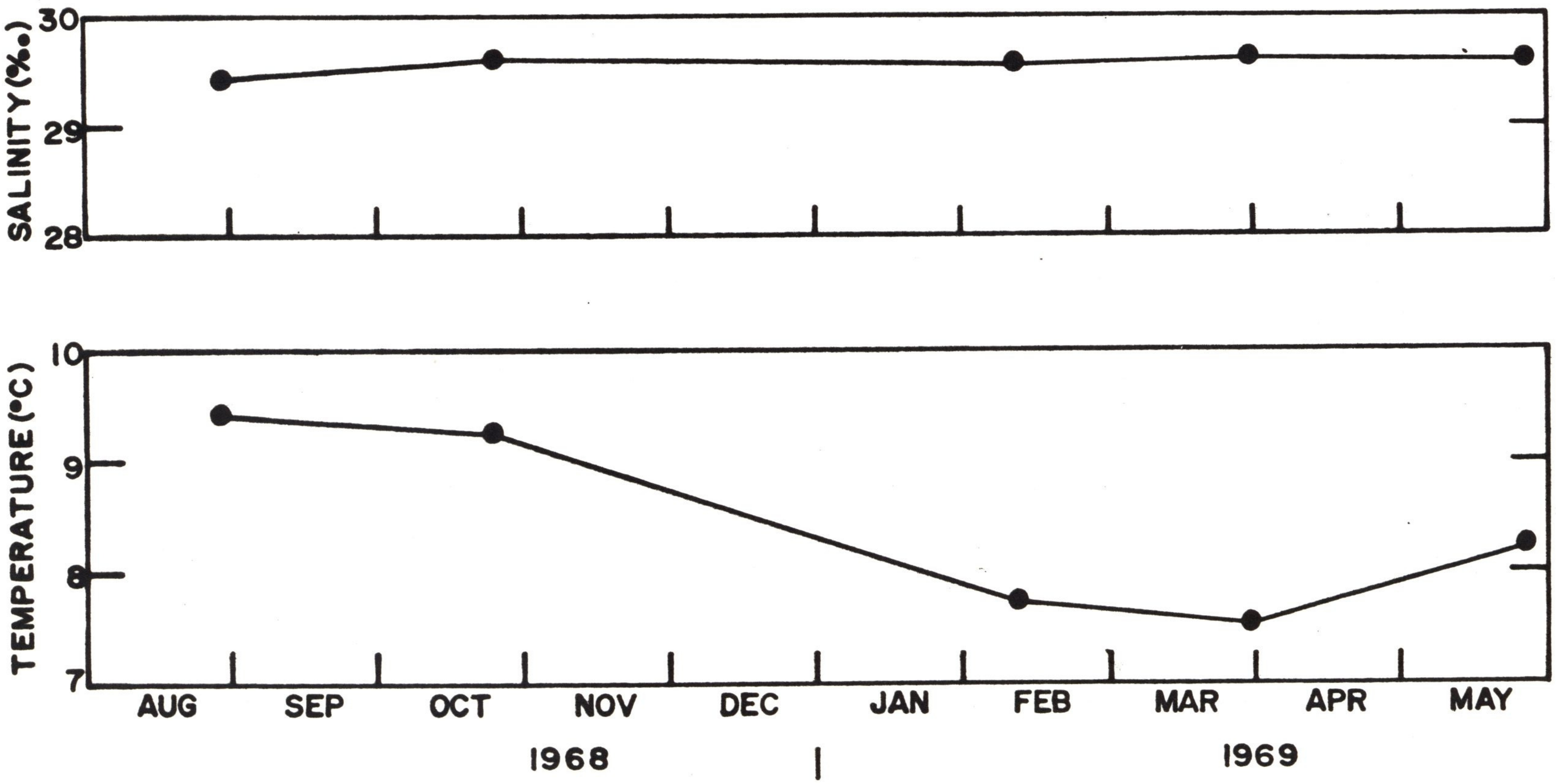

SALINITY (‰)
30
29
28
TEMPERATURE (°C)
10
9
8
7
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
1968
1969

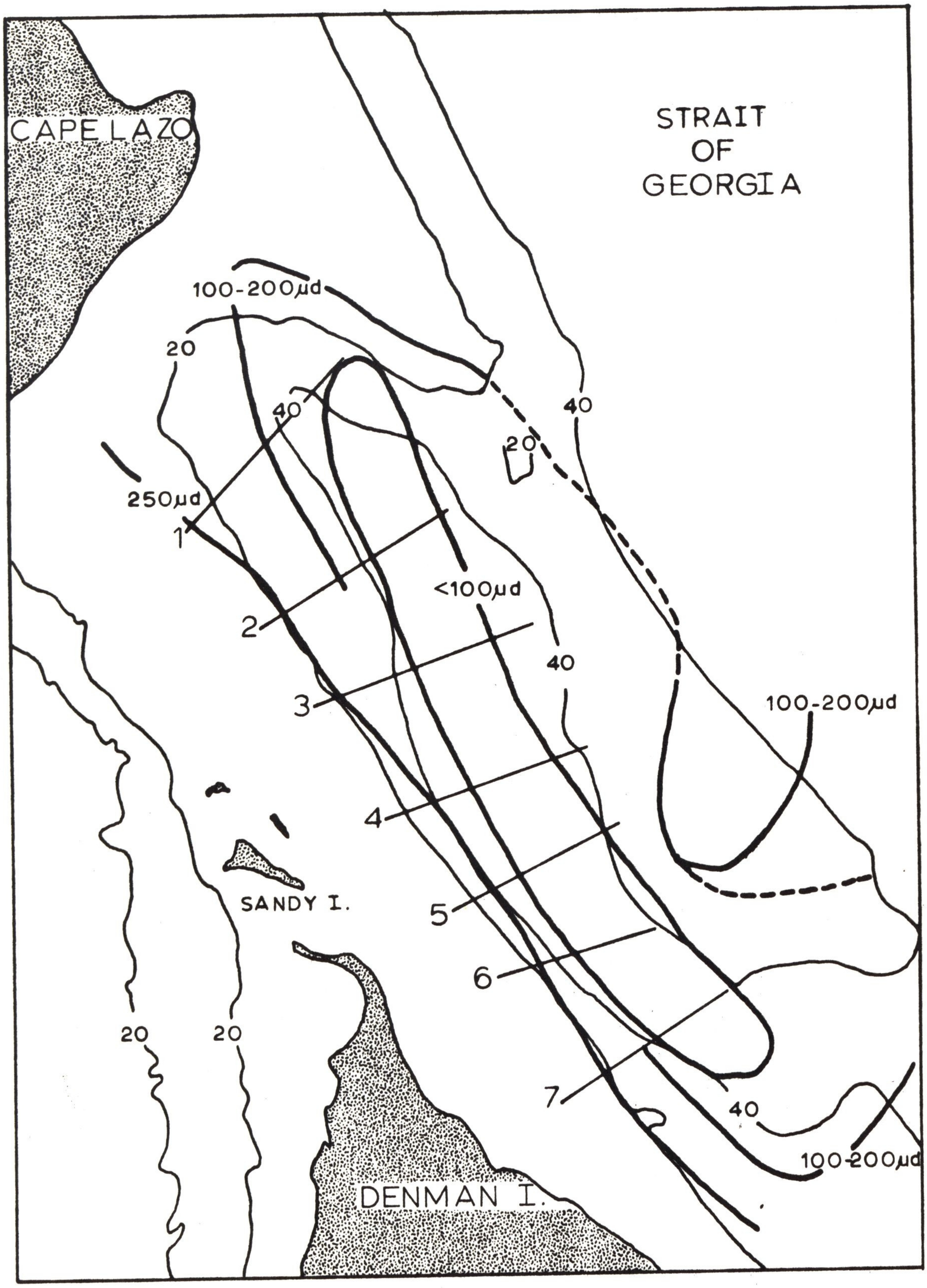
Table 4

Maximum, Minimum, and Mean Bottom Temperatures and Salinities

At Cape Lazo Gully During Sampling Periods.

Sample	Temperature °C			Salinity °/₀₀		
	Min.	Max.	Mean	Min.	Max.	Mean
Aug. 1968	8.48	11.00	9.47	28.01	30.21	29.46
Oct. 1968	9.04	9.67	9.32	28.03	30.06	29.60
Feb. 1969	6.89	8.51	7.69	29.14	29.90	29.52
Mar. 1969	7.18	7.84	7.54	28.99	29.88	29.56
May 1969	8.02	8.64	8.27	29.41	29.63	29.54

Figure 18. Distribution of sediments at Cape Lazo Gully according to their modal grain diameters in microns, μd. (modified from Levings, 1967).


CAPE LAZO
STRAIT
OF
GEORGIA
100-200µd
20
40
250µd
1
2
3
4
5
6
7
<100µd
40
20
40
100-200µd
SANDY I.
20
20
DENMAN I.
40
100-200µd

ranging from less than 100µd to 250µd. The finer sediments are distributed mainly in the bottom of the gully at depths below 40 fathoms. The modal grain size of the sediments gradually increases to 200µd and 250µd in the shallower water on the east and west sides of the gully respectively. The sediment sizes observed in the habitat at Cape Lazo Gully therefore varied from less than 100µd to over 250µd.

Habits

Rossia, like other decapod cephalopods, swims by undulations of its fins and by jets of water forced through its funnel by contractions of the mantle. These are gentle when the squid is moving slowly, the animal appearing to be swimming chiefly by the use of its fins. When disturbed, *Rossia* increases its speed by more forceful contractions and by more rapid movement of the fins.

Specimens that were kept in aquaria spent much of their time nestled on the bottom in one of two attitudes. *Rossia* that had settled down and were undisturbed rested with the body in an anterior-posterior horizontal plane with the arms tucked under the head (Figs. 19 A and B). The second attitude was shown by squid that had recently settled or that were stopping briefly between periods of swimming. In this position the body was inclined at an angle, with the head elevated (Figs. 20 A and B) and supported in this position by the arms. These were extended downward with the distal tips bent posteriorly underneath the head. In both positions the squid folded their fins against the sides of their bodies, presumably to provide a more stable condition by exposing less surface area to the action of water currents. These positions are similar to those described for *R. macrosoma* by Racovitza (1894).

Squid in either position occasionally turned the funnel so that

Figure 19. *Rossia pacifica* resting in the horizontal position.

(A) Front view.

(B) Side View.



19A



19B

Figures 20 A and B. *Rossia pacifica* sitting in the upright position.



20 A



20 B

it was at a right angle to the dorsal-ventral axis and thus opened above the arms (Fig. 21). Pallial water was vented to the side rather than beneath the head. Thus the animal could rest directly on the undisturbed substrate and draw respiratory currents free of debris into the mantle cavity.

Rossia that were kept in an aquarium with sand as a substrate usually excavated a slight hollow to sit in (Figs. 19A and B and 20B). A squid would move about on the bottom by walking on its arms or by slight swimming motions until it found a suitable place. In some cases the squid formed the depressions by using its arms and, possibly, jets of water from the funnel. In other instances, a squid would move its body to and fro against the substrate until a depression had been formed. The arms and jets of water from the funnel were used less in this method of excavation. Having formed an indentation the squid would settle into the upright position; later it would tuck its arms under its head and assume the horizontal position. In some instances depression building did not occur.

The depressions provide partial concealment, permit more equal distribution of the body weight over a larger surface of the substrate, and may aid in stabilizing the squid against bottom currents.

At no time were the *Rossia* observed burying themselves to any great extent in the sand, although one female was observed throwing sand onto itself in the aquarium (Fig. 22). The squid was lying in the horizontal position and at intervals of 20 to 30 minutes extended

Figure 21. Side view of female showing (A) funnel, F, turned laterally, and (B) spermatophoric sperm sacs, SpS, in the nuchal valve pocket.



21

Figure 22 A-E. Sequence of steps by which *Rossia* throws sand onto its back.



22A



22B



22C



22 D



22 E



22 F

its second pair of arms forward (Fig. 22A) and then drew them back over the surface of the substrate (Fig. 22B and C), pulling a small amount of sand toward its head. After repeating this two or three times the squid threw the accumulated sand onto its back by a quick backward movement of the second pair of arms (Fig. 22D,E, and F). The resulting covering may aid in camouflage when the squid is resting on the bottom.

Feeding Behaviour

Observations were made on the feeding behaviour of *R. pacifica* while they were kept in a 50 gallon green fiberglass aquarium that contained no sand. Prey organisms introduced into the aquarium were *Gasterosteus aculeatus* (three-spine stickleback), *Pandalus jordani* (pink shrimp), and *Crago communis* (pistol shrimp). Individual *Rossia* were quite variable with regard to feeding; some fed readily but many were never observed feeding or showing interest in prey organisms. *Rossia* were not seen feeding on crustacea but were often observed feeding on sticklebacks.

When sticklebacks were placed into the aquarium the squid immediately became excited, initially bobbing up and down while remaining in contact with the bottom of the aquarium by means of its arms. The squid then began to swim back and forth short distances near the bottom while exhibiting color changes from a dark red-brown to an opalescent grey-green. The *Rossia* then moved upward to a position approximately level with that of the intended prey. At this time the squid displayed the grey-green coloration, presumably becoming less conspicuous to the fish. Bradbury and Aldrich (1969) noted a similar blanching of color in *Illex illecebrosus illecebrosus* just before the moment of prey capture.

While moving slowly toward its prey the *Rossia* extended its arms into a cone so that the arm tips formed an apex that pointed directly

at the fish. The squid retained its position by slow movements of its fins, making any changes in position that were necessary relative to the position of the fish. The tentacular clubs, that had up to this time remained concealed by the arm cone, now appeared between the third and ventral pairs of arms. When the tentacles had been extended slowly to approximately one third their length (one half again as far as the arm cone), they were swiftly extended to their full length (3 to 4 times the length of the arm cone). The suckered tentacular clubs attached to the fish which was then pulled toward the buccal region of the squid where the oral arms seized the fish and manoeuvred it into a horizontal position across the buccal area. In some instances the fish was held in this position for a number of minutes, and on a few occasions fish that were too large for the squid to hold escaped during this time. Threespine stickleback are not natural prey for *Rossia* and the spines may have hindered orientation of the fish across the buccal region into a position for the kill, thus accounting for the long holding period.

One *Rossia* had a damaged right tentacular club that greatly hindered its ability to catch fish. Both tentacles would slowly extend together, but during the final strike the squid would either miss its mark, or if it succeeded in attaching the left tentacular club the fish would break free.

Rossia killed the fish by biting it dorsally between the head and the dorsal fin severing the spinal cord. Bidder (1950) and Fields (1965)

have observed that *Loligo vulgaris* and *L. opalescens*, respectively, kill fish in a similar manner. *Rossia* then carried the dead fish to the bottom of the aquarium to begin its meal. The fish was now manipulated so that the head region was turned toward the mouth of the squid. At this time the *Rossia* again took on the dark red-brown coloration.

Bidder (1950) states that when *L. vulgaris* is feeding on fish " ... the movements of the jaws during the meal are clearly visible. Usually they keep their normal vertical position in the head and work about a horizontal axis; sometimes, however, the buccal mass rotates about the esophagus, until the jaws are almost horizontal and working about a vertical axis." The action of the buccal mass during the meal is difficult to observe in *Rossia* but it is assumed to be much the same as that described for *L. vulgaris*. The radula of *Rossia* is apparently primarily concerned with the swallowing of food, as described for *L. vulgaris* (Bidder, 1950) and *L. pealii* (Williams, 1909).

In the majority of cases *Rossia* would ingest only the lateral musculature, dropping the remainder of the fish. On several occasions the captured fish was taken away from the squid and placed near it in the tank. In no instance was a squid observed to resume its meal or to pick up any dead fish that were placed in the aquarium. *Rossia* is an active predator and evidently needs the stimulation of living prey to feed, apparently being uninterested in moribund organisms.

On occasions when a number of fish were present in the aquarium *Rossia* were not observed capturing more than one fish for a meal, thus it is not known whether they might capture a number of animals at one time as described by Fields (1965) for *L. opalescens* feeding on shrimp.

Prey capture in *R. pacifica* is in general accord with that described for *Sepia* (Wilson, 1946 and Wells, 1962) and for the loliginids (Williams, 1909 and Fields, 1965) in that the tentacles are used for prey seizure. The details of feeding behaviour in *Rossia* are similar to those of *L. opalescens* but differ from *Sepia* in that *Rossia* keeps its arm cone intact until after the prey is grasped whereas in *Sepia* "... the arms are flexed backwards as the tentacles shoot out." (Wells, 1962), and from *L. pealii* where the arms open to accept the prey as the tentacles are being shot out (Williams, 1909).

Stomach Content Analysis

Stomach contents were analyzed to obtain a better understanding of *Rossia's* feeding habits and of its role in the food web. Stomachs of all the squid collected on the January, August, and October, 1968 and January, February, March, and May, 1969 Cape Lazo trips were examined. The stomach contents were placed in a Syracuse dish and examined with a dissecting microscope.

Crustacea were present in 86.8% of the stomachs that contained food (Table 5). They had been thoroughly dismembered, the stomachs containing mostly hard parts such as intact pleopods and parts of other

TABLE 5. Seasonal Changes in the Percentages of Fish and Crustacea in the Diet of *R. pacifica*.

Month	Jan. 1968	Aug. 1968	Oct. 1968	Jan. 1969	Feb. 1969	Mar. 1969	May 1969	Total or Average
Total number of *R. pacifica*	64	117	432	59	184	175	136	1167
Percentage of stomachs without food	82.2	75.2	61.3	73.9	61.4	57.1	66.2	67.5
Percentage of stomachs with food	18.8	24.8	38.7	27.1	39.7	42.9	35.3	32.5
Percentage of food-containing stomachs with crustacea	91.2	82.8	91.6	75.0	97.3	86.7	83.3	86.8
Percentage of food-containing stomachs with fish	8.3	33.3	16.2	12.5	5.5	13.3	27.1	16.6
Percentage of food-containing stomachs with fish and crustacea	--	10.4	10.2	--	2.7	2.7	10.4	5.2
Percentage of food-containing stomachs with crustacea only	91.2	72.4	81.4	75.0	94.5	84.0	77.1	82.2
Percentage of food-containing stomachs with fish only	8.3	17.2	5.6	12.5	2.7	10.7	16.7	10.5

appendages along with pieces of flesh. No attempt was made to key out any of the crustacea as the taxonomically significant parts such as the rostrum or other parts of the carapace were rarely present. Although it was difficult to ascertain the exact percentages of the various types of crustacea present it appeared that pandalid shrimps made up over 80% of the crustaceans eaten, with small crabs, mysids, and ostracods making up the rest. Whole ostracods were present in two stomachs, five in one and two in the other.

Although the process by which *Rossia* captures and feeds upon shrimp has not been observed, it seems appropriate to draw some conclusions from the stomach contents. *Rossia* appears to dismember the shrimp selectively, eating only the softer portions. Remains of the dorsal exoskeleton of the abdominal region were not found in the stomachs. It is therefore likely that *Rossia* feeds from the ventral side of the abdominal region where it would be easiest to gain access to the softer regions of the prey. In February, 1969 a number of stomachs were filled with shrimp berry (eggs).

Fish remains were found in 16.6% of all stomachs that contained food, varying from 33.3% in August, 1968 to 5.5% in February, 1969 (Table 5). Fish remains consisted of bones, scales, and flesh; the head and internal organs were never present. Fields (1965) described similar findings for *L. opalescens;* however, one stomach was described as being "filled solidly with tiny fish vertebrae, sometimes 12 to 15 still joined, with ribs and flesh, and the remains of at least

50 fish eyes." Such a condition was not observed in any of the *Rossia* stomachs. The stomach of a female *Rossia* with a mantle length of 35.5 mm contained angular pieces of fish (the largest of which measured 6.8 by 4.8 mm) and an 18.6 mm string of this material connected by pieces of skin.

The diets of some squid consist of a moderate percentage of other squids. Fields (1965) calculated that 75.0% of the diet of spawning *L. opalescens* consisted of squid while at other times of the year they made up only 10.0% of the diet. Rao (1954) found cephalopod remains in 30.3% of the diet of *Sepioteuthis arctipinnis* and Squires (1957) found that cephalopods made up a large portion of the diet of *Illex illecebrosus*. *Rossia pacifica* are "cannibalistic" to a far smaller degree than the species of squids examined by those authors cited above. Cephalopod remains were present in only seven of the four hundred twenty stomachs that contained food. The identifiable parts consisted of beaks and epidermis within which the chromatophores were readily visible. Three beaks were found in the stomach of a 30.0 mm female.

Small bivalve molluscs were found in three stomachs and parts of a polychaete in another. Polychaetes were also found by Fields (1965) in the stomach contents of *L. opalescens* and by Squires (1957) in *I. illecebrosus*. In all cases they were a very small portion of the total diet.

Shredded pieces of undigested eelgrass were present in the stomachs of two individuals. The rare presence of plant material in the stomachs of cephalopods has been reported by Massy (1916) for *Graneledone setebos*, Forbes and Hanley (1853) for *Ommastrephes sagittatus*, Williams (1909) for *Loligo pealii*, and Mercer (1965) for *Illex illecebrosus*. Bidder (1966) states that "it is possible that this may represent a corrective, comparable to the grass occasionally eaten by some carnivorous mammals." It seems more probable that the plant material was ingested inadvertently since the material passes through the digestive system without being digested.

Sand occurred in 26 stomachs, probably having been ingested during the capture of benthic prey. Fields (1965) states that sand was also found in the stomachs of *L. opalescens* that had evidently been foraging on benthic animals. The sand may aid in the preliminary breakdown of food material, aiding the muscular grinding of the stomach.

Change in diet with age has been reported by Mercer (1957), Squires (1957), Akimushkin (1963), and Fields (1965). They state that crustacea supply the majority of the diet in younger squid but diminish in importance until, as the squid mature, fish and other squid make up the largest percentage of the diet. Table 6 shows the percentages of the stomachs with food that contained fish and crustacea in three different size classes of *Rossia*. In the smallest size class, up to 20.0 mm dorsal mantle length, crustacea were present in 100% of the stomach

Table 6. Percentages of Stomachs with Fish and with Crustacea as Related to Size Classes of *R. pacifica*.

	Total Squid			Percentage stomachs with food			Percentage of food-containing stomachs with crustacea			Percentage of food-containing stomachs with fish		
	Dorsal mantle length mm			Dorsal mantle length mm			Dorsal mantle length mm			Dorsal mantle length mm		
	0-20	21-30	31-+	0-20	21-30	31-+	0-20	21-30	31-+	0-20	21-30	31-+
Jan. 1968	11	52	1	9.1	21.2	00.0	100.0	90.9	00.0	00.6	9.1	00.0
Aug. 1968	11	79	26	18.2	22.8	34.6	100.0	83.3	77.8	00.0	27.8	33.3
Oct. 1968	263	148	21	40.7	35.8	33.3	93.5	88.7	85.7	13.1	24.5	00.0
Jan. 1969	17	40	2	5.9	32.5	100.0	100.0	76.9	50.0	00.0	15.4	00.0
Feb. 1969	37	122	25	29.7	42.6	40.0	100.0	96.2	100.0	9.1	5.8	00.0
Mar. 1969	9	126	40	11.1	43.7	47.5	100.0	85.5	89.5	00.0	12.7	15.8
May 1969	8	88	40	25.0	25.0	60.0	100.0	81.8	83.3	00.0	31.8	20.8
Average	..	..	..	20.0	31.9	45.1	99.1	86.7	81.1	4.0	18.2	10.0

that contained food except during October when crustacea were present in 93.5% of the stomachs. Fish were absent from the diet in this size class except for October, 1968 and February, 1969 when fish were present in 13.1% and 9.1% of the stomachs, respectively. Squid with a dorsal mantle length of over 20.0 mm feed to a greater extent on fish than do the younger squid, however crustacea still make up the largest portion of the diet (Table 6). Thus *Rossia* does show a slight change in diet with age although it is not as marked as that in species such as *L. opalescens* and *I. illecebrosus*. This is probably due to the smaller adult size of *R. pacifica* and to the relatively greater availability of crustacea than of suitably small fish in its habitat. However, these stomachs were all taken from animals inhabiting one area and the diet may differ in other localities.

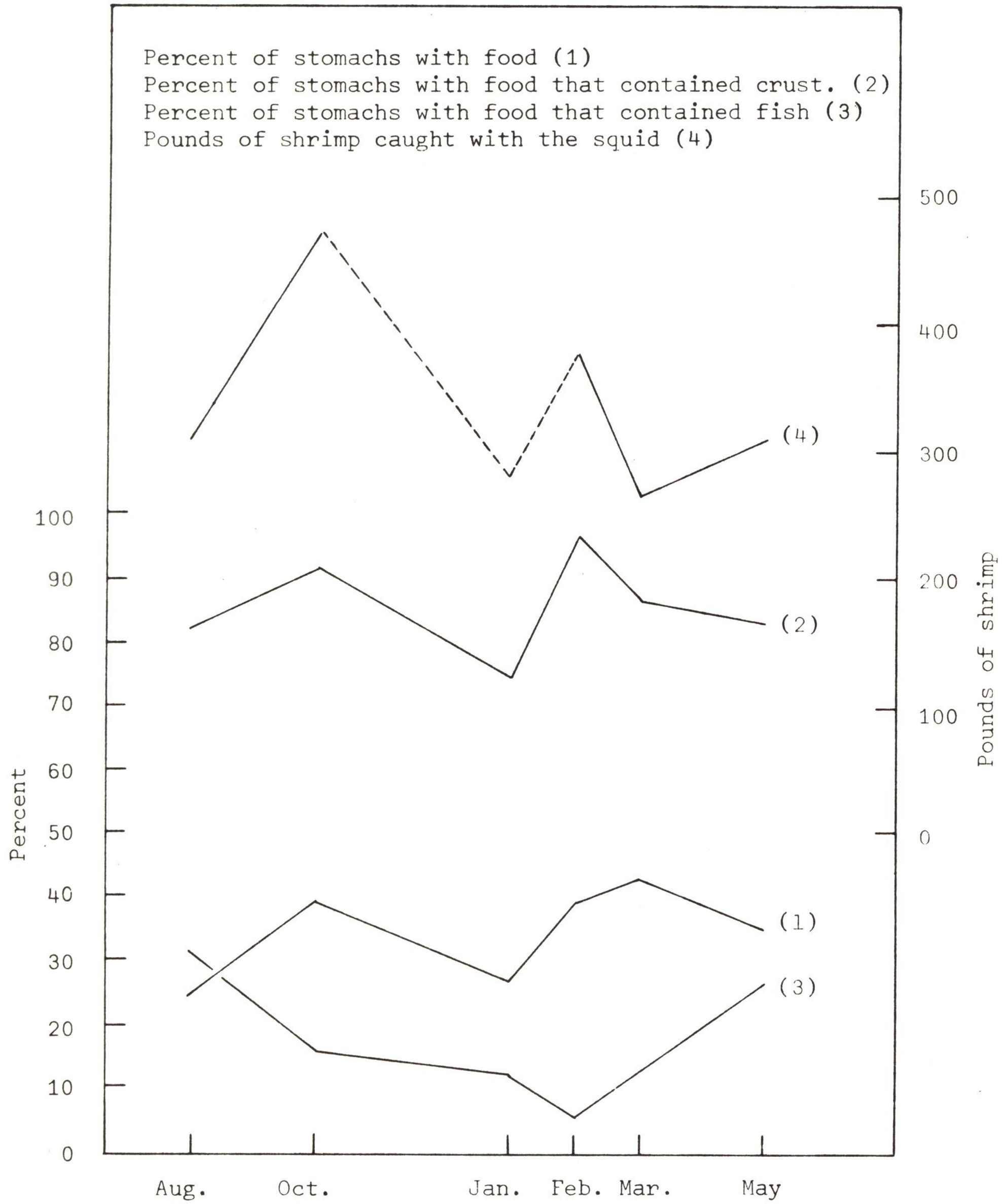
Seasonal Variation in the Diet of *R. pacifica*

There are fluctuations in the proportions of crustacea and fish in the diet of *R. pacifica* during the year (Fig. 23). Because shrimp are a major constituent of the diet, the biomass of shrimp caught during each collecting trip was plotted with the pertinent dietary information (Fig. 23) to see if a relationship existed between the biomass of shrimp present and the amount of crustacea present in the diet.

The total pounds of shrimp caught with the same gear and same amount of fishing effort varied with the time of year from a high of 470

Figure 23. Relationship between biomass of shrimp caught and seasonal variation in the diet of *R. pacifica*.

* Although no shrimp data were collected for January, 1969 previous records for similar years indicate a low biomass corresponding to the value proposed here (Butler, 1969).


Percent of stomachs with food (1)
Percent of stomachs with food that contained crust. (2)
Percent of stomachs with food that contained fish (3)
Pounds of shrimp caught with the squid (4)
Percent
Pounds of shrimp
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
(1)
(2)
(3)
(4)
Aug.
Oct.
Jan.
Feb.
Mar.
May

pounds in October, 1968 to a low of 265 pounds in March, 1969. No data were available for January, 1969; however Butler (1969) states it is likely that due to low temperature there was a low biomass of shrimp present in the area where the *Rossia* were collected.

A direct relationship occurs (except in May, 1969 when it is slightly inverse) between the biomass of shrimp and the percentages of the stomachs with food that contained crustaceans. The percentage of the squid that had food in their stomachs varies from 24% in August, 1968 to 43% in March, 1969. The low percentages of squid with food in August, 1968 and January, 1969 correspond to low percentages of crustacea in the diets and to low biomasses of shrimp present (Fig. 23).

An inverse relationship exists (except in January, 1969) between the percentage of the stomachs that contained crustacea and those that contained fish. In August, 1968 and May, 1969 relatively high percentages of the stomachs contained fish, 33% and 27% respectively. *Rossia pacifica* appears to rely more heavily on fish for food when the shrimp biomass is low. This is most marked in August, 1968 and May, 1969 (Fig. 23).

Predators

Knowledge of the position of *R. pacifica* in the food web is not complete until *Rossia* is considered as a source of food for other

organisms in the food chain. A number of predator and possible predator species were caught in the trawls at Cape Lazo Gully. These included Hake (*Merluccius productus*), Lingcod (*Ophiodon elongatus*), Black Cod (*Anoplopoma fimbria*), Gray Cod (*Gadus macrocephalus*), Pacific Dogfish (*Squalus suckleyi*), Ratfish (*Hydrolagus colliei*), Whiting (*Theragra chalcogrammus*), and the cephalopods *Loligo opalescens*, *Berryteuthis magister*, and *Octopus dofleini*. No stomach analyses were done on these species but Clemens and Wilby (1947) state that squid have been found in the stomachs of Hake, Lingcod, and Dogfish; Fields (1965) states that the remains of *R. pacifica* have been found in the stomachs of *L. opalescens*.

Although Clemens and Wilby do not refer to the species of squid it may be inferred that when such fish come into contact with populations of *Rossia* that they feed on them. *Rossia* is likely to be preyed upon by a considerable number of benthic and nektobenthic fishes but at the present time little is known about these associations.

The author has observed *O. dofleini* feeding on *R. pacifica* in an aquarium. *Rossia pacifica*, as stated earlier, feed to some extent on one another.

Reproductive Biology

The reproductive biology of *R. pacifica* was studied in the Cape Lazo population. The aspects considered are concerned primarily with growth and maturation of the gonads and the inference of spawning time.

Description of the Reproductive Systems and Criteria for Maturity

In *Rossia* a single median ovary or testis is present. Its location and relationship to the viscero-pericardial coelom are similar to those described for *Sepia officinalis* by Tompsett (1939). "The posterior part of the viscero-pericardial coelom is occupied by the gonad. Both the ovary and the testis open into the coelom, and in both sexes the genital duct opens from the ventral wall of the coelom, slightly on the left side towards the posterior end. Thus the genital duct is a continuation of the coelomic cavity." The accessory reproductive structures in *Rossia*, as in the other sepioids, are unpaired and are located on the left side of the animal.

Female

The ovary develops from the dorsal wall of the posterior part of the viscero-pericardial coelom. Tips of multibranched twig-like outgrowths containing blood vessels are sites for egg development.

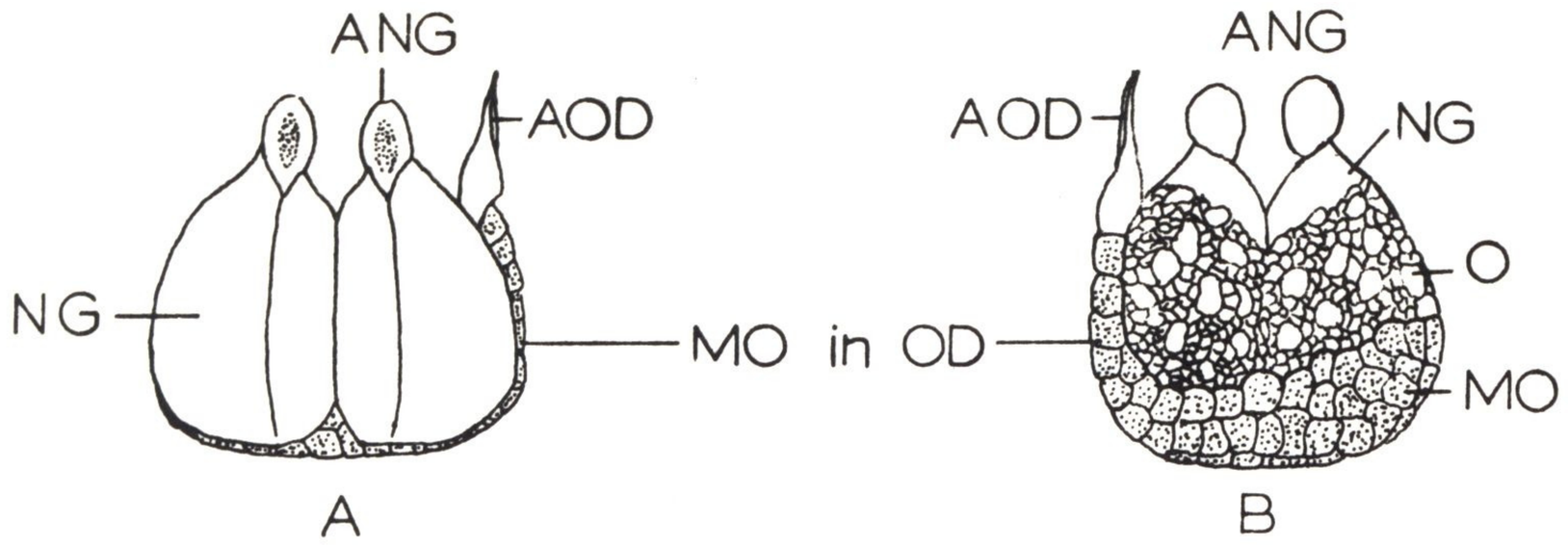
The immature eggs are surrounded by a layer of follicle cells that

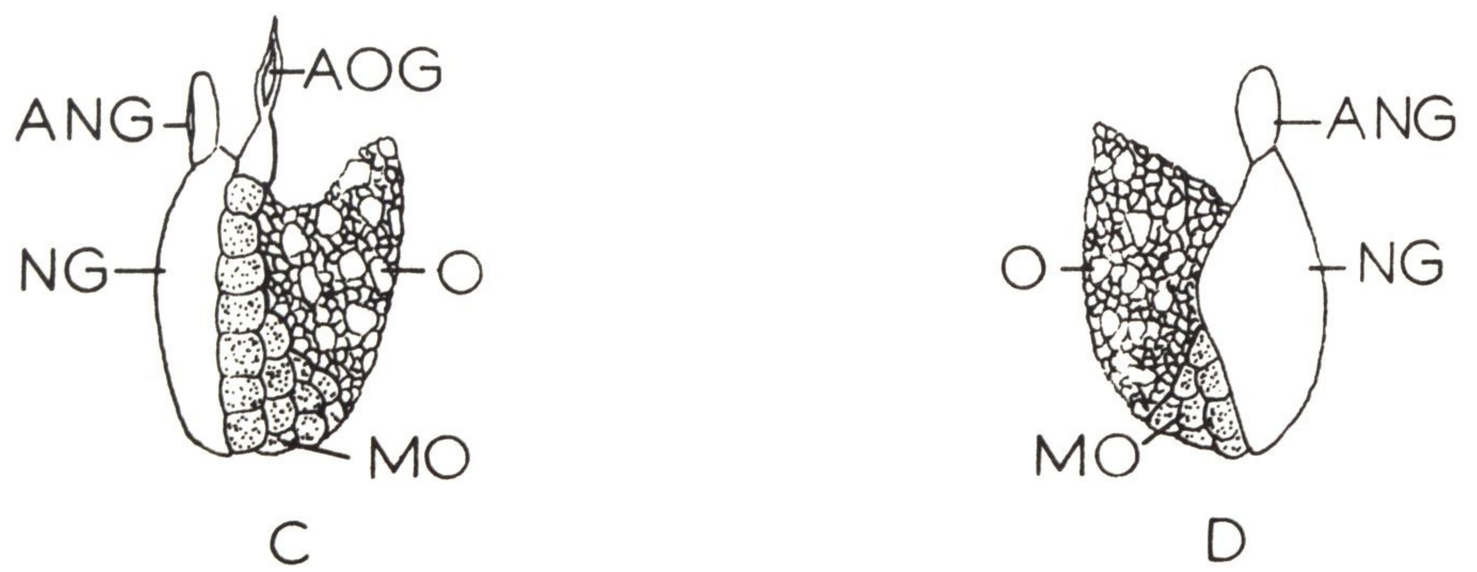
give the egg a crenated appearance. During oogenesis the contents of these cells are absorbed by the eggs. As they increase in size within the coelom the eggs come to occupy the greatest part of the space within the posterior half of the mantle (Fig. 24 A, B, C, and D). Upon ripening the eggs attain a diameter of 4-5 mm and become smooth and glossy. They lose attachment within the ovary and pass out of the coelom into the membranous oviduct where they remain until spawning occurs.

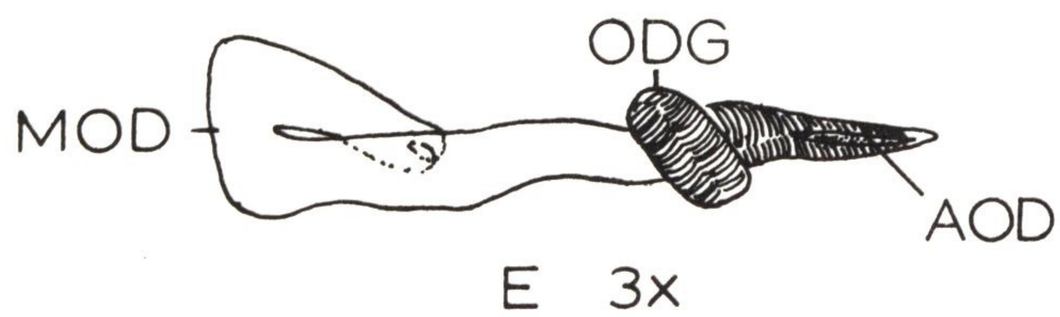
The single oviduct consists posteriorly of a delicate, membranous "J" shaped tube (Fig. 24 E and F) that lies between the viscero-pericardial coelom and the left nidamental gland (Fig. 24 B and C). From its opening out of the coelom, the tube enlarges in diameter and extends posteriorly where it makes a sharp bend on itself. From this point it narrows and proceeds anteriorly. In the empty state the transparent membranous oviduct is flattened and plicate. At its anterior end it enters the oviducal gland (Fig. 24 E and F). The lumen of the gland contains two bands of leaflets. One surrounds the aperture of the membranous oviduct while the second, more elongated leaflet band is found at the anterior end of the gland and ends near the external orifice of the female reproductive system.

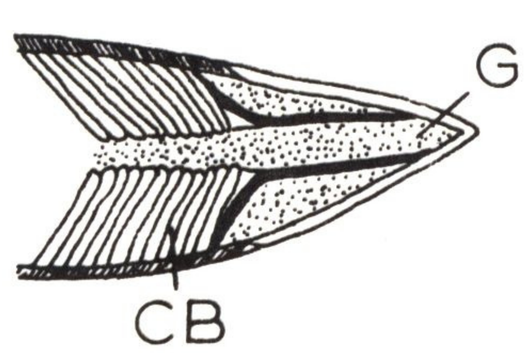
The anterior leaflet band incompletely surrounds the lumen of the gland, and where the leaflets are absent a smooth groove exists (Fig. 24 G). At the anterior end of the oviduct this groove lies opposite the external orifice. The orifice is a longitudinal slit

Figure 24. Female reproductive system: (A) ventral view, (B) dorsal view, (C) right side view, (D) left side view, (E) ventral view of oviduct, (F) dorsal view of oviduct, (G) longitudinal view of the end of the oviduct showing the position of the groove.


ANG
AOD
NG
MO
A
ANG
AOD
NG
O
in OD
MO
B


AOG
ANG
NG
O
MO
C
ANG
O
NG
MO
D


ODG
MOD
AOD
E 3x
ODG
MOD
F 3x


G
CB
G 20x

encompassed by a lip along each side that may serve to close the orifice.

The nidamental glands change from small oblong structures in immature females to large ovoid bodies in mature animals. They are located ventrally in the mantle cavity and extend through the posterior two-thirds of the cavity in a mature specimen (Fig. 24 A,B, C, and D). In mature individuals each gland is approximately one half as wide as it is long. The dorsal surfaces of the glands are flattened and lie against the oviduct and ovary. The lumen of each gland opens near an accessory nidamental gland which is located just dorsal and anterior to the nidamental gland. The openings of these glands are adjacent to the external opening of the oviduct.

The presence of ripe eggs in the oviduct was used as the criterion for maturity in the females.

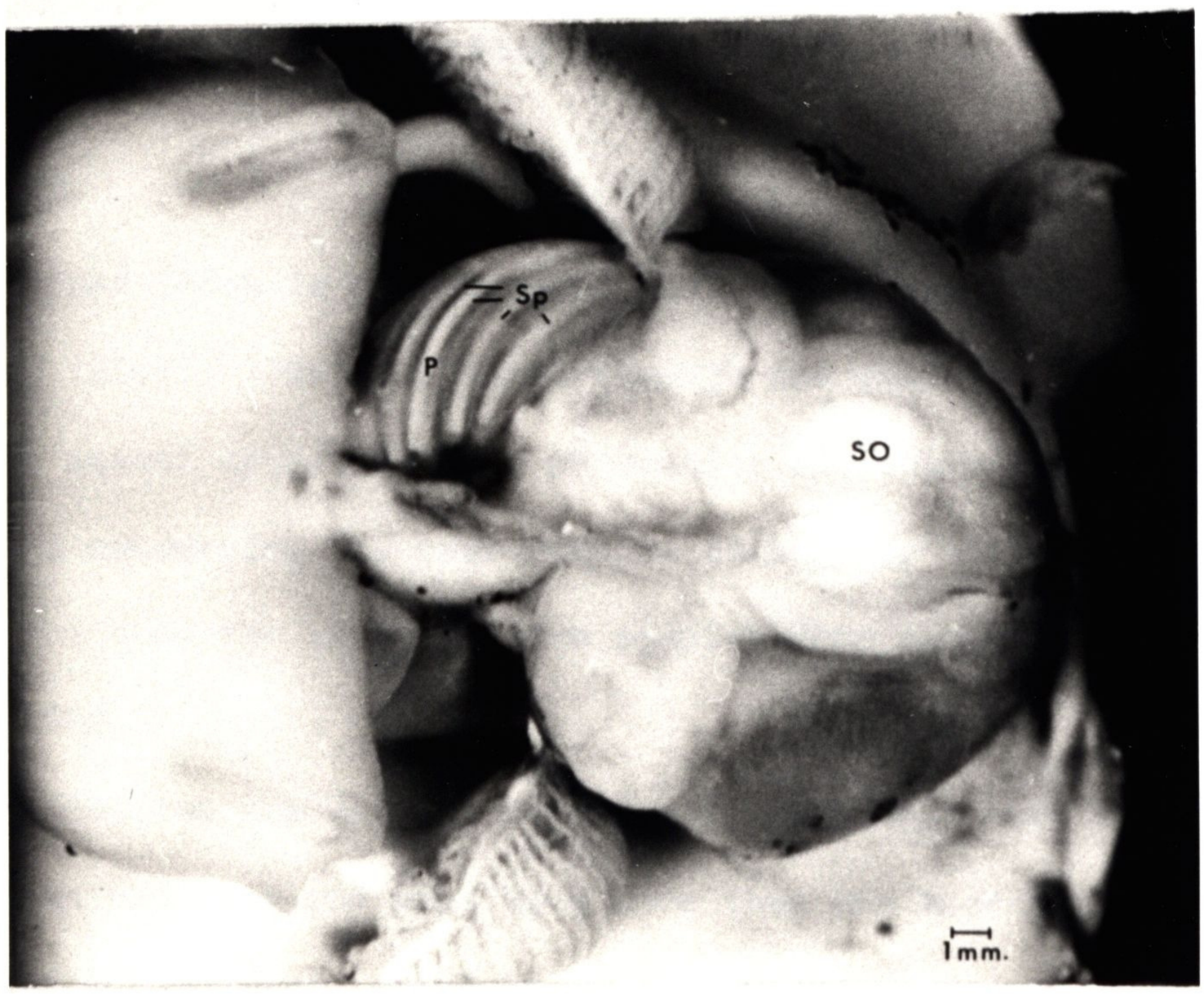
Males

The testis is similar to that described by Tompsett (1939) for *Sepia officinalis*. "The testis is a large compact body which is attached to the posterior-dorsal wall of the viscero-pericardial coelom ... It empties into the coelom by an aperture on its ventral side." The male genital duct is continuous with the coelom and consists of the vas deferens, spermatophoric organ, Needham's sac, and the penis (Fig. 25 A and B). The vas deferens carries sperm to the spermatophoric organ where the spermatophores are produced. After manufacture the spermatophores are packed into Needham's sac where they are stored until mating.

Figure 25. Male reproductive system: (A) dorsal view and (B) ventral view.



25 A



25 B

The presence of spermatophores in Needham's sac was used as the criterion for sexual maturity in the males.

Spermatophore Length Index (SpLI)

The spermatophore length index (Fig. 26) is relatively constant with increasing mantle length, expressing an isometric growth relationship between the spermatophore length and the mantle length.

Sperm Reservoir Index (SpRI)

The sperm reservoir index (Fig. 27) increases sharply between spermatophores of 6 mm and 10 mm length. In spermatophores over 10 mm the sperm reservoir index increases more gradually. The sperm reservoir length therefore increases relative to the total length of the spermatophore with increasing spermatophore size.

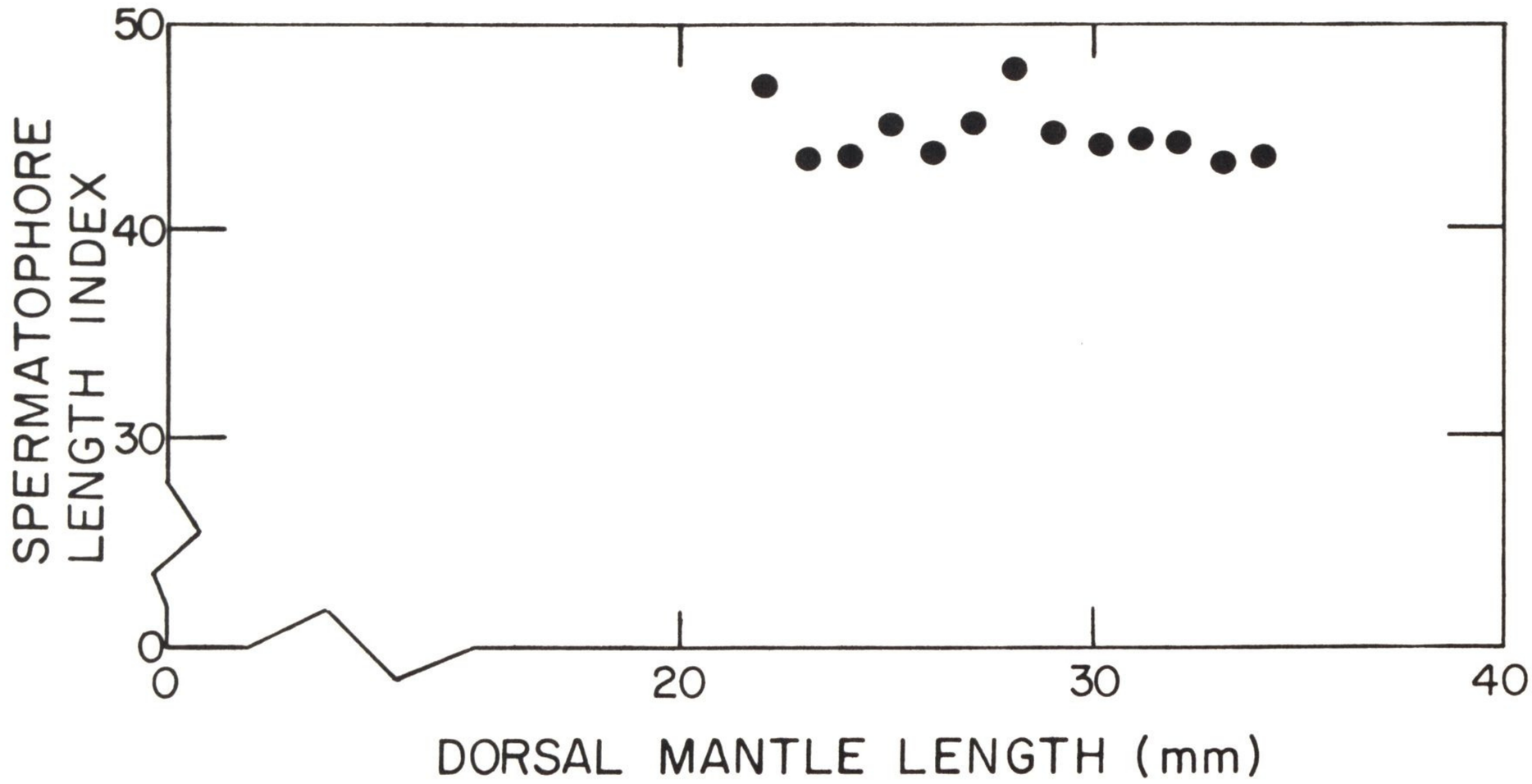
Gonad Index

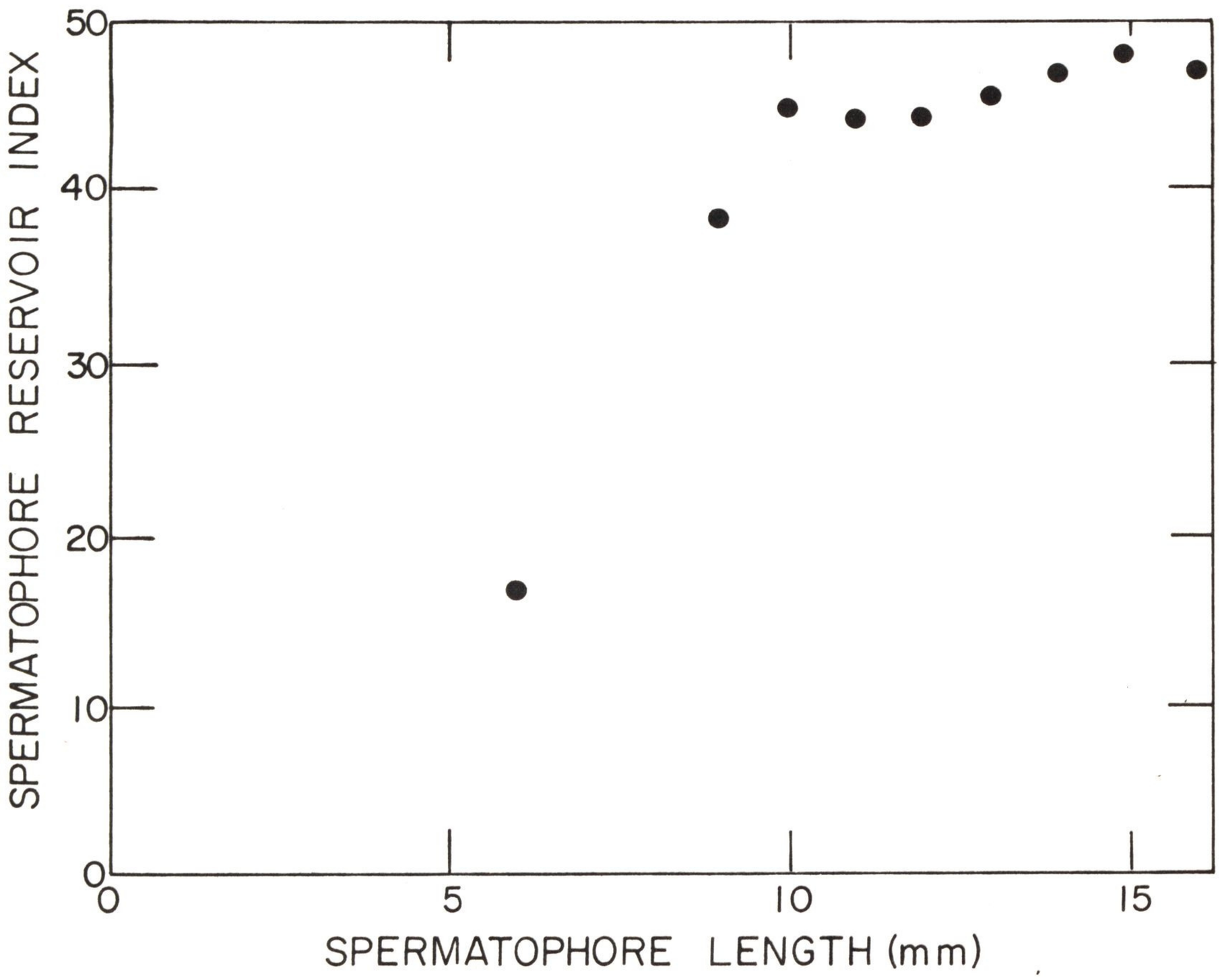
The gonad index is a measure of the reproductive state of a population (Giese, 1959). Plotted through the year the gonad index traces the annual cycle of gonad maturation and spawning thus providing information concerning the reproductive biology of the species. Gonad indices were done for the Cape Lazo samples from August, 1968 through October, 1969.

Gonad indices are usually done for species that have a life span of more than one year and thus have more than one breeding cycle. In the case of *R. pacifica*, which has a life span of one year, increasing

Figure 26. Spermatophore Length Index: Relationship of spermatophore length to mantle length. Each point represents the mean SpLI for the animals at that mantle length.

Figure 27. Sperm Reservoir Index: Relationship of sperm reservoir length of spermatophore length. Each point represents the mean SpRI for the spermatophores of that length.


SPERMATOPHORE LENGTH INDEX
50
40
30
0
0
20
30
40
DORSAL MANTLE LENGTH (mm)


SPERMATOPHORE RESERVOIR INDEX
50
40
30
20
10
0
0
5
10
15
SPERMATOPHORE LENGTH (mm)

gonad indices indicate gonad growth and maturation. Decreasing indices may be caused either by an increasing proportion of small immature animals entering the population sampled or by the spawning out of the adults.

Gonad indices were done for testes, for ovaries, and for one nidamental gland from each female. These were weighed to the nearest milligram using a Mettler balance. Wet weights were determined after the materials had been blotted lightly with filter paper. The material was then dried to a constant weight in an oven at a temperature of 90°C and weighed again. Individual squid that had organs with a wet weight of less than 0.001 gram were not included. This excluded males under 15.0 mm and females under 19.0 mm mantle length.

The wet and dry weights were indexed with the mantle lengths of the specimens and multiplied times 100. The mantle length was used instead of the whole weight of the animals. The mantle length is a satisfactory reference point since the gonad indices are relative measures.

The dry weight indices are considered more significant than the wet weight indices and are referred to exclusively in the following discussion. However, each wet weight index is shown on the same figure with the corresponding dry weight index. These will serve as references for further studies where conditions may not permit doing dry weight indices.

Ovary Index

The ovary and nidamental gland indices for August and October, 1968 were each separated into one for breeding animals of the 1967-1968 year class and one for the immature animals of the 1968-1969 year class. The indices were not split in the October, 1969 sample because the animals in the 1969-1970 year class were too small to be considered (see above).

The dry weight index (Fig. 28) of the 1967-1968 year class increases from 0.60 in August to 1.50 in October, 1968 indicating a further growth of the ovaries in the later spawning animals. The ovary index of the 1968-1969 year class is 0.02 in August, 1968 and remains relatively unchanged through January, 1969 by which time the average size of the females is 23.8 mm. The index increases slowly to 0.34 in May, then rises more rapidly to 0.94 in October, 1969. An increased rate of ovarian growth therefore begins when the females reach a size of approximately 24.0 mm mantle length and continues until spawning occurs.

Nidamental Gland Index

The dry weight nidamental gland index (Fig. 29) of the 1967-1968 year class increases from 0.45 in August to 0.53 in October, 1968. That of the 1968-1969 year class remains relatively constant between August, 1968 and January, 1969, increasing only from 0.01 to 0.02 during this time. From January on the index increases

Figure 28. Ovary index.

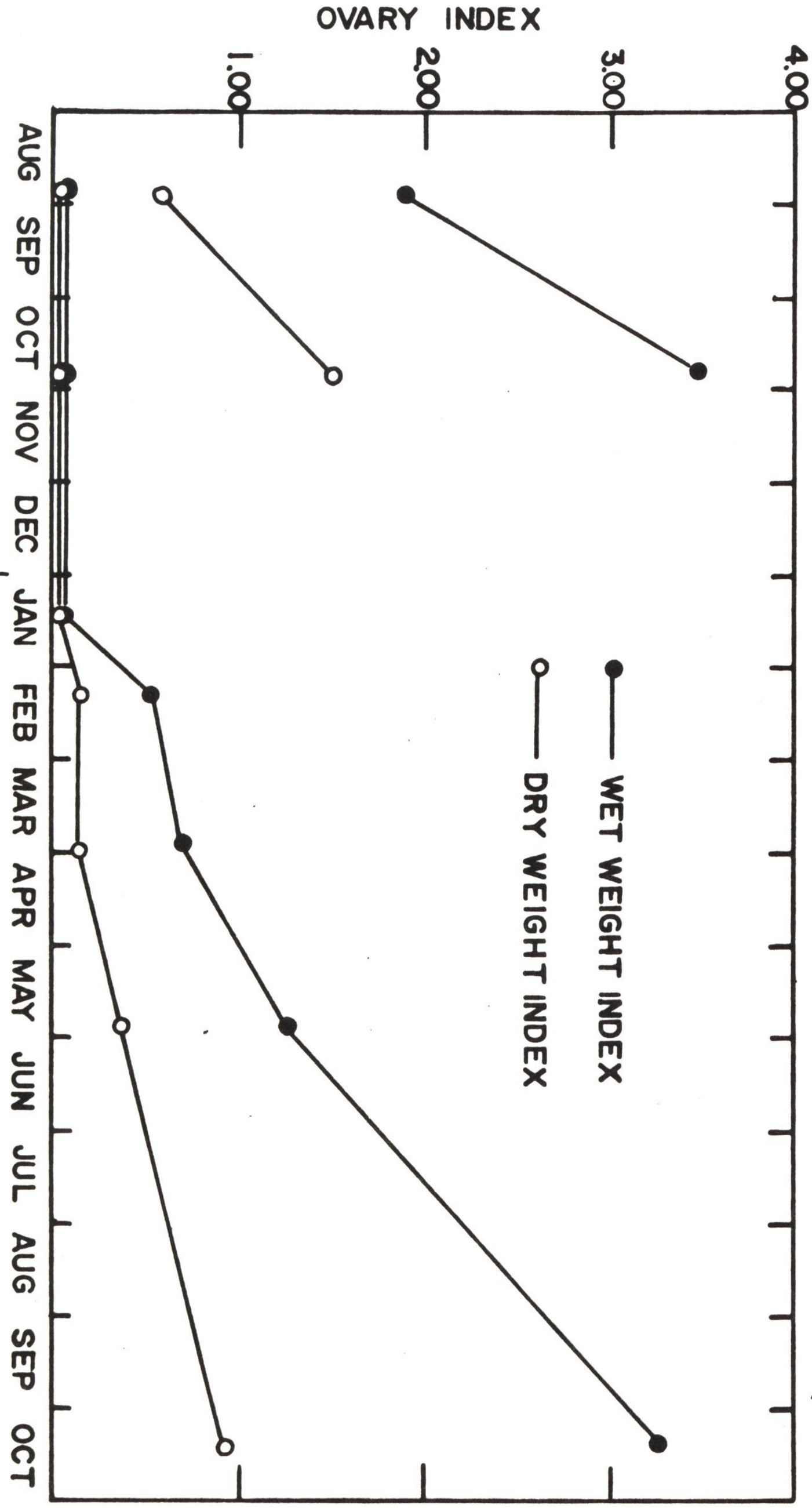
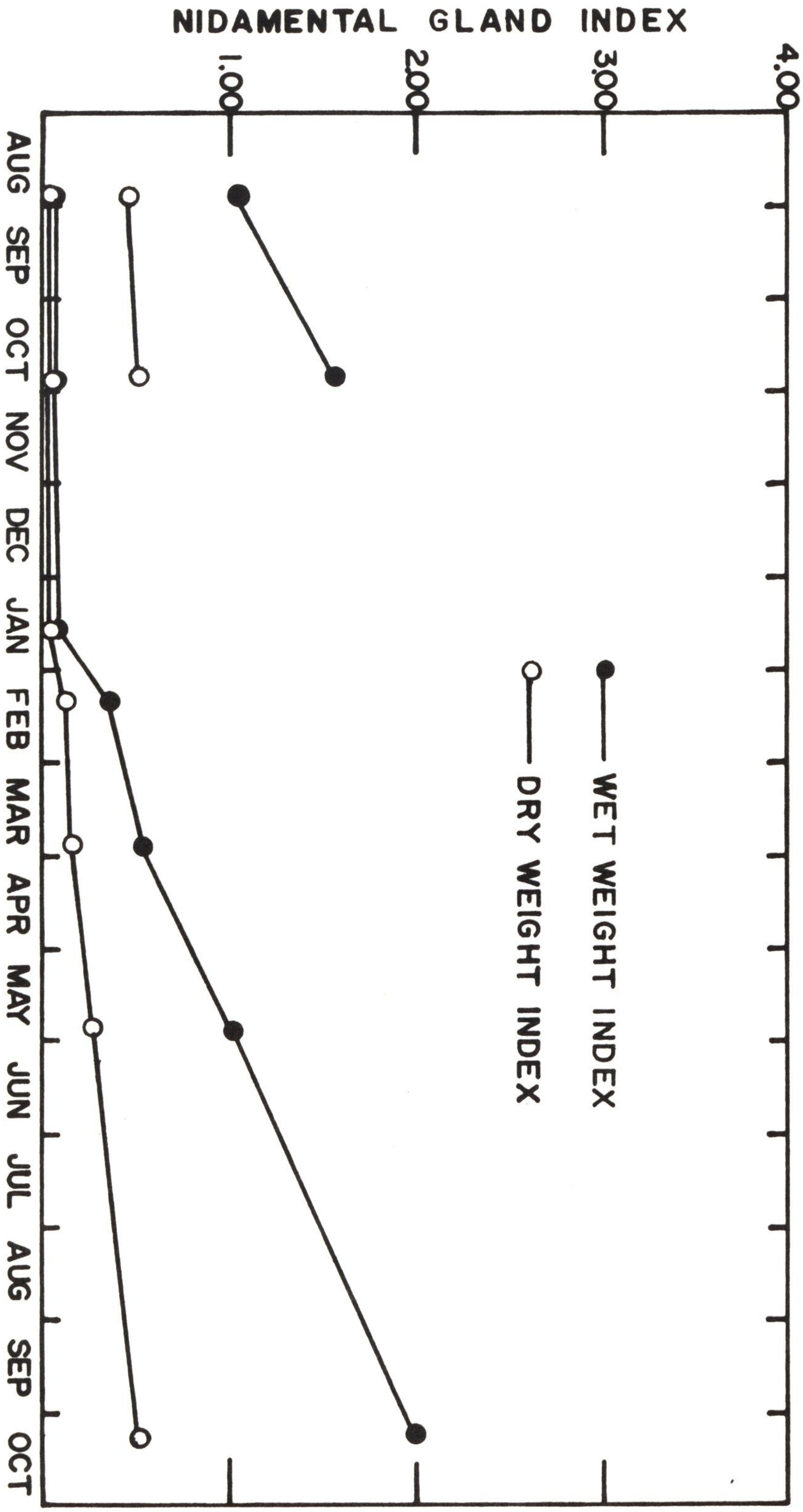

OVARY INDEX
1.00
2.00
3.00
4.00
AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT
1968
1969
WET WEIGHT INDEX
DRY WEIGHT INDEX

Figure 29. Nidamental gland index.


NIDAMENTAL GLAND INDEX
1.00
2.00
3.00
4.00
AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT
1968
1969
- WET WEIGHT INDEX
- DRY WEIGHT INDEX

steadily to 0.55 in October, 1969.

The ovary and nidamental gland indices thus show similar growth patterns; the majority of growth in both cases takes place after the animals have reached a size of approximately 24.0 mm mantle length. The relative sizes both of the ovary and of the nidamental glands increases until spawning occurs.

Testis Index

The gonad index of the testis dry weight (Fig. 30) increases from 0.09 in August, 1968 to 0.15 in March, 1969 indicating a period of testis growth and maturation. The index then decreases to 0.07 in October, 1969 due to the release of sperm from the testis. This does not indicate mating but instead is due to an increase in the production of spermatophores. The average number of spermatophores per spermatophore containing squid correlates inversely with the testis dry weight index (Fig. 30 and Table 7). In August, 1968 the average number of spermatophores is high, 33.6, and the testis index is low, 0.09, while in March, 1969 the average number of spermatophores is low, 18.4, and the testis index is high, 0.15. Between March and October, 1969 the average number of spermatophores increases to 32.0 and the testis index decreases to 0.07. A decreasing testis index is therefore related to the formation of spermatophores which accumulate until mating occurs.

Figure 30. Testis index and average number of spermatophores per spermatophore containing male.

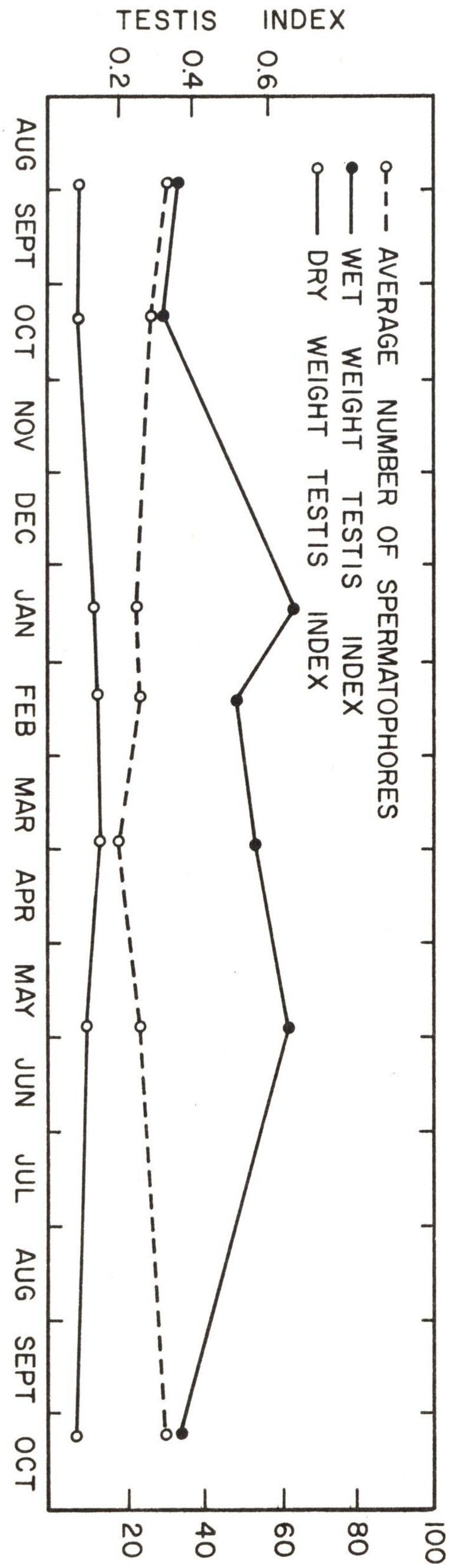

TESTIS INDEX
0.2
0.4
0.6
AVERAGE NUMBER OF SPERMATOPHORES
WET WEIGHT TESTIS INDEX
DRY WEIGHT TESTIS INDEX
AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEPT OCT
20
40
60
80
100
AVG. NUMBER OF SPERM-
ATOPHORES PER SPERM-
ATOPHORE CONTAINING
MALE

Table 7. Numbers of Spermatophores in Males From Cape Lazo Gully.

Sample	Number of Males with Spermato-phores	Maximum Number of Spermato-phores Present in any one Individual	Minimum No. of Spermato-phores Present in any one Indivi-dual	Average No. of Spermato-phores Present in any one Indivi-dual
Aug. 1968	32	87	9	33.6
Oct. 1968	37	77	1	28.9
Jan. 1969	3	53	3	23.5
Feb. 1969	27	68	1	24.2
Mar. 1969	39	44	1	18.4
May 1969	56	60	3	24.5
Oct. 1969	27	78	7	32.0

Spermatophores

The percentage of males that possess spermatophores changes over the year (Fig. 31 and Table 8). The percentage decreases from 50.0 in August, 1968 to 12.5 in January, 1969. This is due to the dying off of the breeding population and the appearance of immature animals of the 1968-1969 year class. The percentage increases from 12.5 in January to 70.0 in May, 1969 coinciding with the maturation of this year class. Between May and October, 1969 the percentage decreases to 48.3, corresponding to the dying off of the 1968-1969 breeding population and the appearance of immature animals of the 1969-1970 year class. These changes are therefore related to the yearly reproductive cycle of the population.

The percentage frequency of spermatophore containing males in each millimeter mantle length size class (Fig. 32) shows a rapid increase from 7.7 in the 22 mm size class to 89.5 in the 28 mm class. Between the 28 and 31 mm size classes there is little variation in the percentage frequency, ranging from 88.9 in the 30 mm size class to 94.5 in the 29 mm size class. There is a gradual decrease in the percentage frequency to 66.7 in the males over 31 mm. This decrease may be due to the presence of partially spawned out males in these size classes. The percentage frequency thus indicates a high proportion of spermatophore containing males in size classes of 28 mm and over.

Whenever spermatophores were present in Needham's sac they were

Figure 31. Percentage of males with spermatophores for each sample.

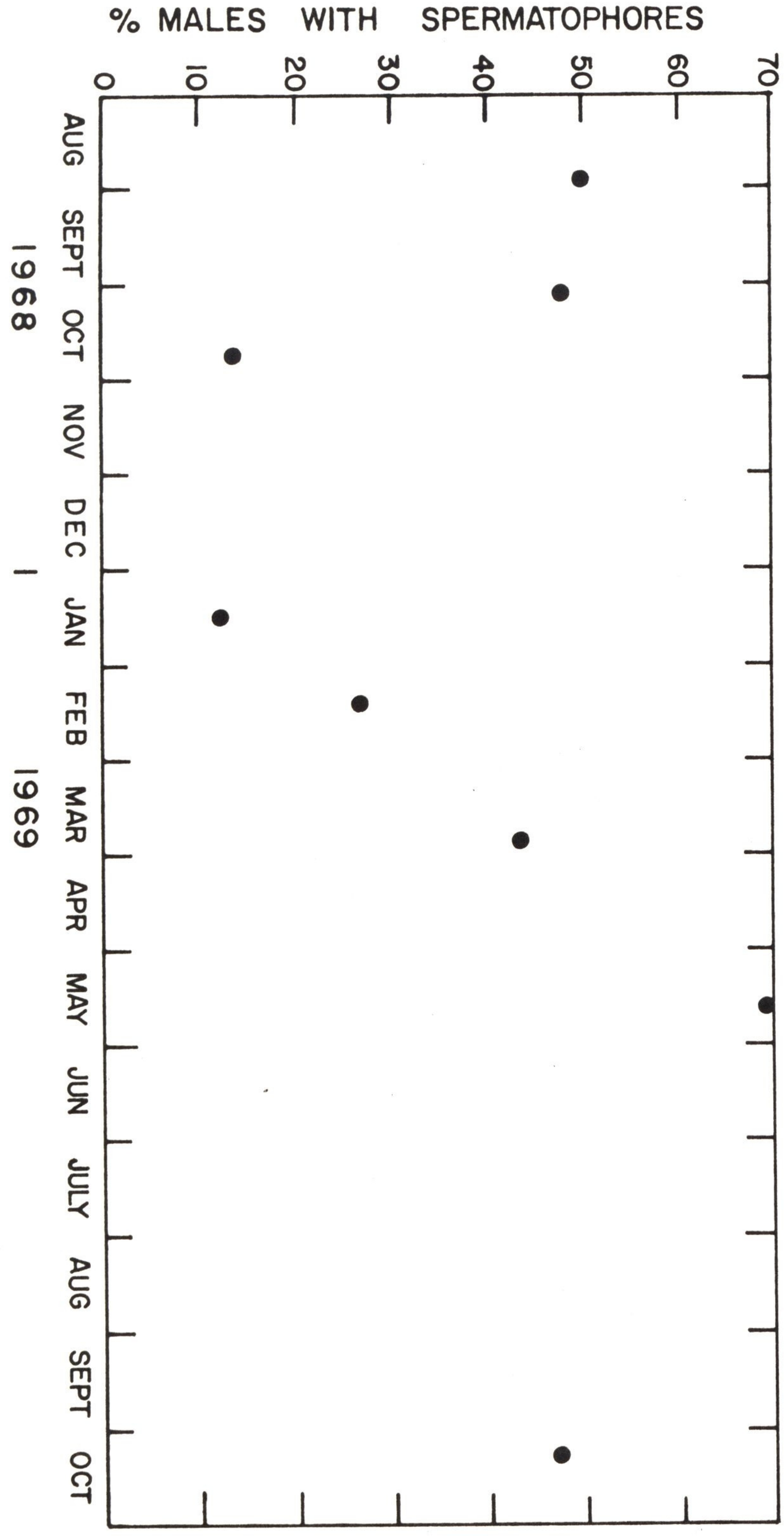
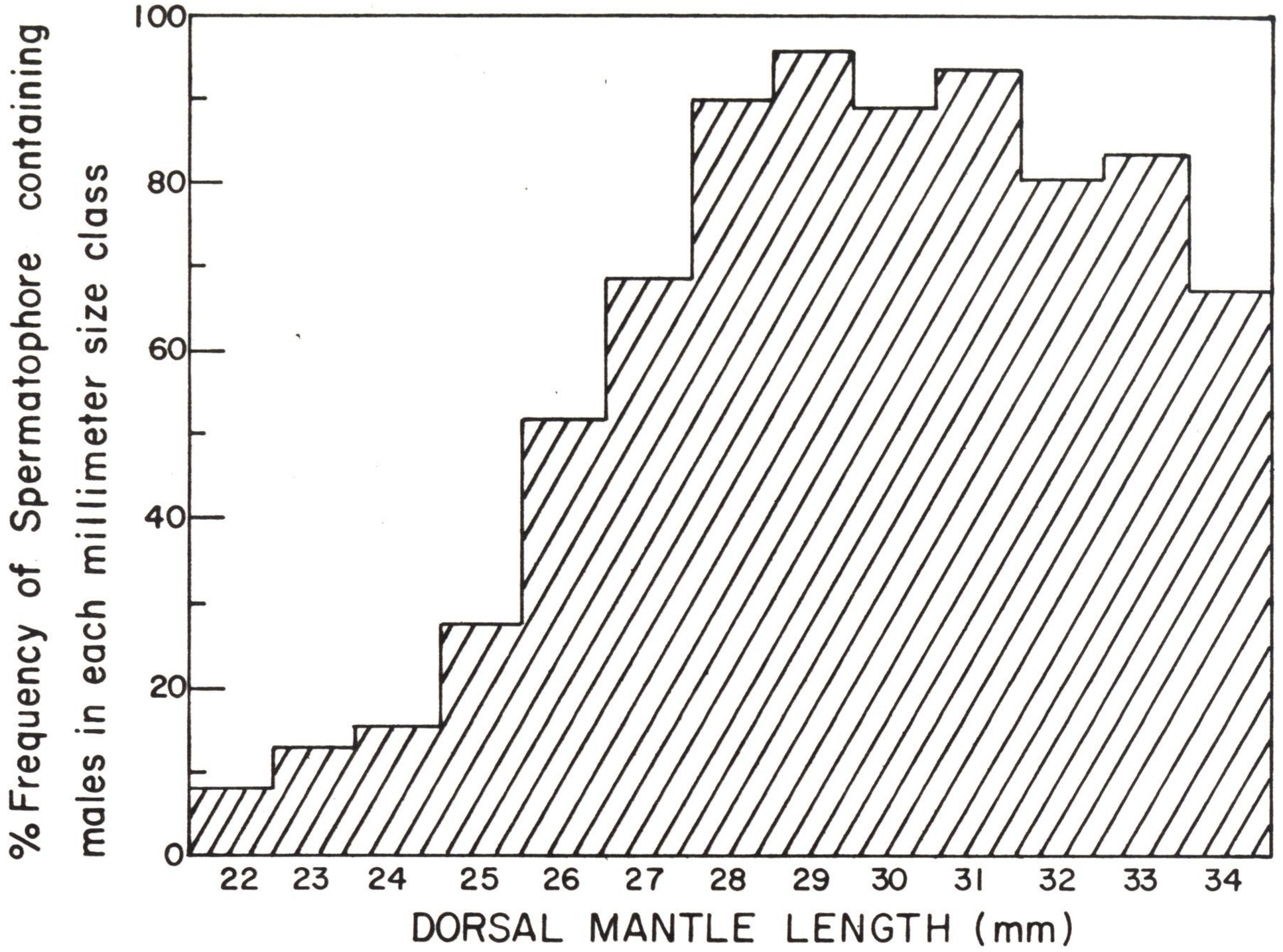

% MALES WITH SPERMATOPHORES
0
10
20
30
40
50
60
70
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
OCT
1968
1969

Table 8. Numbers and Percentage of Males With Spermatophores For Each Sample From Cape Lazo Gully.

Sample	Total Males	Number of Males With Spermato-phores	% Total Males With Spermatophores
Aug. 1968	64	32	50.0
Oct.	251	37	14.7
Jan. 1969	25	3	12.5
Feb.	92	27	29.3
Mar.	90	39	43.3
May	80	56	70.0
Oct.	56	27	48.3

Figure 32. Percentage frequency of spermatophore containing males in each millimeter size class for all seven samples.


% Frequency of Spermatophore containing males in each millimeter size class
100
80
60
40
20
0
22 23 24 25 26 27 28 29 30 31 32 33 34
DORSAL MANTLE LENGTH (mm)

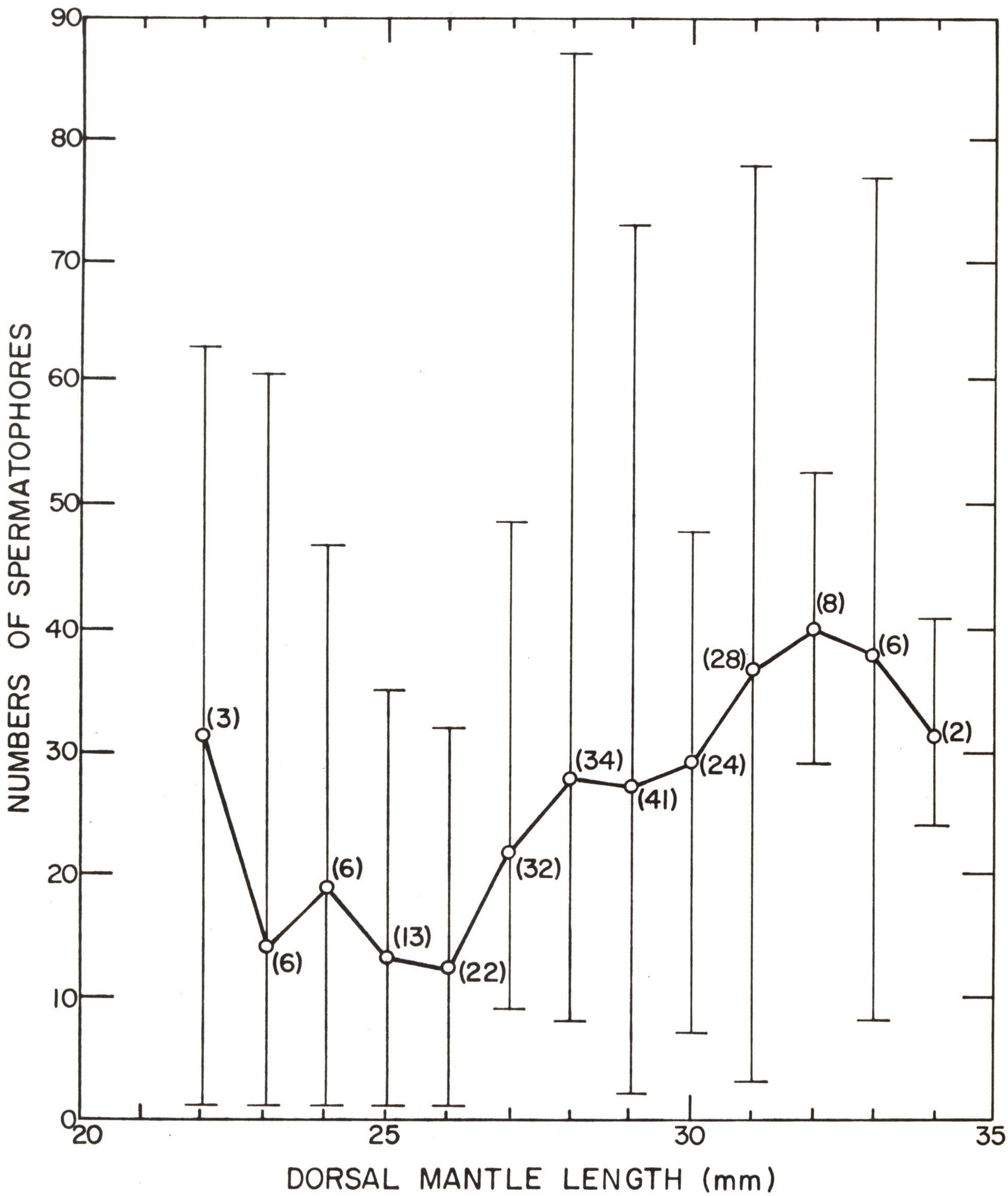
counted. The results (Fig. 33) show that the numbers of spermatophores varied greatly in individuals of each millimeter size class. The greatest number of spermatophores present in any one individual was 87 in a 28 mm specimen. These variations may be due either to a difference in the initiation and/or rate of spermatophore formation, or to mating with release of some spermatophores. It is likely that both phenomena occur; however, the former probably has a greater influence on animals in size classes less than 28 mm while the latter has a greater influence on animals 28 mm and larger. In size classes between 22 and 32 mm there is a general increase in the average number of spermatophores per squid. The high average 32.3, in the 22 mm size class is due to the presence of 63 spermatophores in one, evidently precocious, specimen. In size classes over 32 mm the average numbers of spermatophores per squid decreases, again, probably due to the presence of spawned out animals.

The data obtained suggests that spermatophore formation in *R. pacifica* may occur continually possibly limited by some physiological control or by depletion of the testis. Further studies will have to be done in this area to clarify the situation.

Mating

A pair of *R. pacifica* were observed mating in the aquarium on August 19, 1969. The squid were already in the copulatory position when first observed; thus no record was obtained of courtship be-

Figure 33. Maximum, minimum, and mean numbers of spermatophores present in Needham's sac for each millimeter size class of *R. pacifica*. Combined data of all seven Cape Lazo samples.


NUMBERS OF SPERMATOPHORES
0
10
20
30
40
50
60
70
80
90
20
25
30
35
DORSAL MANTLE LENGTH (mm)
(3)
(6)
(6)
(13)
(22)
(32)
(34)
(41)
(24)
(28)
(8)
(6)
(2)

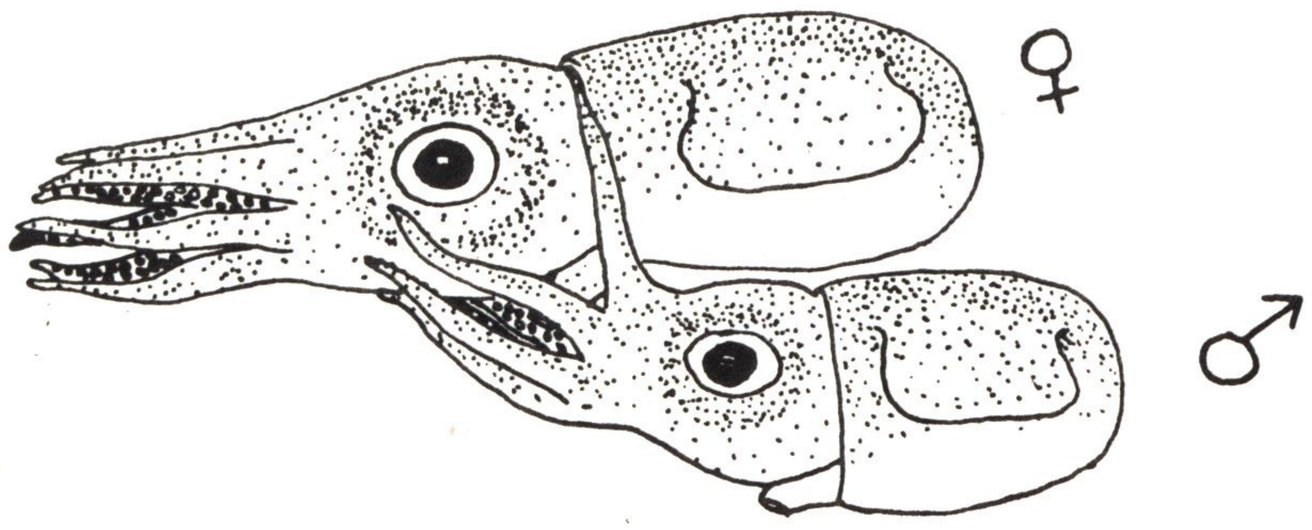
haviour. The male was positioned ventrally and slightly posterior to the female (Fig. 34). The female was firmly held by the male's second, third, and ventral pairs of arms. The male's dorsal hectocotylized pair of arms were wrapped over the openings of the pallial cavity of the female. The left dorsal arm held four spermatophores that were in the process of being transferred to the pallial cavity of the female. These were inserted into the nuchal valve pocket (Figs. 3 and 21).

This observation is in conflict with the assumption made by Racovitza (1894) that *Rossia* mates in the same manner as other sepiolids. According to Racovitza the male sepiolid turns the female upside down when mating with her. It is also of interest to note that the female *Rossia* was very passive during copulation and did not show the violent reactions described by Racovitza for other sepiolids.

Spawning Season

The gonad indices and the size changes of the animals in the population (see section on Population) indicate that the most intense period of spawning occurred during August, September, and October, in 1968. The spawning became more sporadic after this time as indicated by the presence of a low number of large animals present in January and February and by a small number of progeny in the February sample. Because only one sample was done in the fall of 1969 it is difficult to comment on the breeding season other than to

Figure 34. Mating position of *Rossia pacifica*.



compare it to that of 1968. The presence of a higher proportion of mature to immature individuals and the higher gonad indices for the October, 1969 as compared to the October, 1968 sample tend to indicate that the spawning season was later in 1969 than in 1968.

Spawning seasons have been reported upon for a number of species of squid by various authors (Table 9). These seasons last from one to six months depending on the species and the environmental conditions.

Akimushkin (1963) reports that spawning in the Kurile area (i.e. southern Kamchatka, the Kurile Islands, the northern part of the Sea of Japan, the Sea of Okhotsk, and the Bering Sea) does not take place until the late summer or the early fall in contrast to spawning in spring and early summer in other temperate parts of the world's oceans. Akimushkin states the reason for this is the late warming of the waters of the Kurile area. Choe (1966) also suggests that warmer water temperatures act as a stimulus for spawning. Fields (1965) and Choe (1966) report that the elapsed time from egg laying to hatching is appreciably decreased at higher temperatures. A consequence of this phenomenon may be a higher survival rate of the developing squid due to the shortened period of development.

The average bottom temperature at Cape Lazo Gully during the sampling period (see section on Habitat) increases during the fall coinciding with the spawning season and may possibly serve as a stimulus to initiate spawning.

Table 9. Spawning Seasons for Various Species of Squids as Reported by Other Authors

Author	Species	Spawning Season	Length of Spawning Season
Choe (1966)	*Sepia esculenta*	March - June	4 months
	Sepia subaculeata	May - June	2 "
	Sepiella maindroni	May - June	2 "
	Sepioteuthis lessonia	May - mid-June	1.5 "
Rao (1965)	*Sepioteuthis arctipinnis*	Jan. - late June	6 "
Pfeffer (1912)*	*Dosidicus gigas*	Feb. - March	2 "
Ritchie (1920)* Stephen (1944)* Gillespie (1953)*	*Ommastrephes sagittatus*	Feb. - March	2 "
Fields (1965)	*Loligo opalescens*	April - July	3 "
McGowan (1954)	*Loligo opalescens*	February	
Verrill (1882)	*Loligo pealei (sic)*	Late spring and summer	
Tinbergen and Verwey (1945)	*Loligo vulgaris*	Late spring and summer	
Squires (1957)	*Illex illecebrosus illecebrosus*	Early summer	

* From Akimushkin (1963)

Increasing day length may influence the spawning season. Whereas the majority of the species cited in Table 9 spawn with increasing day length *Rossia* spawns during a period of decreasing day length. *Rossia*, because of its benthic habitat, may not be as affected by light as other, more pelagic, species. This is not unique, however, because Fields (1965) found a major secondary spawning peak for *L. opalescens* in November.

The average bottom salinity during the sampling period did not vary appreciably (Fig. 17) and therefore probably had little influence upon the spawning season. Further studies will have to be made concerning the spawning stimulus before definite conclusions can be made.

Fate of Spawning Animals

The majority of squid species that have been studied die after spawning. This has been demonstrated for male and female *Loligo opalescens* by McGowan (1954), Fields (1950 and 1965), and Hobson (1968); for female *L. pealii* by Arnold (1962); for male and female *Ommastrephes sloani pacificus* and male and female *Sepia esculenta* by Hamabe (1963) and for female *Sepioteuthis sepioidea* by Arnold (1965). Roper (1965) reports that this phenomenon was not observed for spawning *Doryteuthis plei*.

The fate of spawning populations may be investigated in a number of ways; 1) by actual observation of the spawning animals, 2) by the presence of moribund animals during spawning, and 3) by observing

the fluctuations in the size composition of the population.

The specimens of male and female *R. pacifica* observed mating in the aquaria were found dead a few days after the mating occurred. The female had deposited eggs by this time. Other *Rossia* taken at the same time and held under similar conditions survived three times longer than the mated pair. Additional evidence for death after spawning in *R. pacifica* is a decrease in the mean size of the males and females during the summer and fall (see section on Population). This disappearance of the larger members of the population again suggests the dying off of spawned out individuals.

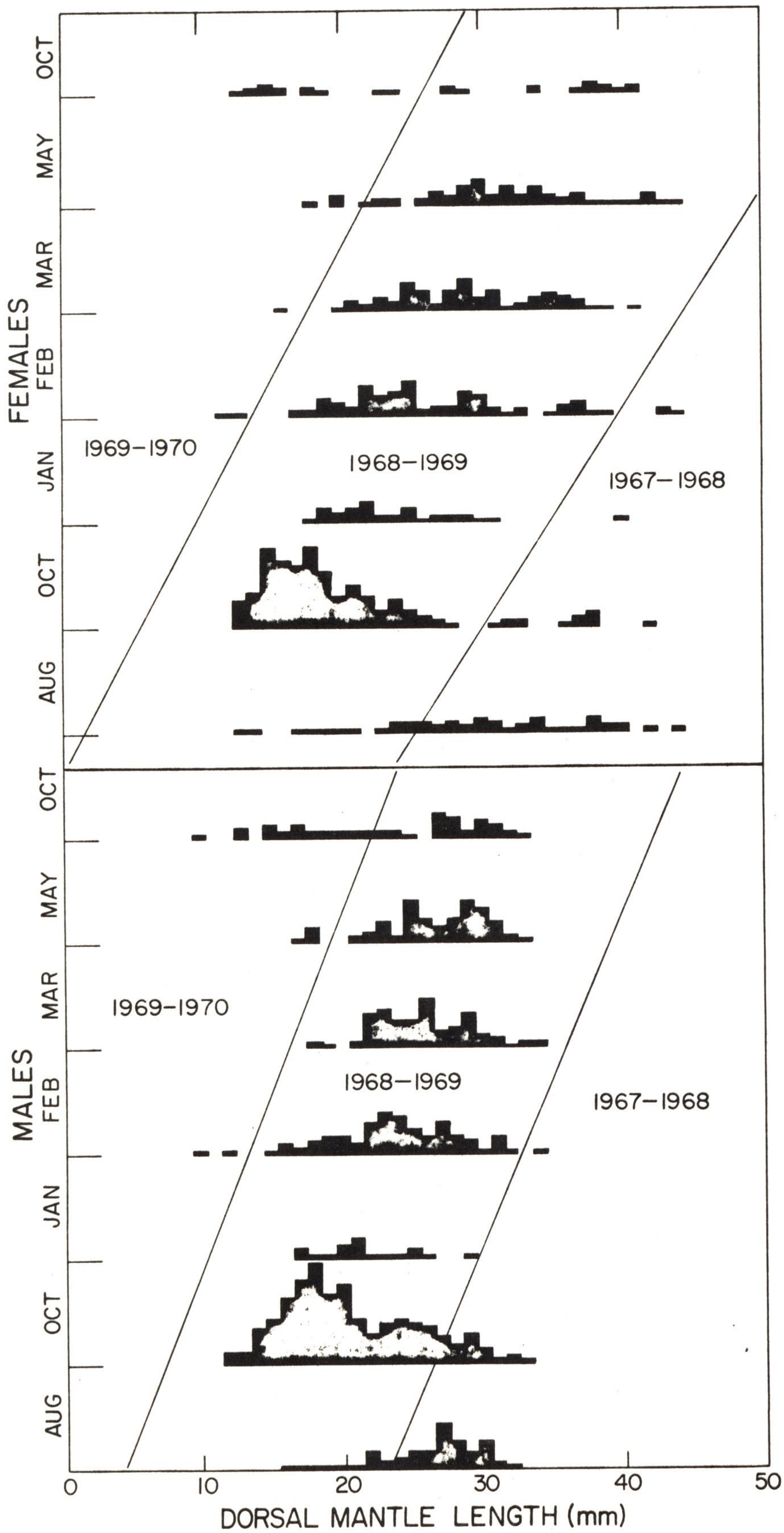
Population Studies

Population studies have been carried out on few cephalopod species, thus our knowledge in this area is limited. Cephalopods, by their very nature, are difficult to collect in the large numbers that are required for such studies. Those species that have been studied are mainly commercially important ones such as *Ommatostrephes todarus* (Fridriksson, 1943), *Loligo vulgaris* (Tinbergen and Verwey, 1945), *L. opalescens* (Fields, 1950 and 1965), *L. pealii* (Summers, 1967 and 1968), *Illex illecebrosus illecebrosus* (Squires, 1957), and *Sepioteuthis arctipinnis* (Rao, 1957). The population at Cape Lazo Gully was studied in order to provide additional knowledge of the life history of *R. pacifica*.

Composition of the Cape Lazo Gully Population

The size distributions of males and females per sample are shown in Figure 35. The male population in the August, 1968 sample consists largely of mature animals of 22 mm dorsal mantle length and over, along with a low number of immature animals. In October, 1968 a new 1968-1969 year class appears, consisting of small individuals that are the progeny of the early spawning members of the 1967-1968 year class. Later spawning members of the same year class are still present in October. The male population in the January, 1969 sample is made up almost entirely of the 1968-1969 year class with the exception of a few late spawners of the previous

Figure 35. Frequency of *R. pacifica* in each millimeter size class in the seven samples from Cape Lazo Gully.


FEMALES
OCT
MAY
MAR
FEB
JAN
OCT
AUG
1969–1970
1968–1969
1967–1968
MALES
OCT
MAY
MAR
FEB
JAN
OCT
AUG
1969–1970
1968–1969
1967–1968
0
10
20
30
40
50
DORSAL MANTLE LENGTH (mm)

year class. The February, March, May, and October, 1969 samples show growth in the males to the adult condition in October.

The female population in August, 1968 shows a wide size range varying from 13 to 44 mm dorsal mantle length. This is due to the presence of both the 1967-1968 (spawning animals) and the 1968-1969 (newly hatched) year classes. Each year class has a wide size spectrum due to the long spawning season (see Spawning). The size range of the females is greater than of the males which reach their maximum length sooner and at a smaller size than do the females. In October, 1968 there is a large increase in the 1968-1969 year class. There are also a number of spawning females of the 1967-1968 year class present. The January, February, March, May, and October, 1969 samples show the growth of the 1968-1969 year class. The 1967-1968 year class is still represented by a low number of large females in January and February that may represent very late spawning animals or animals that did not spawn. The former is more probable because of the presence of a few recently hatched squid in the February sample.

The October, 1969 sample includes two year classes, the 1968-1969 year class that has now reached spawning condition and a new 1969-1970 year class. In this sample the members of the 1968-1969 year class are as advanced in size as the previous year class in the sample from October, 1968. For both sexes, however, the members of the 1969-1970 year class appear to be rather smaller in size in the October, 1969 sample than the members of the 1968-1969 year class in

the October, 1968 sample. Large numbers of a new year class, as present in the October, 1968 sample are not found in the 1969 sample. These differences between the October, 1968 and October, 1969 samples could be accounted for by a later spawning season in 1969. Many of the squid in the 1969-1970 year class thus would not have been hatched yet or if hatched, would have been too small to have been retained in the trawl. The later spawning season is also indicated by the gonad indices (see Gonad Index and Spawning).

Sex Ratio

Sex ratios have been reported for a number of cephalopod species by various authors. Rao (1954) states that the percentages of males and females in a sample of 815 *Sepioteuthis arctipinnis* were 52.8% and 47.1% respectively or (1.1: 1.0). Fields (1965) showed that the percentages of males and females in a sample of 2,621 *Loligo opalescens* collected from fish catches were 50.3% and 49.7% (1.0: 1.0). The sex ratios in spawning schools of *Loligo* species have been described by numerous authors. Tinbergen and Verwey (1945) report 57% males (1.3: 1.0) for a cumulative total of 13,141 specimens of *L. vulgaris* that were collected from five consecutive spawning seasons. Haefner (1959) reports 70% males (2.3: 1.0) for a sample of 1108 *L. pealei*. McGowan (1954) reports 63% males (1.7: 1.0) for *L. opalescens* and Fields (1965) reports 50.9% males from samples containing 7,660 spawning squid of the same species.

Sex ratios were determined for the 1203 *R. pacifica* in the seven samples from Cape Lazo Gully (Table 10). In all cases the males were in excess of the females, ranging from 50.6% of the population in March, 1969 to 67.4% in October, 1969. The cumulative percentages were 54.5% males and 45.5% females (1.2:1.0). The slight excess of males to females might be accounted for by possibly more successful avoidance of the trawl by the larger females (see Collecting Methods).

Growth Changes

The mean mantle lengths of the males and females per sample were calculated and plotted against the time of year when the samples were collected (Fig. 36). There is a sharp decrease in the average mantle lengths for male and female squid from August to October, 1968. It is apparent that the average mantle lengths may begin decreasing before August since the August averages are lower than those of the following May. This decrease is due to the dying off of the adult animals after spawning (see Spawning) and an influx of small individuals of the new year class.

The average size of the females is larger than that of the males except for the October, 1968 sample (Fig. 36 and Table 11). Figure 36 indicates that a growth differential appears between the males and females at approximately 23 mm mantle length. This size difference increases from October through the winter, spring, and summer. There is no difference between the average mantle lengths of the males and females in the October, 1968 sample because the population at this

Table 10. Percentage and Ratio of Males and Females Per Sample From the Cape Lazo Collection.

Sample	Total	Number of Males	Number of Females	% Males	% Females	M:F Ratio
Aug. 1968	113	61	52	54.0	46.0	1.2:1.0
Oct. 1968	447	252	195	56.4	43.6	1.4:1.0
Jan. 1969	60	24	36	40.0	60.0	1.5:1.0
Feb. 1969	181	94	87	51.9	48.1	1.1:1.0
Mar. 1969	175	89	86	50.9	49.1	1.0:1.0
May 1969	144	80	64	55.5	44.5	1.3:1.0
Oct. 1969	83	56	27	67.4	32.6	2.1:1.0
Total	1,203	656	547	....	....	.....
Average	.....	...	...	54.5	45.5	1.2:1.0

time consists primarily of young animals among which the growth differential has not yet appeared. This sample contains a few of the larger 1967-1968 year class animals, therefore the average size of the 1968-1969 year class in this sample would be lower than shown in Fig. 36.

Male and female average mantle lengths (Fig. 36 and Table 11) show that the *Rossia* grow most rapidly up to February (approximately 26.5 mm for the females and 23.6 for the males), after which the growth rate tapers off. The males increase only 0.5 mm between March and May and thus are nearing their maximum size during this time. Females continue to increase in size through May, decreasing only slightly in growth rate (Figs. 35 and 36). Thus growth is more rapid in the females than in the males and occurs over a longer period of time.

The decrease in average mantle lengths between May, 1969 and October, 1969 is due to dying of spawned out animals of the 1968-1969 year class and to the influx of newly hatched squid of the 1969-1970 year class.

Weight Length Relationship

The average wet weight for each millimeter mantle length size class was determined for 122 males and 68 females of *R. pacifica* (Fig. 37). The weight of the squid increases at a faster rate than the mantle length. The weight length relationships of the male and female squid show little deviation from one another.

Figure 36. Mean mantle lengths of male and female *R. pacifica* from each of the Cape Lazo samples.

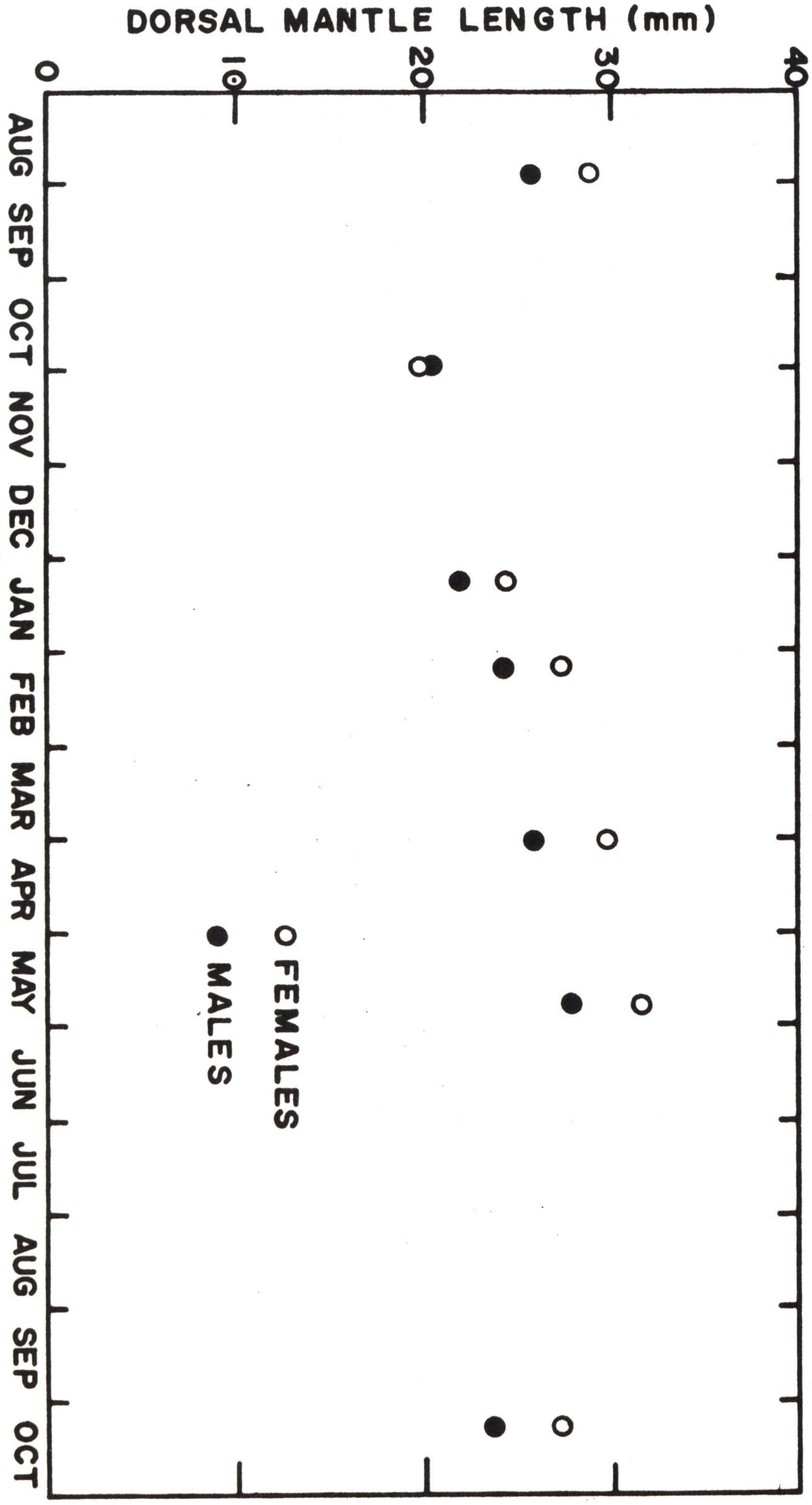
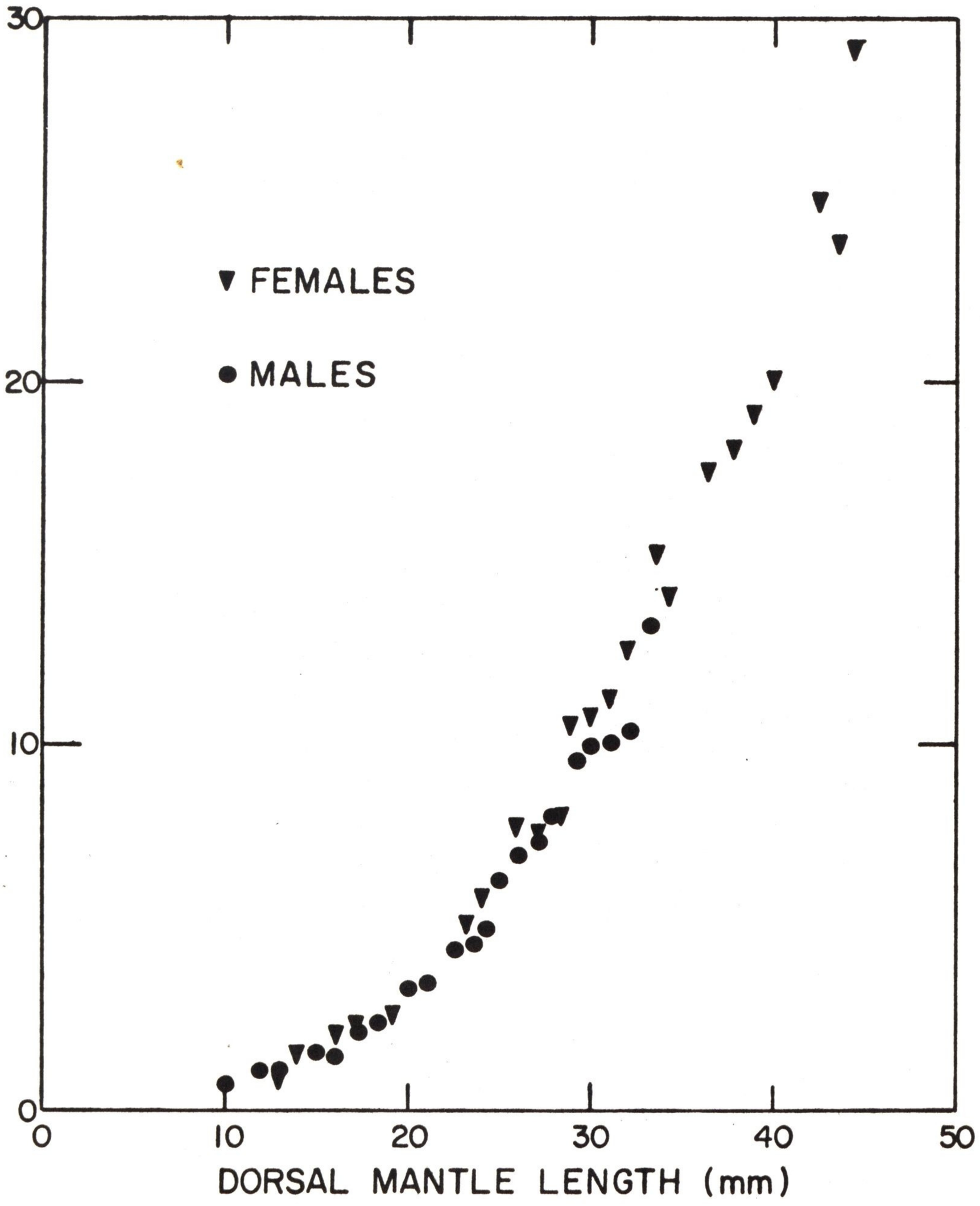

DORSAL MANTLE LENGTH (mm)
0
10
20
30
40
AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT
1968
1969
O FEMALES
● MALES

Table 11. Average Mantle Lengths of Males and Females and Differences Between These Averages for Samples From Cape Lazo Gully.

Sample	Males Average Mantle Lengths (mm)	Females Average Mantle Lengths (mm)	Difference Between Average Male and Female Mantle Lengths (mm)
Aug. 1968	25.7	28.3	2.6
Oct. 1968	20.1	20.1	0.0
Jan. 1969	22.1	23.8	1.7
Feb. 1969	23.6	26.5	2.9
Mar. 1969	25.8	29.1	3.3
May 1969	26.3	31.5	5.2
Oct. 1969	23.5	26.2	2.7

Figure 37. Weight-length relationship of *R. pacifica*. Each point represents the average wet weight for animals of that millimeter mantle length size class.


30
20
10
0
WET WEIGHT (grams)
▼ FEMALES
● MALES
0
10
20
30
40
50
DORSAL MANTLE LENGTH (mm)

Population Size

The relative size of the Cape Lazo population was measured throughout the year by calculating the catch per unit effort for each sample. Records were kept of the fishing effort for the August and October, 1968 and February, March, May, and October, 1969 samples (Table 12). The catch per unit effort was calculated by dividing the total number of squid per sample by the total number of hours spent fishing for that sample. This gives an estimate of the changes in abundance of the population over the year. The estimates for each month are directly comparable since the same collecting gear and techniques were used throughout the sampling.

The number of *Rossia* captured per unit effort (Table 12) varied from 15.7 squid/hour in October, 1969 to 84.8 squid/hour in October, 1968. The high rate of success in October, 1968 correlates with the influx of a large number of small squid of the new 1968-1969 year class into the population. The low catch of *Rossia* in October, 1969 may be due to the later spawning season thus only a low number of squid of the new 1969-1970 year class were present, the majority of the new year class still being unspawned or unhatched or hatched and too small to be captured in the net.

The catch of *Rossia* per unit effort was relatively constant for the August, 1968 and February, March, and May, 1969 samples, ranging from 31.9 squid/hour in August to 43.7 squid/hour in May.

The absolute size of the *Rossia* population at Cape Lazo Gully is under the control of both natural and man-made factors. Predation

Table 12. Abundance of *R. pacifica* at Cape Lazo Gully According to Catch per Unit Effort.

Sample	Hours Effort	Total Squid Per Sample	Squid Per Hours Effort
August 1968	5.5 hrs.	117	31.9
October	5.5	466	84.8
February 1969	5.5	184	33.5
March	4.2	175	41.6
May	3.0	131	43.7
October	5.3	83	15.7

upon *Rossia* by fish and other squid (see Predators) is likely to be the most important environmental control. Predator species such as the Lingcod, *Ophion elongatus*, and the squid, *Loligo opalescens*, appear to be migratory on the Cape Lazo grounds. Thus their influence upon the *Rossia* population is likely to differ during the year.

The presence of shrimp and ground fishing vessels at Cape Lazo Gully may exert a heavy pressure upon the *Rossia* population. These fishing vessels are apt to collect large numbers of *Rossia* most of which perish in the loaded trawls. The number of draggers present on the grounds at any one time during the year fluctuates according to the weather and fishing conditions at that time. The fishing activities at the gully are, therefore, also sporadic during the year.

A detailed examination of these regulating factors is beyond the scope of the present study.

SUMMARY

1. The temperature, salinity, and sediment size at Cape Lazo Gully varied from 7.18°C to 11.00°C, 28.01 °/$_{oo}$ to 30.21 °/$_{oo}$, and from less than 100µd to over 250µd respectively.

2. In life *R. pacifica* exhibit color changes from a dark red-brown to an opalescent grey-green and do not tend to mimic the substrate color.

3. The morphometric indices of *R. pacifica* indicate relative growth relationships and in some cases appear to be valid taxonomic criteria for separating *R. pacifica* from other species of the genus.

4. The arm formulas are inconsistent, the most common being 3>2>4>1 and 3>2=4>1.

5. When resting on the bottom *R. pacifica* either has its body in a horizontal position or sits with its anterior end elevated, supported by its arms. In some cases *R. pacifica* forms a depression to sit in.

6. In some instances *R. pacifica* were observed throwing sand onto their backs.

7. *Rossia pacifica* were observed feeding on fish which they captured with their tentacles.

8. Crustacea were present in 86.6% of the stomachs that contained food and fish were present in 16.6%. Shrimp made up the largest

portion of the crustacean diet. Small amounts of bivalve molluscs, ostracods, and squid were also found.

9. The proportions of crustacea to fish in the diet were higher in the smaller squid, becoming less in the larger squid. Seasonal variations in the diet were correlated with the biomass of shrimp present where the squid were collected; the higher the biomass of shrimp the higher was the proportion of shrimp in the diet.

10. Female squid are larger than males of the same age and grow to a larger size than the males.

11. Gonad indices indicate that the ovary and nidamental glands begin to mature when the females reach a dorsal mantle length of approximately 24.0 mm.

12. Spermatophore formation in the males begins when the males have a size of approximately 23.0 mm dorsal mantle length.

13. During mating the male takes a position ventral to the female and holds her by means of his second, theird, and ventral pairs of arms. His dorsal arms are used for transferring the spermatophores into the nuchal valve pocket of her pallial cavity.

14. The sex ratio at Cape Lazo Gully was 1.2 males to each female.

15. Spawning occurs in the late summer and fall with the most active period being from August through October. The spawning season may be correlated with an increase in the water temperature.

16. *Rossia pacifica* have a life span of approximately one year at the end of which they mate, spawn, and die.

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GLOSSARY OF ABBREVIATIONS USED IN FIGURES

ANG - Accessory Nidamental Gland

AOD - Aperture of the Oviduct

CB - Ciliated Band

FuC - Funnel Cartilage

G - Groove

MO - Mature Ova

MOD - Membranous Oviduct

NG - Nidamental Gland

NS - Needham's Sac

NuC - Nuchal Cartilage

O - Ovary

OD - Oviduct

ODG - Oviducal Gland

P - Penis

SO - Spermatophoric Organ

Sp - Spermatophore

SpS - Sperm Sac

T - Testis

To - Tooth

APPENDIX

APPENDIX I. Measurements and Morphometric Indices of Fresh *Rossia pacifica*.

SEX	TL	ML	MW	HW	FW	FL	FL'	AI	AII	AIII	AIV	T	TC	TLI	ALI	MAI	HWI	MWI	FWI	FLI	FLI'
M	79.1	33.5	27.8	26.5	49.8	21.7	18.4	29.8	30.2	35.1	33.5	80.9	18.1	241.5	44.4	104.8	79.1	83.0	148.7	64.8	54.9
M	79.6	31.8	28.6	26.2	48.6	20.2	16.2	27.9	37.9	36.3	33.9	74.6	17.3	234.6	47.6	119.2	82.4	89.9	152.8	63.5	50.9
M	77.8	31.3	23.6	26.3	43.5	19.3	14.1	25.0	35.2	32.7	29.6	60.1	16.2	192.0	45.2	112.5	84.0	75.4	148.6	61.7	45.0
M	70.2	28.5	25.8	23.1	45.0	19.6	12.0	25.0	23.2	31.4	26.0	59.6	13.2	209.1	44.7	110.2	81.1	90.5	157.9	68.8	42.1
M	87.8	36.2	32.0	30.0	51.6	25.0	18.8	27.5	33.3	35.4	39.0	-	-	-	44.4	107.7	82.9	88.4	142.5	69.1	51.9
M	52.8	22.9	20.5	19.2	34.9	15.8	11.8	13.5	19.6	22.7	23.6	51.3	11.0	224.0	44.7	103.1	83.8	89.5	152.4	69.0	51.5
M	66.7	28.3	23.6	23.2	42.3	19.6	13.9	24.2	30.4	26.9	32.7	58.3	17.3	206.0	49.0	113.4	82.0	83.4	153.0	69.3	49.1
M	82.0	31.3	27.0	26.2	51.3	21.0	15.1	31.7	36.8	36.7	36.8	71.0	14.3	226.8	44.9	117.6	83.7	86.3	163.9	67.1	48.2
M	47.6	20.0	17.6	15.9	32.4	13.0	9.4	14.3	19.2	20.9	21.1	69.1	14.2	345.5	44.3	105.5	79.5	88.0	162.0	65.0	47.0
F	90.9	37.5	30.1	27.4	63.5	28.0	19.2	29.7	39.0	37.0	38.9	-	-	-	42.9	104.0	73.1	80.3	169.3	74.7	51.2
M	80.0	31.2	24.5	24.6	49.8	21.9	15.1	31.0	41.0	32.7	31.7	76.7	17.0	245.8	51.2	131.4	78.8	78.5	159.6	70.2	48.4
M	49.9	15.4	16.8	17.4	34.7	13.6	9.1	17.9	23.3	24.0	22.0	72.7	11.6	472.1	48.1	155.8	113.0	109.1	225.3	88.3	59.1
M	52.6	19.0	16.5	15.3	31.0	13.1	8.7	17.2	20.0	25.8	21.3	76.2	10.0	400.1	49.0	135.8	80.5	86.8	163.2	68.9	45.8
M	46.1	16.4	14.8	16.2	31.3	13.2	8.4	16.5	18.0	19.1	18.2	67.6	8.7	412.2	41.4	116.5	98.8	90.2	190.9	80.5	51.2
F	44.8	15.9	13.0	14.0	26.0	10.9	8.0	17.6	19.0	18.0	19.5	69.3	9.4	435.8	43.5	122.6	88.1	81.8	163.5	68.6	50.3
M	90.7	31.3	22.2	26.0	51.2	23.0	16.2	36.7	43.2	47.5	46.9	139.0	18.7	444.0	52.4	151.8	83.1	70.9	163.6	75.4	51.8
M	88.9	31.7	26.7	25.6	53.2	23.7	15.1	36.9	41.3	43.7	42.1	83.4	16.6	263.1	49.2	137.9	80.8	84.2	167.8	74.8	47.6
M	83.7	29.7	25.2	23.0	50.2	21.9	14.8	35.3	29.3	39.4	39.9	89.6	17.2	284.8	48.0	134.3	77.4	84.8	169.0	73.7	49.8
M	89.5	32.8	27.6	24.3	54.6	21.6	14.5	25.5	31.6	37.3	36.0	91.2	18.8	278.0	41.7	113.7	74.1	84.1	166.5	65.9	44.2
F	103.9	45.0	34.7	29.0	68.6	27.0	19.5	29.5	36.9	42.0	32.7	100.0	21.1	222.0	40.4	93.3	64.4	77.1	152.4	60.0	43.3
F	93.8	41.7	33.6	25.8	61.2	23.4	18.4	27.6	32.7	34.5	34.5	112.0	24.0	268.6	36.8	82.7	61.9	80.6	146.8	56.1	44.1
M	79.6	30.5	25.1	23.2	44.4	18.6	13.3	24.8	31.6	33.7	28.7	113.7	19.3	-	42.3	110.5	76.1	82.3	145.6	61.0	43.6
M	76.7	28.9	24.3	19.9	46.5	16.5	12.0	24.4	31.5	28.4	28.3	69.6	15.9	240.8	41.1	109.0	68.9	84.1	160.9	57.1	41.5
M	86.3	33.0	25.3	26.0	49.4	20.2	13.0	30.0	37.2	37.2	32.1	76.7	16.8	232.4	43.1	112.7	78.8	76.7	149.7	61.2	34.9
M	73.2	29.7	24.2	23.5	47.9	17.7	13.1	26.1	27.0	33.7	25.7	101.2	15.4	340.7	46.0	113.5	79.1	83.2	161.3	59.6	44.1
F	83.6	33.5	25.9	25.4	50.8	22.8	16.4	28.7	32.0	34.5	34.0	158.1	23.2	471.9	41.3	103.0	75.8	77.3	151.6	68.1	49.0
M	69.4	29.1	24.6	25.4	46.2	20.6	14.6	25.0	28.2	30.2	31.4	70.0	14.5	240.5	45.2	107.9	83.2	84.5	158.8	70.8	50.2
M	65.1	24.8	20.9	19.7	39.0	17.0	10.8	1918	27.3	29.1	20.5	78.5	14.7	316.5	44.7	117.3	78.2	84.3	157.3	68.5	43.5
F	63.9	23.9	20.0	20.0	38.4	17.6	11.2	23.3	26.4	28.8	25.8	72.0	16.7	301.3	45.1	120.5	83.7	83.7	160.7	73.6	46.9
F	69.3	25.7	22.2	19.7	42.0	18.4	14.5	22.4	24.4	26.4	28.9	69.2	19.4	269.3	41.7	112.5	76.7	86.4	163.4	71.6	56.4
M	61.8	25.0	18.8	18.6	39.3	15.4	10.5	20.0	21.4	26.2	24.2	69.4	12.3	277.6	42.4	104.8	74.4	75.2	157.2	61.6	42.0
M	56.2	23.4	19.7	18.4	38.2	13.2	10.4	19.0	23.6	24.7	20.8	108.7	15.1	446.5	44.0	105.6	78.6	84.2	163.2	56.4	44.4
F	115.0	43.4	35.0	30.1	61.1	27.1	21.3	31.8	36.9	39.4	35.7	106.2	24.0	244.7	34.3	91.0	69.4	80.6	140.8	62.4	49.1
F	83.2	35.2	28.8	24.7	56.6	19.7	16.2	29.6	32.6	32.8	28.6	81.6	22.0	231.8	39.4	93.2	70.2	81.8	160.8	56.0	46.0
F	96.3	42.5	34.0	27.9	64.5	27.0	19.2	30.4	34.8	34.8	34.4	98.2	25.2	231.1	36.1	81.9	65.6	80.0	151.8	63.5	45.2
F	95.6	43.4	33.5	27.0	66.9	26.7	20.2	28.4	34.5	35.4	33.1	99.6	21.6	229.5	37.0	81.6	62.2	77.2	154.1	61.5	46.5
F	103.4	45.2	32.9	27.3	59.8	26.8	21.3	32.5	34.0	37.6	37.8	111.0	20.5	243.4	36.6	83.6	60.4	72.8	132.3	59.3	47.1
M	73.2	32.2	25.1	23.5	45.4	19.2	14.7	28.7	29.8	30.2	26.7	62.6	16.0	194.4	41.3	93.8	73.0	78.0	141.0	59.6	45.7
M	79.0	32.3	26.6	27.0	51.0	20.5	15.7	25.7	28.4	31.4	30.9	113.1	15.5	350.2	39.7	97.2	83.6	82.4	157.9	63.5	48.6
M	65.7	26.5	22.0	21.5	37.5	17.2	13.0	20.2	26.7	24.7	25.3	67.0	14.8	252.8	40.6	100.8	81.1	83.0	141.5	64.9	49.1
M	77.3	30.4	25.3	23.2	44.0	18.2	14.2	25.9	28.5	29.5	27.8	71.0	19.7	233.6	38.2	97.0	76.3	83.2	144.7	59.9	46.7
F	76.8	31.0	24.2	22.5	43.2	18.9	14.2	23.6	29.8	31.6	27.2	121.4	22.4	391.6	41.1	101.9	72.6	78.1	139.4	61.0	45.8
M	49.7	20.8	17.7	16.9	32.1	12.2	9.9	17.8	23.2	20.6	19.3	80.2	14.9	385.6	46.7	111.5	81.3	85.1	154.3	58.7	47.6
M	41.4	17.2	16.0	13.5	27.3	11.6	8.3	11.7	14.6	15.4	15.8	66.4	10.3	386.0	28.2	91.9	78.5	93.0	158.7	67.4	48.3
F	104.0	41.2	34.7	28.9	66.1	26.2	20.7	34.3	36.1	40.1	29.2	71.5	21.3	173.5	38.6	97.3	68.2	84.2	160.4	63.6	50.2
F	70.0	28.0	24.6	21.3	43.2	20.4	13.8	24.3	30.4	30.4	29.8	61.3	22.8	218.9	43.4	108.6	76.1	87.9	154.3	72.9	49.3
M	52.4	20.2	18.0	19.1	33.5	13.5	9.2	15.3	17.8	19.3	20.1	71.5	12.2	354.0	38.4	99.5	94.6	89.1	165.8	66.8	45.5
M	45.6	18.4	15.6	16.6	30.4	12.1	8.6	13.4	17.5	18.2	19.4	72.1	11.4	391.8	42.5	105.4	90.2	84.8	165.2	65.8	46.7
F	43.3	17.2	16.7	14.2	28.8	14.2	8.0	14.6	16.4	16.4	14.2	57.7	10.8	335.5	37.9	95.3	82.6	97.1	167.4	82.6	46.5
F	41.1	15.6	16.2	13.6	28.3	10.5	7.2	12.8	15.5	17.0	15.9	59.4	9.5	380.8	41.4	109.0	87.2	103.8	181.4	67.3	46.2
M	44.0	17.7	17.1	14.8	29.5	12.2	7.9	13.9	17.3	19.0	17.1	69.4	9.2	392.1	43.2	107.3	83.6	96.6	166.7	68.9	44.6
M	37.9	14.9	13.7	12.7	23.7	9.2	6.1	11.7	12.6	14.2	12.5	47.9	6.5	321.5	37.5	95.3	85.2	91.9	159.1	61.7	40.9
F	37.0	14.0	14.1	11.8	26.0	9.7	6.0	10.5	12.3	14.4	12.6	50.8	7.6	362.9	38.9	102.9	84.3	100.7	185.7	69.3	42.9
M	60.8	22.6	20.8	19.1	38.6	15.2	10.3	21.0	23.9	24.6	32.7	78.6	13.4	347.8	40.5	108.9	84.5	92.0	170.8	67.3	45.6
M	55.3	21.3	20.3	16.8	34.7	13.7	9.1	18.4	21.2	24.2	20.8	76.2	14.4	357.7	43.8	113.6	78.9	95.3	162.9	64.3	42.7
M	53.7	19.8	19.9	18.2	35.3	14.1	8.8	17.2	21.2	22.0	21.1	74.0	13.1	373.7	41.0	111.1	91.9	100.5	178.3	71.2	44.4
F	50.0	19.6	18.2	16.1	33.5	13.0	9.1	16.2	19.9	21.0	16.2	69.2	11.5	353.1	42.0	107.1	82.1	92.9	170.9	66.3	46.4
F	51.5	18.9	17.3	15.0	31.1	12.8	8.2	17.2	21.6	23.3	22.0	74.0	11.7	391.5	45.2	123.3	79.4	91.5	164.6	67.7	43.4
F	46.3	18.0	16.4	15.7	31.4	12.4	7.4	14.9	16.8	19.6	16.3	63.8	12.3	354.4	42.3	108.9	87.2	91.1	174.4	68.9	41.1
F	48.3	16.3	15.3	14.0	28.2	11.3	7.6	16.2	19.5	21.2	17.8	72.0	12.1	441.7	43.9	130.1	85.9	93.9	173.0	69.3	46.6
M	31.1	11.8	13.0	11.3	22.4	8.4	5.4	9.5	11.8	12.2	10.6	50.0	8.2	423.7	39.2	103.4	95.8	110.2	189.8	71.2	45.8
M	87.3	34.0	25.9	28.8	53.5	23.6	17.6	36.8	42.9	44.4	41.3	100.5	18.8	295.6	53.1	130.6	75.3	76.2	156.5	69.7	51.8

APPENDIX II. Measurements and Morphometric Indices of Preserved *Rossia pacifica*.

SEX	TL	ML	MW	HW	FW	FL	FL'	AI	AII	AIII	AIV	T	TC	TLI	ALI	MAI	HWI	MWI	FWI	FLI'
F	99.0	52.0	33.0	30.0	65.0	-	27.5	35.0	45.0	42.0	42.0	90.0	-	173.1	45.5	115.6	57.7	63.5	125.0	52.9
	51.5	20.0	18.0	18.0	32.5	-	11.0	24.0	75.5	26.5	23.0	64.0	-	320.0	51.5	75.5	90.0	90.0	162.5	55.0
M	59.0	26.5	23.0	22.5	40.0	-	15.0	22.0	27.0	28.0	22.5	62.0	-	234.0	47.5	94.6	84.9	86.8	150.9	56.6
F	65.0	27.0	22.0	20.0	42.5	-	15.5	21.0	25.5	28.0	26.0	68.0	-	251.9	43.1	96.4	74.1	81.5	157.4	57.4
M	58.0	24.0	18.5	19.0	37.5	-	13.5	22.0	25.0	28.5	25.0	50.0	-	208.3	49.1	84.2	79.2	77.1	156.3	56.3
F	60.0	23.5	21.0	19.0	37.0	-	14.0	20.0	25.0	26.0	23.0	53.0	-	225.5	43.3	90.4	80.9	89.4	157.4	59.6
F	63.0	25.0	21.5	20.0	38.5	-	16.0	24.0	29.6	31.0	28.0	73.0	-	292.0	49.2	80.6	80.6	86.0	154.0	64.0
F	54.0	26.0	20.6	21.5	37.0	-	16.0	21.0	24.0	25.0	23.0	67.0	-	257.7	46.3	104.0	82.7	76.9	142.3	61.5
F	47.5	22.0	18.0	19.0	30.5	-	14.0	18.0	20.0	22.0	19.0	62.5	-	284.1	46.3	100.0	86.4	81.8	138.6	63.6
F	54.0	22.5	16.0	17.5	32.5	-	14.0	19.5	21.5	25.0	23.0	49.0	-	217.8	46.3	90.0	77.8	71.1	144.4	62.2
F	49.0	21.5	16.0	18.0	31.0	-	11.0	17.0	22.0	23.5	21.0	54.0	-	251.2	48.0	91.5	83.7	74.4	144.2	51.2
F	39.0	17.0	14.0	15.0	29.5	-	11.5	15.0	17.0	19.0	15.5	35.0	-	205.9	48.7	89.5	88.2	82.4	173.5	67.6
F	60.0	27.0	20.0	21.0	37.0	-	15.0	22.0	28.0	29.0	25.0	90.0	-	333.3	48.3	93.1	77.8	74.1	137.0	55.6
F	60.0	25.5	20.5	20.0	39.0	-	16.0	21.5	24.5	28.5	25.5	-	-	-	47.5	89.5	78.4	80.4	152.9	62.7
F	48.5	20.0	17.0	17.0	33.0	-	12.0	17.0	22.0	22.5	20.0	60.0	-	300.0	46.4	88.9	85.0	85.0	165.0	60.0
F	50.0	22.0	19.5	20.0	36.5	-	12.0	19.5	22.0	24.0	22.0	69.0	-	313.6	48.0	91.7	90.9	88.6	165.9	54.5
M	47.5	20.5	17.0	17.5	31.0	-	11.0	19.0	22.0	23.5	20.0	44.0	-	214.6	49.5	87.2	85.4	82.9	151.2	53.7
F	53.5	21.0	21.0	19.0	38.0	-	12.0	21.5	24.0	27.0	24.5	60.0	-	258.7	50.5	77.8	90.5	100.0	181.0	57.1
M	57.0	27.5	23.5	21.5	38.0	-	13.0	22.0	25.0	28.0	23.0	55.0	-	200.0	49.1	98.2	78.2	85.5	138.2	47.3
M	44.0	20.5	17.0	26.0	30.0	-	10.0	15.0	19.0	21.5	18.5	53.0	-	258.5	48.9	95.3	126.8	82.9	146.3	48.8
M	63.0	27.0	20.5	39.0	38.0	-	14.0	27.0	31.0	33.0	30.0	55.0	-	203.7	52.4	81.8	144.4	75.9	140.7	51.9
M	50.0	23.0	17.0	18.0	34.0	-	12.0	20.5	24.0	26.0	22.0	51.0	-	221.7	52.0	88.5	78.3	73.9	147.8	52.2
M	50.5	24.0	19.0	18.5	34.0	-	13.0	17.5	21.0	24.0	21.0	54.0	-	225.0	47.5	100.0	77.1	79.2	141.7	54.2
F	51.0	19.5	16.0	18.0	31.5	-	11.0	18.0	20.0	24.0	20.0	60.0	-	307.7	47.1	81.3	97.3	82.1	161.5	56.4
F	45.5	25.0	18.0	18.0	35.0	-	13.5	22.5	24.0	26.5	22.5	72.0	-	288.0	58.2	94.3	72.0	72.0	140.0	54.0
M	48.0	19.0	17.5	17.0	26.0	-	10.0	17.0	20.0	22.5	19.0	47.0	-	247.4	46.9	84.4	89.5	92.1	136.8	52.6
M	44.0	19.5	16.0	15.5	30.0	-	10.0	17.0	20.5	21.5	20.0	53.0	-	271.8	48.9	90.7	79.5	82.1	153.8	51.3
M	54.0	25.0	21.0	20.0	39.0	-	14.0	21.0	22.5	25.5	22.5	52.0	-	208.0	47.2	98.0	80.0	84.0	156.0	56.0
M	64.0	28.5	20.0	22.0	38.0	-	15.0	26.5	30.5	32.5	27.5	57.0	-	210.0	50.0	82.0	84.0	80.0	148.0	54.0
M	61.0	25.0	20.0	21.0	37.0	-	13.5	24.5	30.5	29.0	23.0	52.5	-	322.6	46.2	86.1	96.8	83.9	167.7	51.6
F	39.0	15.5	13.0	15.0	26.0	-	8.0	14.0	16.5	18.0	17.0	50.0	-	--	109.7	108.8	64.9	73.0	124.3	51.4
F	81.0	37.0	27.0	24.0	46.0	-	19.0	28.0	31.0	34.0	32.0	-	-	--	45.2	97.0	75.0	78.1	134.4	46.9
F	73.0	32.0	25.0	24.0	43.0	-	15.0	26.0	29.5	33.0	26.0	-	-	176.3	116.1	105.6	63.2	73.7	121.1	55.3
F	81.0	38.0	28.0	24.0	46.0	-	21.0	27.0	34.0	36.0	33.0	67.0	-	--	47.1	95.3	70.5	70.5	111.5	45.9
M	68.0	30.5	21.5	21.5	34.0	-	14.0	27.0	32.0	32.0	29.0	-	-	--	41.5	117.6	60.0	68.8	116.2	48.7
F	82.0	40.0	27.5	24.0	46.5	-	19.5	29.0	31.5	34.0	31.0	-	-	--	44.2	98.5	65.7	74.6	132.8	53.7
M	77.0	33.5	25.0	22.0	44.5	-	18.0	28.0	32.0	34.0	30.0	-	-	--	45.8	95.4	74.2	77.4	122.6	87.1
F	71.0	31.0	24.0	23.0	38.0	-	27.0	28.0	30.5	32.5	29.5	-	-	--	42.0	115.8	58.0	70.5	122.7	52.3
F	90.5	44.0	31.0	25.5	54.0	-	23.0	28.5	36.0	38.0	33.0	-	-	--						

APPENDIX III. Berry's 1912 Table of "Measurements of *Rossia pacifica*" and indices of these measurements.

Locality	Boca de Quadra, Alaska.	Admiralty Inlet, Alaska.	Behm Canal, Alaska	Monterey Bay.	Monterey Bay.	Monterey Bay.	Monterey Bay.	Monterey Bay.	Monterey Bay.	Var. diegensis San Diego.	Var. diegensis San Diego.	Var. diegensis San Diego.
Sex												
Station	Sta. 4223	Sta. 4220	Sta. 4234	Sta. 4446	Off Salinas R.	Sta. 4492	Sta. 4492	Sta. 4457	Sta. 4446	Sta. 4377	Sta. 4356	Sta. 4356
Total length, excluding tentacles	*mm.* 105	*mm.* 69	*mm.* 75	*mm.* 80	*mm.* 76	*mm.* 73	*mm.* 80	*mm.* 88	*mm.* 96	*mm.* 50	*mm.* 52	*mm.* 72
Length of mantle (dorsal)	48	31	32	33.5	31	30	37	42	45.5	22	23	32.5
Width of body	31	19	18	22	21	22	26.5	27	25.5	16	14	19
Across fins	68	36	39	44.5	40	43	48	51	52	31	31	44
Length of fin (extreme)	33	19	19	23	19.5	20	24	28.5	27	15	15	21
Length of fin at plane of attachment	25.5	17	15	17.5	15	16.5	19	22	23	11	11	16
Width between eyes	22	18	18	18	18.5	18	21	23	23	16	13	18
Length of dorsal arm	34	26	24	30	26	28	28	29	30	30	18	23
Second arm ..	36	28	29	32	32	31	30	37	34	22	20	24
Third arm ...	42	29	33	36	38	33.5	34	39	35	23	23	27
Ventral arm	39	25	29	33	32	29	30	35	34	20	21	23.5
Tentacle, excluding club	57	10	12.5	..	53	15	11	45	9	15	15	9
Arm length index	..	42.0	44.0	45.0	50.0	45.9	42.5	44.3	36.5	64.0	44.2	37.5
Mantle arm index	87.5	93.6	103.1	107.5	122.6	111.7	91.9	92.9	74.7	104.6	100.0	83.1
Head width index	45.8	58.1	56.3	53.7	59.7	60.0	46.8	54.8	50.5	72.7	65.2	64.6
Mantle width index	64.6	61.3	56.3	65.7	67.7	73.3	71.6	64.3	56.0	72.7	60.9	58.5
Fin width index	141.7	116.1	121.9	132.8	129.0	143.3	129.7	121.4	114.3	140.9	134.8	135.4
Fin length attachment index	53.1	54.8	46.9	52.2	48.4	55.0	51.4	52.4	50.5	50.0	47.8	49.2

Modified from Berry, 1912.

APPENDIX IV

Confidence Levels of Regressions For Morphometric Indices

Index	Preserved		Fresh	
	Males	Females	Males	Females
TLI	99	90	99	95
ALI	ns.	99	95	ns.
MAI	90	99	ns.	99
MWI	99	99	99	99
HWI	98	99	99	99
FWI	99	99	99	99
FLI	..	..	ns.	ns.
FLIA	ns.	ns.	ns.	ns.

APPENDIX V

Regression Equations for Morphometric Indices

Index	Preserved		Fresh	
	Males	Females	Males	Females
TLI	y=432.84-8.53(x)	y=327.19-3.00(x)	y=560.18-10.14(x)	y=444.18-4.64(x)
MAI	y=121.76-.48(x)	y=138.9-1.17(x)	y=109.6-.09(x)	y=126.6-7.9(x)
MWI	y=105.5-1.15(x)	y=100.9-.79(x)	y=108.8-.84(x)	y=103.1-.60(x)
HWI	y=94.59-.61(x)	y=103.96-.93(x)	y=99.89-.67(x)	y=97.19-.74(x)
FWI	y=186.00-1.75(x)	y=192.7-1.69(x)	y=200.80-1.57(x)	y=185.80-.87(x)

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