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The comparative osteology of the trunk skeleton of five year classes of the Golden shiner, Notemigonus crysoleucas (Mitchell)

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THE COMPARATIVE OSTEOLOGY OF THE TRUNK SKELETON OF FIVE YEAR CLASSES OF THE GOLDEN SHINER, NOTEMIGONUS CRYSOLEUCAS (MITCHILL)

A Thesis

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INTRODUCTION

The golden shiner, Notemigonus crysoleucas, forms a monotypic species in the fish family, Cyprinidae. It is a medium-sized minnow which inhabits ponds and sluggish freshwater streams in North America from latitude 30°N. to 50°N. In the south its range is restricted to the area east of the Appalachian Mountains. The northern and western part of the range extends to Wyoming and south to the drainages of the Arkansas and upper Ohio Rivers.

This abundant species has been studied extensively as a bait fish by Swingle (1949), and Bauman (1946). Cooper (1936) studied age and growth in Michigan. The Weberian Ossicles of N. crysoleucas were included in a study of certain Ostariophysii by Krumholz (1943). Gill parasites of the species were investigated by Mueller and Van Cleave (1932). Wiebe, McGavock, Fuller, and Markus (1934) used N. crysoleucas in a study of the fish's ability to extract oxygen at different hydrogen-ion concentrations. The species was also used by Clausen (1936) in oxygen consumption studies among freshwater fishes. A review of the literature of N. crysoleucas indicates that there have been no studies made of the trunk skeleton. Accordingly, in the present paper the comparative osteology, exclusive of the head, is described among five year classes of N. crysoleucas.

MATERIALS AND METHODS

The fish used in this study were taken from a small creek which drains Westhampton Lake located on the campus of the University of Richmond in Henrico County, Virginia. The creek is approximately three-fourths of a mile in length and connects the lake with the James River.

A total of twelve collections were made from February 16 to May 10, 1956. A ten-foot minnow seine was used for collecting. A total of 102 N. crysoleucas were collected and placed in ten percent formalin until hardened. A scale sample to be used in ageing was taken from each fish just posterior to the pectoral fin and dorsal to the lateral line; the remaining scales were removed and the fish was eviscerated through a ventral incision. The sex of each fish was determined by examination of the gonads. The specimens were cleared and stained by the alizarin technique for bone following the method of Evans (1948). Each fish was given an identification number on a tag placed under the opercular flap.

The fish were divided into year classes on the basis of scale readings. The scales to be read were placed in water under a binocular dissecting microscope and cleaned by removal of the skin with a flattened needle. The wet scales were mounted on a slide in a few drops of Gurr's water mounting medium and after 24 hours were read by microscopic examination and by projection. Age was determined and specimens were classed by a count of the annuli. A complete annulus represents one year of age, hence a specimen whose scales show one annulus was put in year class I. Scales were read three times. The criterion used to establish age was two readings in agreement. When all three readings were in disagreement a fourth reading was taken. The age of the fish represents the number of winters passed. Many specimens taken as late as April or May showed growth beyond the last clearly marked annulus, but no attempt was made to interpolate this extra growth. In three of the older fish (year class V), annuli boundaries were not clearly defined and the scales were difficult to read. Possibly these fish were older than five years but were included in year class V because only five annuli were discernible.

Skeletal parts were counted and measurements taken after specimens were cleared and stained. Fin ray counts include all elements. Measurements of skeletal parts in millimeters were taken with dividers. Counts and measurements conform to those standards given by Hubbs and Lagler (1949: 8-15) unless otherwise noted.

The statistics used were taken from Fisher (1950: 114-128), Freund (1952), and Cazier and Bacon (1949: 352-373). Tables 1 and 2 are based on those used by Raney and Lachner (1946: 680). The term "sample" when used in this paper refers to the total number of fish used in the study (102 specimens).

The Student "t" statistic was used in making all significance tests. The level of significance in all cases was .95. In Tables 1-28, "t" was calculated for the difference in the largest and smallest means of each table and checked for significance at the .95 level by use of the table of critical values of "t" in Fisher (1950: 174). If significant differences were found the data were presented graphically (Figs. 1-5) following Hubbs and Hubbs (1953: 51).

DISCUSSION OF RESULTS

AGE AND GROWTH. The results of the age study are summarized in Tables 1 and 2. The data from Table 1 are shown graphically in Figure 1. Although there is considerable overlap, these data clearly indicate that means of the year classes are distinct (Fig. 1). The values of "t" between these means are listed in Table 1. In this study year class II through IV were the largest while classes I and V were much smaller. The period of greatest growth (Table 1) is during the first year (mean 62 mm.) During the second year only a 12 mm. mean increase in length is indicated, while the third and fourth year show increases of 28 mm. and 24 mm. in mean length respectively. The fifth year shows a mean increase of 36 mm. The small number of individuals in year class I and the small increase in length between year class I and II may possibly be due to collecting procedure. Collections made near the lake outlet contained no small N. crysoleucas, whereas those made near the mouth of the creek provided small as well as larger specimens. Since the majority of collections were made upstream, this has probably given bias toward larger fish in year class I. Year class V shows a relatively large increment in mean length, which is a reflection of the extremely large-sized females included in this year class but which are possibly older. The length measurement shows no evidence for sexual dimorphism (Table 2). The total number of males and females for the whole sample was 47 and 55 respectively.

VERTEBRAL COLUMN. The total number of vertebrae in N. crysoleucas ranges from 37 to 39, including the urostyle. The mode is 38 which occurs in 66 specimens; 17 had 37 vertebrae and 19 had 39 vertebrae. Tables 3 and 4 summarize the data for caudal vertebrae and trunk vertebrae. The first completely formed haemal arch was used to mark the first caudal vertebra. The centra are typical amphicœlous type and resemble two shallow cones placed apex to apex.

As N. crysoleucas is in the order Cyprinoformes (Berg 1940) parts of the first four vertebrae are modified and are closely associated with the auditory apparatus. These will be treated separately.

Each vertebra is reinforced by plates of bone located dorsally and ventrally in the concavity formed about the exterior of the cones (Pl. I, Figs. B and D). The anterior ends of the dorsal plates are continuous with the neural arch. The ventral plates bear a similar relationship to the haemal arches in the caudal vertebrae and although present in the trunk vertebrae, they are reduced. The outer edges of the dorsal plates are sculptured with various shaped spines and sometimes contain small openings; the ventral plates are limited to a single spine which extends ventrally. No openings were observed in the plates of the haemal arches. The centra appear uniform in length throughout the entire column, except the first four and last three which are noticeably shorter.

All vertebrae except the first three and the urostyle have well-developed neural arches and spines. Caudal vertebrae have completely developed haemal arches and spines.

Each of the trunk vertebrae except the third has stout transverse processes. Typically in vertebrae 5 through 16 the transverse processes are very short and flat, and serve as articulating surfaces for the ribs. In trunk vertebrae 17 through 20 the transverse processes are progressively longer and project more ventrally (Pl. I, Fig. B). The ribs associated with these last processes are not consistent in number or size and are smaller than the first 14 ribs. Differences noted in Tables 5 and 6 are due to the variability in number of ribs present on vertebrae 17 through 20. The typical number of ribs was 14.

Table 25 gives a summary of quotients of standard length to the length of the first left rib by year classes. Figure 4 shows graphically the data presented in Table 25. This graph suggests that there is a significant trend toward greater rib length with age. Year classes I and II are significantly different statistically from year classes III, IV, and V. The difference between means of year classes II and III has a "t" value of 2.2900.

VERTEBRAE 1 THROUGH 4. In N. crysoleucas the first four vertebrae are associated with the Weberian Ossicles, a series of modified vertebral processes which aid the fish in the transmission of vibrations from the air bladder to the membranous labyrinth. The body of the vertebrae are also modified in that they are shortened along their anterior-posterior axis. Vertebrae 3 and 4 are longer than 1 and 2, but are shorter than the typical trunk or caudal vertebrae. This actual difference in length is exaggerated in appearance by the greater diameter of the centra in the first four vertebrae. Vertebra 1 has anteriorly a pair of rod-shaped transverse processes. The transverse processes of the second vertebra are centrally located, longer than the first pair, flattened dorso-ventrally, and slightly curved posteriorly. The third vertebra lacks a transverse process as such, but the tripus, the largest of the Weberian Ossicles, appears to be a modified transverse process of this vertebra (Pl. III, Fig. B). The fourth vertebra has long rib-like processes on either side which project ventro-anteriorly. On the medial side of these processes are located bony extentions that fuse in a median sagittal plane under the centrum and form a foramen and median ventral spine (Pl. I, Fig. C). The neural arches of vertebrae 1 through 4 are fused; the neural spines of vertebrae 1 through 3 are fused, but that of number four is free.

The Weberian Ossicles are located along the first four vertebrae in a series of four on each side. From posterior to anterior they are called the tripus, intercalarium, scaphium, and claustrum. The tripus (Pl. III, Fig. C,1) has a central portion which pivots at its union medially with the centrum. There is an anterior ramus that connects by a ligament to the intercalarium and a posterior ramus that terminates in a hook. The hooked portion rests against the air bladder.

Krumholz (1943: 36) states that in N. crysoleucas the tripus is articulated on the second vertebra and that in the Evantognathi (Cyprinoidei, Berg 1940: 444) the ventral processes of the second and third vertebrae are fused. Observations in this study have not corroborated his findings. It is presumed that Krumholz is referring to the transverse processes, as no other processes occur ventrally on these vertebrae in N. crysoleucas. In the 102 specimens examined the tripus was articulated on the third vertebra, and in no case were the transverse processes of the second and third vertebrae fused.

The intercalarium (Pl. III, Fig. C,2) is V-shaped, intermediate in location between the anterior ramus of the tripus and the ventral edge of the scaphium, and connected to these structures by ligaments from the ventral arm of the "V". The intercalarium is articulated at the apex of the "V" with the centrum of the second vertebra. Krumholz (1943: 38) describes this bone in N. crysoleucas as rudimentary. In the specimens of the present study the intercalarium was well developed and appeared to be a functional part of the Weberian apparatus.

The scaphium (Pl. III, Fig. C,3), which articulates with the first vertebra, is composed of a thickened U-shaped rim of bone in which sits a thin concave sheet of bony material. The concave portion overlies the lateral side of the claustrum.

The claustrum (Pl. III, Fig. C,4) is a wedge-shaped ossicle with concave surfaces and is located between the scaphium and the anterior edge of the neural arch. It lies next to the nerve cord medially and anteriorly it connects with the membranous labyrinth. No proportional difference in size could be established between corresponding ossicles among the specimens in the five year classes studied.

HYPURAL PLATE. The last three vertebrae, the antepenultimate, penultimate, and ultimate or urostyle are modified and aid in the support of the caudal fin. The centrum of the urostyle lacks the characteristic posterior half found in other vertebrae (Pl. II, Fig. D). Each vertebra has at least one well developed neural arch and spine, and also a haemal arch and spine. The neural spine on the antepenultimate and penultimate is more elongated and flattened than that of the typical vertebra. These two spines along with the dorsal caudal radial give support dorsally to the first unbranched caudal fin rays. The haemal spines of the antepenultimate and penultimate are elongated, flattened, functional hypurals. On the antepenultimate of three specimens the neural arches and spines are duplicated, while four of the fish had corresponding hypurals in duplicate. On the penultimate the neural arches and spines of 33 fish were double but only one fish had a double hypural on this vertebra. These observations are based on the whole sample of 102 specimens.

The urostyle has an elongated process directed dorsally, at least one neural arch, and a haemal arch. There are typically six hypurals associated with the urostyle (Table 13). The two most dorsal hypurals (H_1 and H_2) are quite flat and wide distally, as are the two most ventral ones (H_5 and H_6). Hypurals 3 and 4 are similar to the urostylar process in size and converge upon each other at the centrum. Hypurals 1 and 2 are not fused, but are held in place by uncalcified cartilage. Hypurals 5 and 6 articulate ventrally on the centrum of the urostyle. Hypurals 1 through 6 support the majority of the caudal fin rays. The caudal rays ranged in number from 27 to 38 (Table 16).

DORSAL FIN. The total number of dorsal fin rays is usually ten and only ten percent of the specimens deviated from this number (Table 11). The first dorsal ray is completely embedded, small and splint-like, and probably contributes little to the support of the fin. The second dorsal ray lies close to the third and is about one-third as long. The third is the longest of the rays in the fin. The first three dorsal rays are always unbranched; the remaining rays are branched. The last two rays are fused at their bases and articulate with the same pterygiophore.

The number of pterygiophores in the dorsal fin is usually two less than the total number of rays in the fin (Table 12). A typical pterygiophore consists of a spine with four bony ridges at right angles to each other. The complete structure tapers to a point ventrally. At the articulating end the spine becomes enlarged in diameter, is bent caudally, and is composed of two to three sections. The right and left halves of the ray typically straddle the terminal portion of a pterygiophore and rest on the spine of the pterygiophore immediately following. With this arrangement each ray receives support from two pterygiophores, except the first two and the last rays which are supported by a single large pterygiophore (Pl. II, Fig. C). The ventral ends of the pterygiophores are usually located between the tips of successive neural spines. The ventral end of the first dorsal pterygiophore is located between the neural spines of vertebrae 14 and 15, and the ends of the remaining pterygiophores are found consecutively between the neural spines to vertebra 21.

The base of the dorsal fin is proportionately longer in older fish. The means of quotients from standard length to base length of the dorsal fin become significantly smaller by the third year, which indicates that the length of the fin base actually increases at a greater rate than does the standard length of the fish (Table 21, and Fig. 2). The difference between means of year classes II and III has a "t" value of 1.9801. There is no evidence that the lengths of the corresponding longest and shortest rays in the dorsal fin are proportionately different among the year classes (Table 27).

ANAL FIN. Table 14 shows that the total number of anal rays is more variable than the dorsal rays. The mode is 16 and the range is from 13 to 18. The first three rays are unbranched and bear the same length relationship and same arrangement as was given for the corresponding dorsal rays. The remaining anal rays are branched and the last is double as in the dorsal fin.

The anal pterygiophores typically number two less than do the rays. Table 15 shows that the mean count of anal pterygiophores is 14 for the year classes. The ray structure and the articulating arrangement between rays and pterygiophores is identical to that of the dorsal fin. The first and second anal pterygiophores are always closely associated with the haemal spine of the first caudal vertebra. The remaining pterygiophores seldom alternate consecutively between the adjacent haemal spines as in the dorsal fin, but often there are two or three between the spines.

The proportional relationship of the length of the base of the anal fin to the standard length of the fish was measured as was done with the dorsal fin. These data are summarized in Table 22 by year classes. No evidence was found to indicate that the length of the anal fin base is proportionately different among the year classes. The proportional relationships between the longest and shortest rays were measured but there is no evidence that the lengths of the corresponding longest and shortest rays in the anal fin differ proportionately among the year classes (Table 28).

PELVIC GIRDLE AND FINS. The pelvic girdle consists of two elongated bones that join by medial projections that extend ventrally and caudally and are held together by ligaments (Pl. II, Fig. B). Each of these basal elements are forked anteriorly for about one-half their length. The prongs of the fork are winged by longitudinal ridges that run the length of the bone, and which probably serve to anchor the bones in the surrounding tissues. At the posterior end the girdle elements are enlarged and articulate in the depression formed by the divided ends of the fin rays. The articulation is reinforced by surrounding cartilage. Four small slightly calcified cartilages line the articulating surface of the rays. The pelvic rays for each fin are usually nine in number, although six specimens had ten and seven specimens had eight (Tables 19 and 20). Each fin ray has a dorsal and ventral bony projection at its base directed mesially and lies against the adjacent ray. These projections probably give added strength to the fin at its base.

The proportional relationship of the length of the pelvic fin to the standard length of the specimen shows that no significant differences exist among year classes I through IV. Year class V was significantly different statistically (t between means of year classes I and V = 2.3294), but because of the influence of the three questionable fish in this group (see MATERIALS AND METHODS, p. 2), the difference is not considered biologically significant (Table 23). A comparison was made between the pelvic girdle length (from the median lateral process to anterior tip) and the standard length of the fish. The data are given in Table 24 and

Figure 3, and show that there is a significant difference in means between year class I and the remaining four classes. The difference between means of year classes I and II has a "t" value of 2.1276. This is interpreted to mean that the anterior rami of the pelvic girdle in year old _N. crysoleucas_ are relatively shorter than in older fish.

PECTORAL GIRDLE AND FINS. The pectoral girdle consists of six elements on each side (Pl. II, Fig. A). The uppermost, the posttemporal, is a thin, tear-shaped bone which articulates dorsally with the skull and ventrally with the supracleithrum. The supracleithrum, similar in shape to the posttemporal, joins the cleithrum ventrally. The cleithrum is the largest bone in the girdle; it is L-shaped with the angle directed posteriorly. The small, thin, rod-shaped postcleithrum is projected from the vertical part of the cleithrum in a median ventral direction. The postcleithrum is flattened at its ventral extremity and fuses with the scapula, which lies directly beneath it, and with the coracoid which is ventral and anterior. The coracoid is the second largest bone in the girdle. It is roughly oval in outline and fuses with the cleithrum laterally and anteriorly. These articulations form a large foramen in the space between them. The scapula is flattened, square in outline, and has a large foramen in its center. It is fused laterally and anteriorly to the cleithrum, medially to the coracoid, and dorsally to the postcleithrum. The posterior edge is articulated to the rays via two actinosts or radials. There are four actinosts in all, the medial two being associated mostly with the posterior portion of the coracoid. The two girdle halves are joined ventrally under the gills of the fish along the median borders of the two coracoids and the anterior tips of the cleithra.

The rays of the pectoral fin are similar to the pelvic rays and articulate in the same fashion. Their proximal ends form a groove into which the radials fit. The pectoral rays differ from those of the pelvic fin in that there is only a ventral process present at the base. Tables 17 and 18 summarize data obtained from counts of right and left pectoral fin rays. The modal number of pectoral fin rays was 16.

The length of the pectoral fin was compared to the standard length of the fish and results are given in Table 26 and Figure 5. The means of the quotients of year classes I and II are significantly different from year classes IV and V. There is a trend for the means to decrease from year classes I to V. The difference in means between year classes II and IV has a "t" value of 2.4793. This indicates that the pectoral fin increases in length at a greater rate than does the body length during the first five years of life.

INTERNEURALS AND INTERMUSCULAR BONES. Small interneural bones (homologous with the more posterior pterygiophores) lie between each of the neural spines of vertebrae 4 through 13. The first and largest is a rectangular-shaped bone (Pl. IV). The next three are not as large and are triangular in shape. The last five interneurals are S-shaped with their long axis directed dorso-ventrally.

From the fourth vertebra to the urostyle intermuscular ribs are found embedded between the epaxial muscles. They are also found within the hypaxial musculature from the region of the last true rib to the urostyle (Pl. III, Fig. A, and Pl. IV). The data from counts made of intermuscular ribs is given in Tables 7 through 10. The mode for the epaxial ribs was 44 and for those of the hypaxial region the modal number was 17.

SUMMARY

The study is based on 102 cleared and stained specimens of N. crysoleucas, 47 males and 55 females. By use of the scale method the sample was grouped into five separate year classes. The mean length and range of variability in mm. for years one through five were: year class I, 62 (55-65); year class II, 74 (60-95); year class III, 102 (80-140); year class IV, 126 (90-140); year class V, 162 (135-185). Differences between these means are all significant at the .95 level. No evidence of sexual dimorphism was found among the year classes. The Weberian Ossicles were found to be relatively uniform in size and shape throughout. Vertebrae 1 through 4 are associated with the ossicles and are shorter in length and greater in diameter than are the other vertebra. Similarity in proportional measurements and counts was the rule. When differences were found significant at the .95 level they were portrayed graphically by use of significance charts. These differences were as follows:

1. The ribs are proportionately longer in older specimens, and a definite trend for greater rib length exists from year class I to year class V.
2. The length of the dorsal fin base is relatively shorter in year classes I and II than in older fish.
3. With age the pectoral fin increases in length at a rate greater than that of the body of the fish.
4. The anterior rami of the pelvic girdle becomes relatively longer as the fish becomes older.

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Table 1. Length frequencies for each year class of N. crysoleucas.

Year Class		I	II	III	IV	V
standard	55	2	--------	--------	--------	--------
length	60	7	3	--------	--------	--------
in	65	1	5	--------	--------	--------
mm.	70	--------	13	--------	--------	--------
	75	--------	4	--------	--------	--------
	80	--------	2	1	--------	--------
	85	--------	3	5	--------	--------
	90	--------	1	7	1	--------
	95	--------	1	0	1	--------
	100	--------	--------	3	2	--------
	105	--------	--------	1	0	--------
	110	--------	--------	5	1	--------
	115	--------	--------	0	1	--------
	120	--------	--------	2	3	--------
	125	--------	--------	0	2	--------
	130	--------	--------	1	7	--------
	135	--------	--------	0	4	2
	140	--------	--------	1	3	0
	145	--------	--------	--------	--------	0
	150	--------	--------	--------	--------	2
	155	--------	--------	--------	--------	0
	160	--------	--------	--------	--------	0
	165	--------	--------	--------	--------	2
	170	--------	--------	--------	--------	0
	175	--------	--------	--------	--------	0
	180	--------	--------	--------	--------	2
	185	--------	--------	--------	--------	1
	190	--------	--------	--------	--------	--------
No.		10	32	26	25	9
$\bar{x}$		62	74	102	126	162
s		3.30	8.20	15.58	14.56	19.54
S.E.		1.10	1.45	3.05	2.91	6.92

Year classes I - II, "t" = 4.7058
Year classes II -III, "t" = 6.2222
Year classes III- IV, "t" = 3.9603
Year classes IV - V , "t" = 3.6622

Table 2. Length frequencies by sex for each year class of N. crysoleucas.

Year Class		I		II		III		IV		V	
	Sex	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
standard	55	1	1	----	----	----	----	----	----	----	----
length	60	4	3	3	----	----	----	----	----	----	----
in	65	0	1	2	3	----	----	----	----	----	----
mm.	70	----	----	4	9	----	----	----	----	----	----
	75	----	----	1	3	----	----	----	----	----	----
	80	----	----	2	0	1	----	----	----	----	----
	85	----	----	2	1	2	3	----	----	----	----
	90	----	----	0	1	3	4	1	----	----	----
	95	----	----	1	----	0	0	0	1	----	----
	100	----	----	----	----	2	1	1	1	----	----
	105	----	----	----	----	0	1	0	0	----	----
	110	----	----	----	----	2	3	1	0	----	----
	115	----	----	----	----	0	----	0	1	----	----
	120	----	----	----	----	2	----	2	1	----	----
	125	----	----	----	----	0	----	0	2	----	----
	130	----	----	----	----	1	----	6	1	----	----
	135	----	----	----	----	0	----	2	2	----	2
	140	----	----	----	----	1	----	2	1	----	0
	145	----	----	----	----	----	----	----	----	----	0
	150	----	----	----	----	----	----	----	----	2	0
	155	----	----	----	----	----	----	----	----	0	0
	160	----	----	----	----	----	----	----	----	0	0
	165	----	----	----	----	----	----	----	----	1	1
	170	----	----	----	----	----	----	----	----	0	----
	175	----	----	----	----	----	----	----	----	0	----
	180	----	----	----	----	----	----	----	----	2	----
	185	----	----	----	----	----	----	----	----	1	----
	190	----	----	----	----	----	----	----	----	----	----
No.		5	5	15	17	14	12	15	10	6	3
$\bar{x}$		62	62	74	74	110	98	127	124	169	147
s		2.7	4.1	9.9	6.9	19.0	11.0	14.2	15.0	16.3	17.5
S.E.		1.3	2.1	2.6	1.7	5.3	3.3	3.7	5.0	7.3	12.4

Tables 3-4. Frequency distributions of trunk vertebrae and caudal vertebrae in year classes I-V in N. crysoleucas.

Table 3. Trunk vertebrae

Class No.	19	20	21	No.	$\bar{x}$	s	2 S.E.
I	4	6	-	10	19.6	.516	.344
II	14	15	3	32	19.7	.520	.185
III	6	19	1	26	19.8	.379	.149
IV	10	15	-	25	19.6	.490	.196
V	2	7	-	9	19.8	.442	.312
Sample	36	62	4	102	19.7	.729	.146

Table 4. Caudal vertebrae

Class No.	17	18	19	20	No.	$\bar{x}$	s	2 S.E.
I	-	2	8	-	10	18.8	.421	.281
II	1	16	14	1	32	18.5	.646	.229
III	2	18	6	-	26	18.2	.646	.253
IV	1	17	7	-	25	18.2	.520	.208
V	1	6	2	-	9	18.2	.601	.425
Sample	5	59	37	1	102	18.3	.680	.136

Tables 5-6. Frequency distributions of the left rib and right rib in year classes I-V in *N. crysoleucas*.

Table 5. Left rib

Class No.	13	14	15	No.	$\bar{x}$	s	2 S.E.
I	-	7	3	10	14.3	.483	.322
II	2	23	7	32	14.1	.492	.174
III	1	20	5	26	14.2	.564	.221
IV	1	23	1	25	14.0	.283	.113
V	-	8	1	9	14.1	.333	.235
Sample	4	81	17	102	14.1	.632	.126

Table 6. Right rib

Class No.	13	14	15	No.	$\bar{x}$	s	2 S.E.
I	-	7	3	10	14.3	.483	.322
II	1	24	7	32	14.2	.452	.160
III	1	19	6	26	14.2	.628	.246
IV	1	24	-	25	14.0	.198	.079
V	-	7	2	9	14.2	.442	.312
Sample	3	81	18	102	14.2	.621	.124

Tables 7-8. Frequency distributions of the left dorsal and left ventral intermuscular ribs in year classes I-V in N. crysoleucas.

Table 7. Left dorsal ribs

Class No.	33	34	35	36	No.	$\bar{x}$	s	2 S.E.
I	-	4	3	2	9	34.8	.837	.592
II	2	15	12	3	32	34.5	.750	.265
III	-	19	6	1	26	34.3	.352	.138
IV	2	15	8	-	25	34.2	.586	.234
V	1	6	2	-	9	34.1	.601	.425
Sample	5	59	31	6	101	34.4	.938	.188

Table 8. Left ventral ribs

Class No.	16	17	18	19	20	21	No.	$\bar{x}$	s	2 S.E.
I	-	4	4	-	-	1	9	17.9	3.94	2.79
II	1	13	14	3	1	-	32	17.7	.799	.283
III	-	10	14	2	-	-	26	17.7	.666	.261
IV	-	12	12	1	-	-	25	17.6	.572	.229
V	1	7	1	-	-	-	9	17.0	.500	.353
Sample	2	46	45	6	1	1	101	17.6	.842	.168

Tables 9-10. Frequency distributions of the right dorsal and right ventral intermuscular ribs in year classes I-V in *N. crysoleucas*.

Table 9. Right dorsal ribs

Class No.	32	33	34	35	36	37	No.	$\bar{x}$	s	2 S.E.
I	-	-	5	4	-	-	9	34.4	.536	.379
II	1	2	17	6	5	1	32	34.5	1.02	.362
III	-	2	13	10	1	-	26	34.4	.906	.355
IV	-	-	17	7	1	-	25	34.4	.558	.223
V	-	1	6	2	-	-	9	34.1	.601	.425
Sample	1	5	58	29	7	1	101	34.4	.100	.200

Table 10. Right ventral ribs

Class No.	16	17	18	19	20	21	No.	$\bar{x}$	s	2 S.E.
I	-	5	2	1	-	1	9	17.9	3.94	2.79
II	2	15	9	5	1	-	32	17.7	.885	.313
III	-	11	12	3	-	-	26	17.7	.724	.284
IV	-	10	13	2	-	-	25	17.7	.615	.246
V	1	6	2	-	-	-	9	17.1	.601	.425
Sample	3	47	38	11	1	1	101	17.7	.908	.182

Tables 11-12. Frequency distributions of the rays and the radials of the dorsal fin in year classes I-V in *N. crysoleucas*.

Table 11. Dorsal fin rays

Class No.	8	9	10	11	No.	$\bar{x}$	s	2 S.E.
I	-	-	10	-	10	10.0	.000	.000
II	-	1	29	2	32	10.0	.326	.115
III	-	1	22	3	26	10.1	.537	.210
IV	1	1	22	1	25	9.9	.190	.076
V	-	1	8	-	9	9.9	.335	.237
Sample	1	4	91	6	102	10.0	.370	.074

Table 12. Dorsal fin radials

Class No.	7	8	9	No.	$\bar{x}$	s	2 S.E.
I	-	10	-	10	8.0	.000	.000
II	1	30	1	32	8.0	.249	.088
III	1	21	4	26	8.1	.508	.199
IV	1	23	1	25	8.0	.283	.113
V	-	9	-	9	8.0	.000	.000
Sample	3	93	6	102	8.0	.307	.062

Tables 13-14. Frequency distributions of the hypurals of the caudal fin, and the rays of the anal fin in year classes I-V in *N. crysoleucas*.

Table 13. Hypurals of the caudal fin

Class No.	8	9	No.	$\bar{x}$	s	2 S.E.
I	10	-	10	8.0	.000	.000
II	28	4	32	8.1	.436	.154
III	23	3	26	8.1	.445	.174
IV	21	4	25	8.2	.368	.147
V	8	1	9	8.1	.335	.237
Sample	90	12	102	8.1	.339	.068

Table 14. Rays of the anal fin

Class No.	13	14	15	16	17	18	No.	$\bar{x}$	s	2 S.E.
I	1	-	3	5	1	-	10	15.5	1.08	.718
II	-	-	10	16	6	-	32	15.9	1.13	.400
III	-	-	10	7	8	1	26	16.0	.916	.359
IV	-	-	7	13	5	-	25	15.9	.689	.276
V	-	-	1	7	1	-	9	16.0	.500	.353
Sample	1	-	31	48	21	1	102	15.9	.828	.166

Tables 15-16. Frequency distributions of the radials of the anal fin, and the caudal fin rays in year classes I-V in *N. crysoleucas*.

Table 15. Radials of the anal fin

Class No.	12	13	14	15	16	17	No.	$\bar{x}$	s	2 S.E.
I	1	3	5	1	-	-	10	13.6	.843	.562
II	-	8	17	7	-	-	32	14.0	.787	.278
III	-	9	7	7	2	1	26	14.2	1.14	.445
IV	-	7	14	4	-	-	25	13.9	.653	.261
V	-	1	7	1	-	-	9	14.0	.500	.353
Sample	1	28	50	20	2	1	102	14.0	.789	.158

Table 16. Caudal fin rays

Class No.	27	28	29	30	31	32	33	34	35	36	37	38	No.	$\bar{x}$	s	2 S.E.
I	-	-	-	1	3	3	2	1	-	-	-	-	10	31.9	1.20	.797
II	-	-	-	1	3	8	7	8	3	1	-	1	32	33.2	2.51	.888
III	1	-	-	1	3	8	1	7	3	-	1	-	25	32.8	1.97	.789
IV	-	1	-	2	2	5	3	8	2	-	-	-	23	32.7	1.78	.740
V	-	-	-	-	1	2	3	-	1	1	-	-	8	33.1	1.64	1.238
Sample	1	1	-	5	12	26	16	24	9	2	1	1	98	32.8	1.75	.350

Tables 17-18. Frequency distributions of the left and right pectoral rays in year classes I-V in N. crysoleucas.

Table 17. Left pectoral rays

Class No.	13	14	15	16	17	18	19	No.	$\bar{x}$	s	2 S.E.
I	-	-	2	5	2	1	-	10	16.2	.919	.613
II	1	-	5	15	8	3	-	32	16.2	.919	.325
III	-	-	3	10	11	1	1	26	16.5	.884	.347
IV	-	1	3	11	4	4	1	24	16.4	1.24	.506
V	-	-	1	3	3	2	-	9	16.7	1.00	.707
Sample	1	1	14	44	28	11	2	101	16.4	1.109	.222

Table 18. Right pectoral rays

Class No.	14	15	16	17	18	19	No.	$\bar{x}$	s	2 S.E.
I	1	3	2	3	1	-	10	16.0	1.24	.829
II	1	2	15	11	2	1	32	16.4	.887	.314
III	-	5	8	8	5	-	26	16.5	.884	.347
IV	-	3	11	9	2	-	25	16.4	.800	.320
V	2	-	1	5	1	-	9	16.3	.447	.316
Sample	4	13	37	36	11	1	102	16.4	1.014	.202

Tables 19-20. Frequency distributions of the left and right pelvic rays in year classes I-V in N. crysoleucas.

Table 19. Left pelvic rays

Class No.	8	9	10	No.	$\bar{x}$	s	2 S.E.
I	1	9	-	10	8.9	.316	.211
II	1	30	1	32	9.0	.246	.087
III	-	25	1	26	9.0	.213	.076
IV	1	24	-	25	9.0	.198	.079
V	-	9	-	9	9.0	.000	.000
Sample	3	97	2	102	9.0	.228	.460

Table 20. Right pelvic rays

Class No.	8	9	10	No.	$\bar{x}$	s	2 S.E.
I	1	9	-	10	8.9	.316	.211
II	1	30	1	32	9.0	.246	.087
III	-	23	3	26	9.1	.448	.176
IV	1	24	-	25	9.0	.198	.079
V	1	8	-	9	8.9	.335	.237
Sample	4	94	4	102	9.0	.279	.056

Tables 21-22. Frequency distributions of quotients x 10 of the standard length to base length of dorsal fin, and to base length of anal fin in year classes I-V in N. crysoleucas.

Table 21. Base length of dorsal fin

Class No.	Quotients x 10															
	72-74	75-77	78-80	81-83	84-86	87-89	90-92	93-95	96-98	99-101	102-104	105-107	No.	$\bar{x}$	s	2 S.E.
I	-	-	1	-	2	1	2	1	1	-	-	2	10	93	9.12	6.08
II	-	-	3	4	3	8	5	7	1	1	-	-	32	88	5.42	1.92
III	-	4	1	9	6	2	2	2	-	-	-	-	26	84	5.41	2.12
IV	3	-	4	8	6	4	-	-	-	-	-	-	25	82	4.20	1.68
V	1	1	3	2	-	2	-	-	-	-	-	-	9	81	5.16	3.65
Sample	4	5	12	23	17	17	9	10	2	1	-	2	102	85	6.54	1.30

The mean difference between year classes I and III has a "t" value of 2.1951.
The mean difference between year classes II and III has a "t" value of 1.9801.

Table 22. Base length of anal fin

Class No.	Quotients x 10														
	50-51	52-53	54-55	56-57	58-59	60-61	62-63	64-65	66-67	68-69	70-71	No.	$\bar{x}$	s	2 S.E.
I	-	1	1	1	1	-	1	4	-	1	-	10	61	4.98	3.32
II	1	2	3	5	6	8	3	4	-	-	-	32	59	3.52	1.25
III	-	-	6	6	5	3	3	2	1	-	-	26	59	3.81	1.49
IV	-	2	7	3	5	1	4	2	-	-	1	25	58	4.41	1.76
V	1	2	2	2	-	1	-	1	-	-	-	9	56	4.30	3.03
Sample	2	7	19	17	17	13	11	13	1	1	1	102	59	4.18	0.84

Tables 23-24. Frequency distributions of quotients x 10 of the standard length to pelvic fin length, and to pelvic girdle length in year classes I-V in *N. crysoleucas*.

Table 23. Pelvic fin length

Class No.	Quotients x 10														
	50-52	53-55	56-58	59-61	62-64	65-67	68-70	71-73	74-76	77-79	80-82	No.	x̄	s	2S.E.
I	-	-	3	2	3	-	1	-	-	-	1	10	63	6.84	4.56
II	1	1	4	8	10	5	3	-	-	-	-	32	62	4.27	1.51
III	-	2	11	6	4	3	-	-	-	-	-	26	60	4.02	1.58
IV	2	5	8	7	2	1	-	-	-	-	-	25	58	3.55	1.42
V	-	4	3	2	-	-	-	-	-	-	-	9	56	2.05	1.45
Sample	3	12	29	25	19	9	4	-	-	-	1	102	60	4.70	0.94

Table 24. Pelvic girdle length

Class No.	Quotients x 10												
	110-116	117-123	124-130	131-137	138-144	145-151	152-158	159-165	166-172	No.	x̄	s	2S.E.
I	-	1	1	-	1	1	2	3	1	10	150	15.19	10.13
II	1	5	6	7	9	1	2	1	-	32	135	11.22	3.97
III	1	5	9	3	5	2	1	-	-	26	133	10.67	4.18
IV	4	5	6	8	2	-	-	-	-	25	127	9.37	3.75
V	2	2	3	-	-	2	-	-	-	9	128	13.63	9.63
Sample	8	18	25	18	17	6	5	4	1	102	133	12.72	2.54

The mean difference between year classes I and II has a "t" value of 2.1276.
The mean difference between year classes II and IV has a "t" value of 2.0725.

Tables 25-26. Frequency distributions of quotients x 10 of the standard length to length of the first left rib, and to pectoral fin length in year classes I-V in N. crysoleucas.

Table 25. Length of first left rib

Class No.	Quotients x 10												
	49-51	52-54	55-57	58-60	61-63	64-66	67-69	70-72	73-75	No.	$\bar{x}$	s	2 S.E.
I	-	-	-	-	2	3	1	3	1	10	67	4.51	3.01
II	-	1	-	5	7	11	4	3	1	32	64	4.23	1.50
III	-	-	4	7	12	2	1	-	-	26	61	2.88	1.13
IV	-	2	5	8	7	2	1	-	-	25	59	3.36	1.34
V	3	1	3	1	1	-	-	-	-	9	55	4.04	2.85
Sample	3	4	12	21	29	18	7	6	2	102	62	5.02	1.00

The mean difference between year classes I and III has a "t" value of 2.9126.
The mean difference between year classes II and III has a "t" value of 2.2900.

Table 26. Pectoral fin length

Class No.	Quotients x 10														
	47-48	49-50	51-52	53-54	55-56	57-58	59-60	61-62	63-64	65-66	67-68	No.	$\bar{x}$	s	2 S.E.
I	-	-	1	3	1	2	-	1	2	-	-	10	57	4.72	3.15
II	-	3	2	9	5	6	4	1	2	-	-	32	56	3.72	1.32
III	1	2	7	6	1	5	2	-	1	-	1	26	55	4.42	1.73
IV	2	2	8	8	3	2	-	-	-	-	-	25	53	2.74	1.10
V	2	4	1	2	-	-	-	-	-	-	-	9	50	2.14	1.51
Sample	5	11	19	28	10	15	6	2	5	-	1	102	54	4.15	0.84

The mean difference between year classes I and V has a "t" value of 3.0042.
The mean difference between year classes II and IV has a "t" value of 2.4793.
The mean difference between year classes IV and V has a "t" value of 2.2900.

Tables 27-28. Frequency distributions of quotients x 10 of the third dorsal ray to last dorsal ray, and of the third anal ray to last anal ray in year classes I-V in N. crysoleucas.

Table 27. Dorsal rays

Class No.	Quotients x 10																
	22	23	24	25	26	27	28	29	30	31	32	33	34	No.	$\bar{x}$	s	2 S.E.
I	1	-	1	1	2	-	3	-	1	-	1	-	-	10	27	2.97	1.98
II	-	1	-	1	1	4	9	-	11	-	3	2	-	32	29	2.22	0.78
III	-	1	-	1	3	1	4	5	8	1	1	2	-	26	29	2.37	0.93
IV	-	-	-	-	-	4	3	6	6	3	1	-	1	24	29	1.71	0.70
V	-	-	-	1	1	1	2	1	1	1	1	-	-	9	28	2.22	1.57
Sample	1	2	1	4	7	10	21	12	27	5	7	4	1	101	29	2.34	0.46

Table 28. Anal rays

Class No.	Quotients x 10																
	22	23	24	25	26	27	28	29	30	31	32	33	34	No.	$\bar{x}$	s	2 S.E.
I	1	-	2	1	-	-	2	-	1	-	-	3	-	10	28	3.96	2.64
II	-	-	3	6	6	1	12	-	3	-	-	-	-	31	27	1.84	0.66
III	-	-	4	2	2	1	5	2	6	1	1	-	1	25	28	2.61	1.04
IV	-	-	1	-	5	4	3	2	4	2	1	-	1	23	28	2.43	1.01
V	-	-	-	-	2	1	2	1	1	-	-	1	-	8	28	2.34	1.77
Sample	1	-	10	9	15	7	24	5	15	3	2	4	2	97	28	2.55	0.52

Figure 1. A graphical comparison of the length frequencies from five year classes of *N. crysoleucas*.

Fig. 1

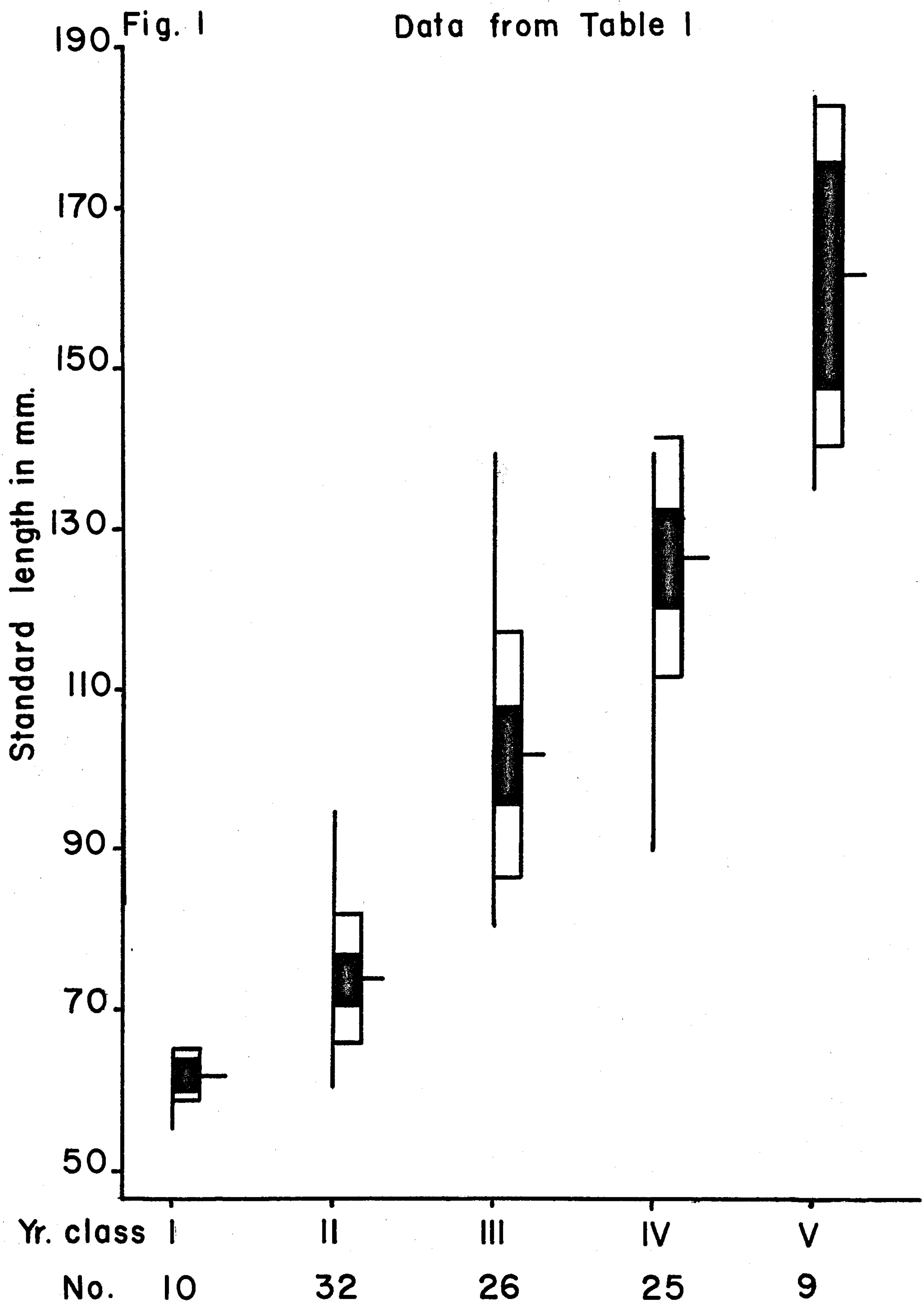

Data from Table I
190
170
150
130
110
90
70
50
Standard length in mm.
Yr. class I II III IV V
No. 10 32 26 25 9

Figure 2. A graphical comparison of quotients x 10 of standard length to base length of the dorsal fin in five year classes of *N. crysoleucas*.

Fig. 2 Data from Table 21

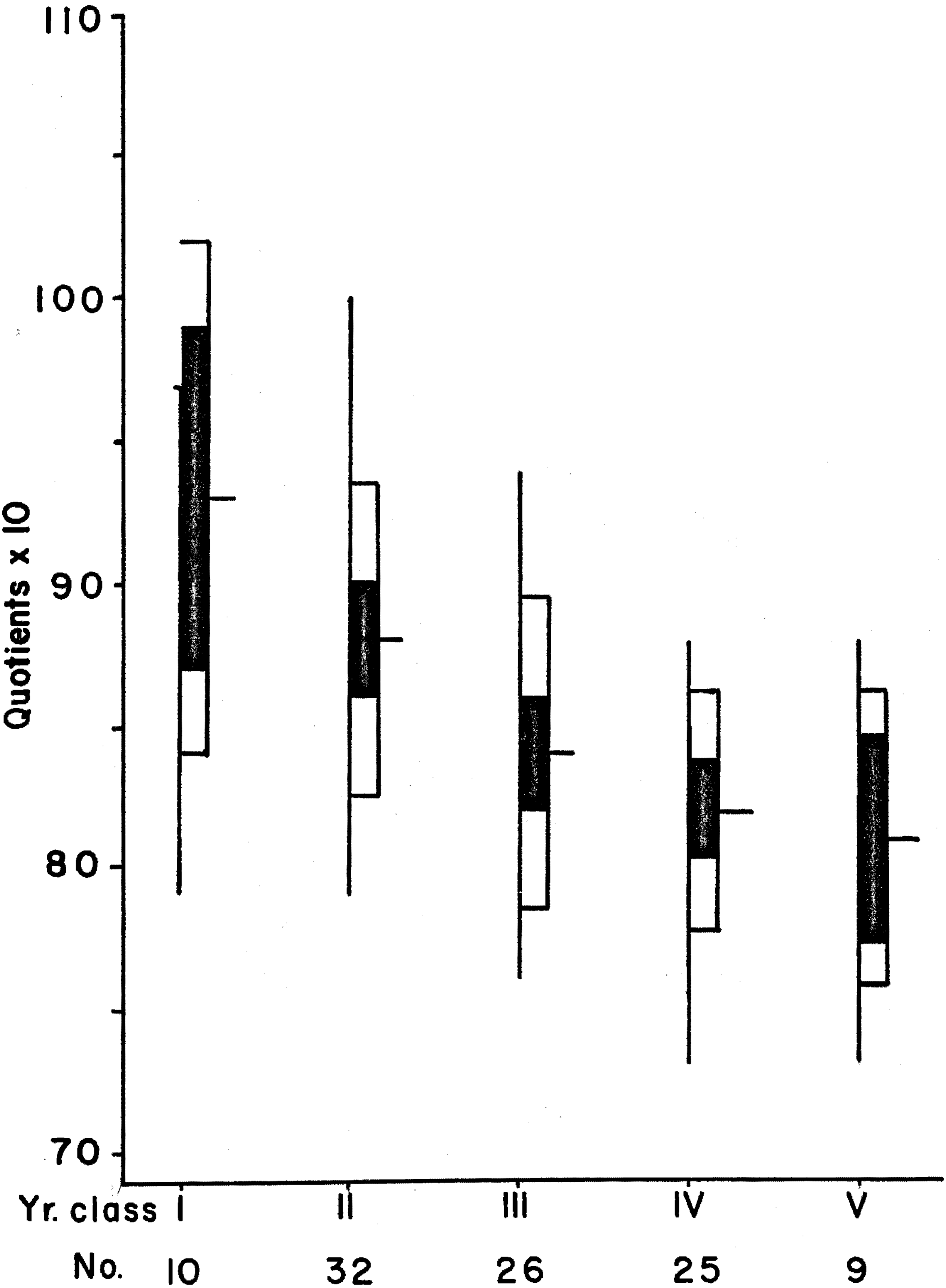


Figure 3. A graphical comparison of quotients x 10 of standard length to length of the pelvic girdle in five year classes of *N. crysoleucas*.

Fig. 3 Data from Table 24

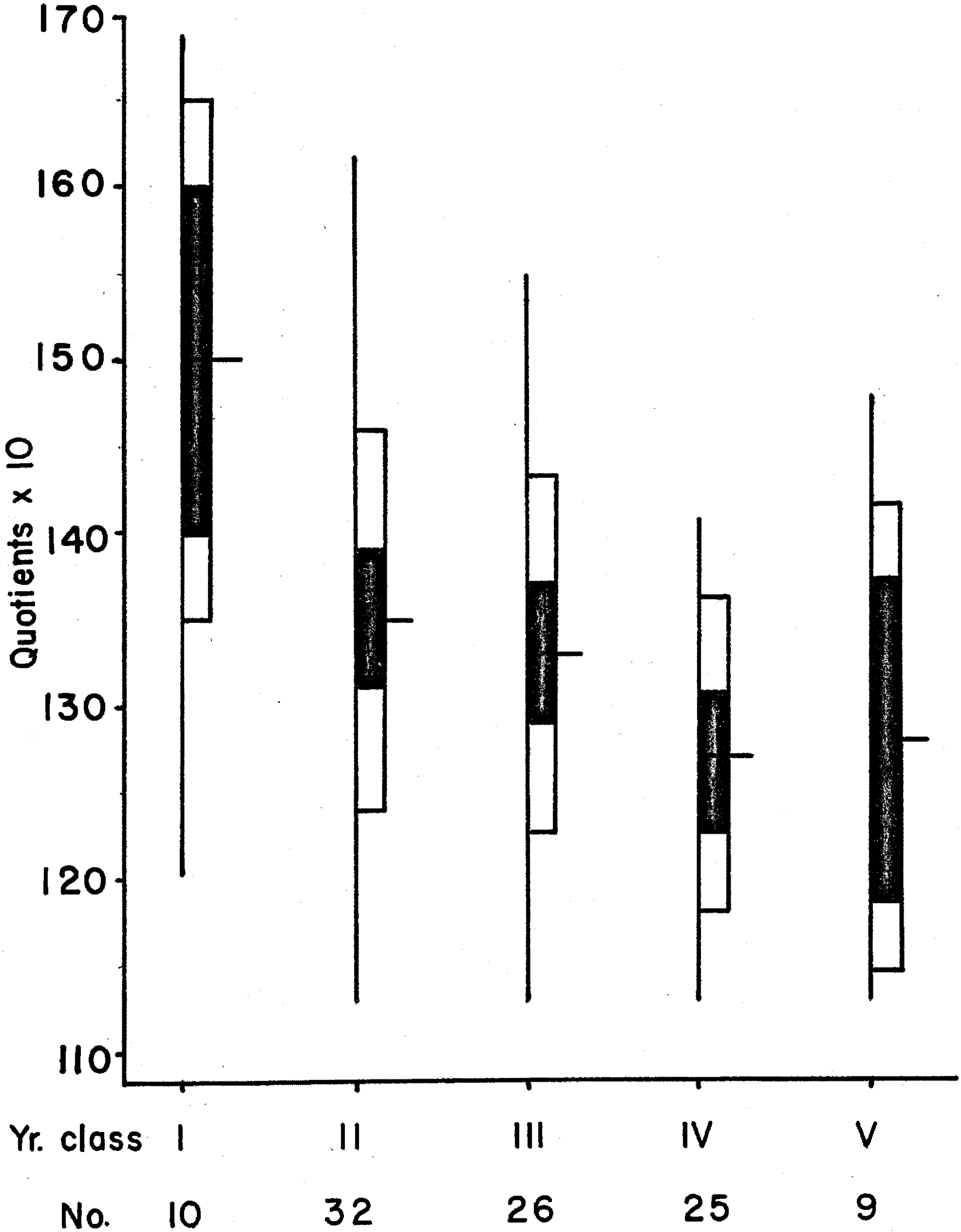


Figure 4. A graphical comparison of quotients x 10 of standard length to length of the first left rib in five year classes of *N. crysoleucas*.

Fig. 4 Data from Table 25

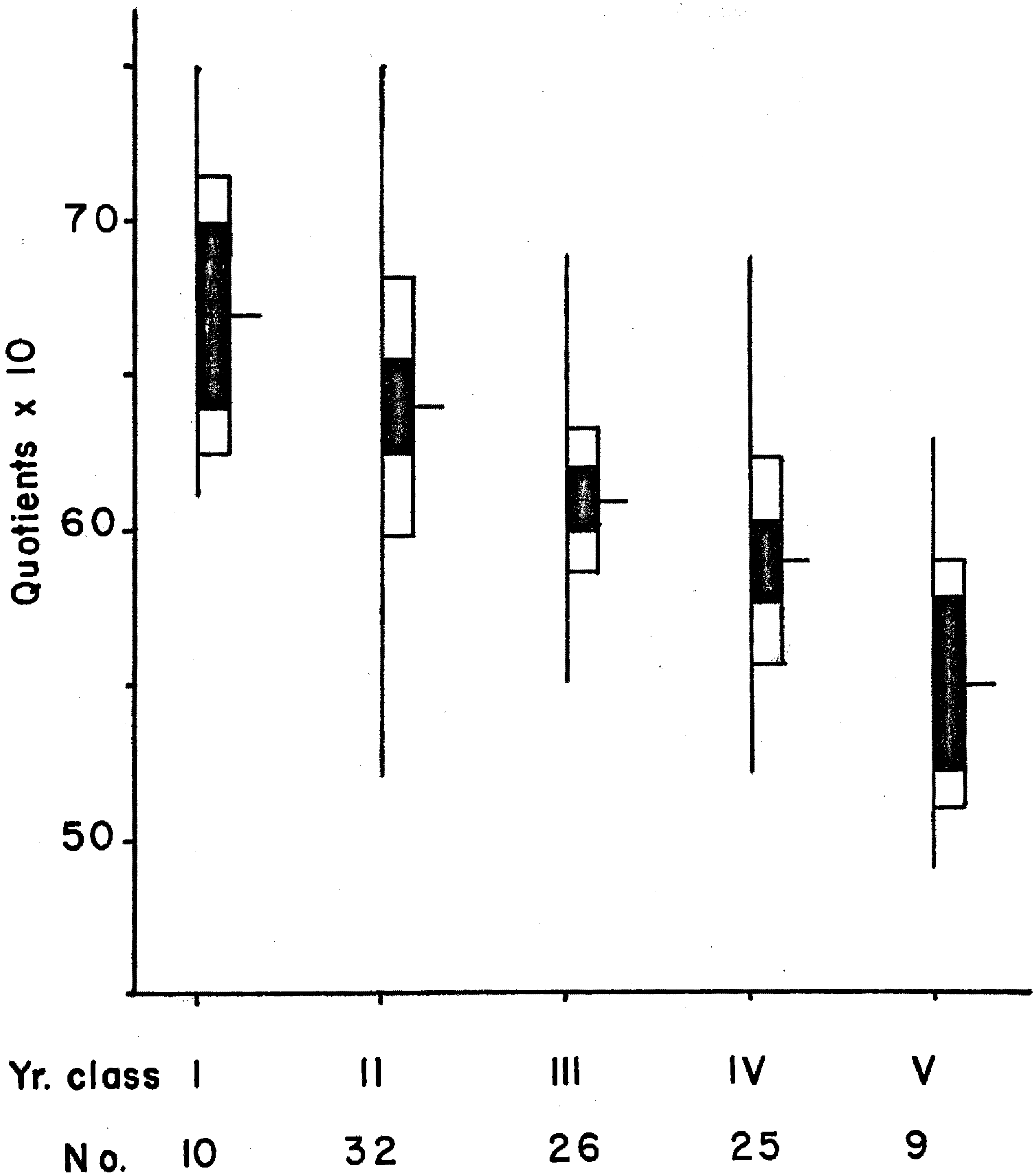


Figure 5. A graphical comparison of quotients x 10 of standard length to length of the pectoral fin in five year classes of *N. crysoleucas*.

Fig. 5

Data from Table 26

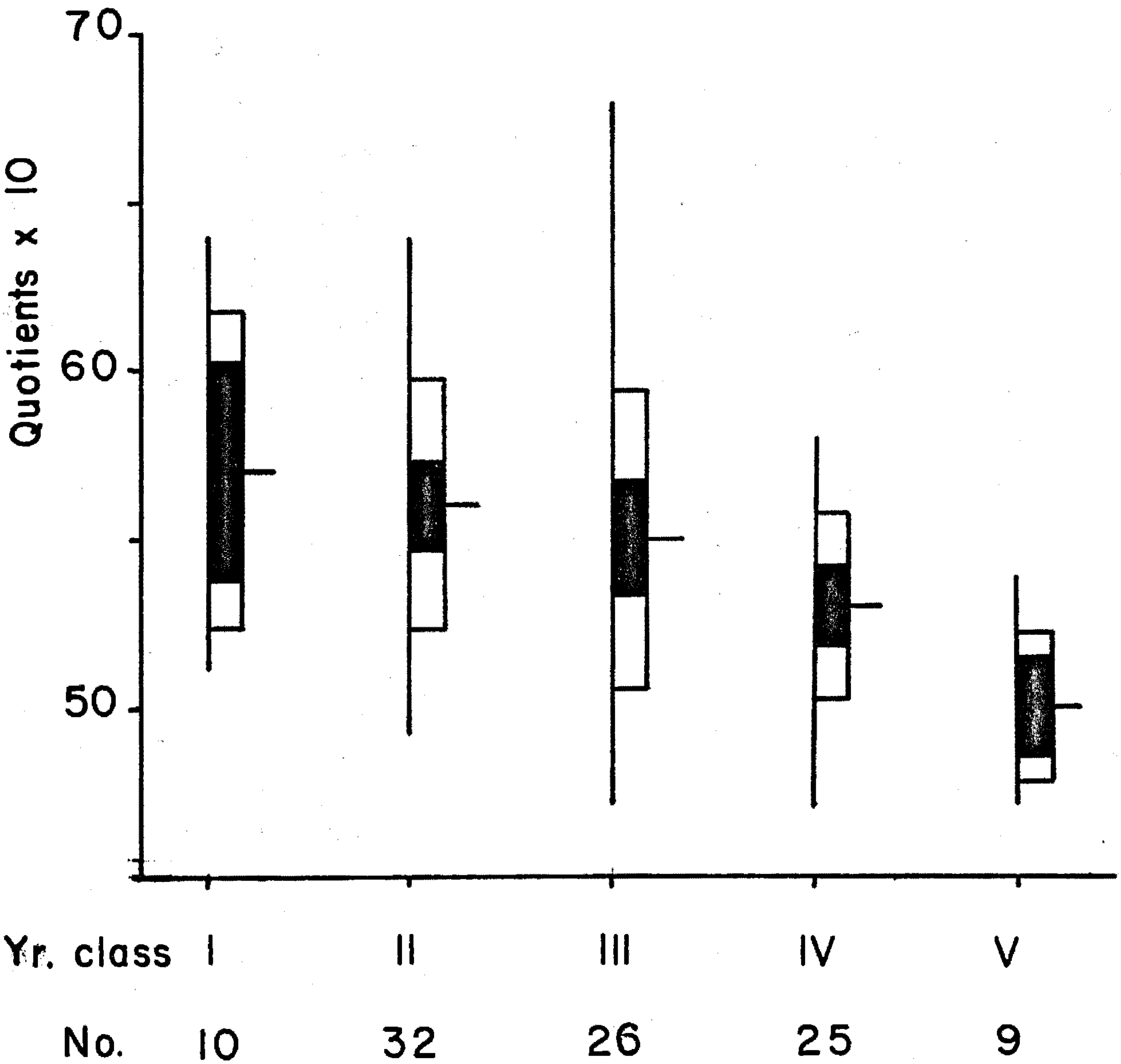
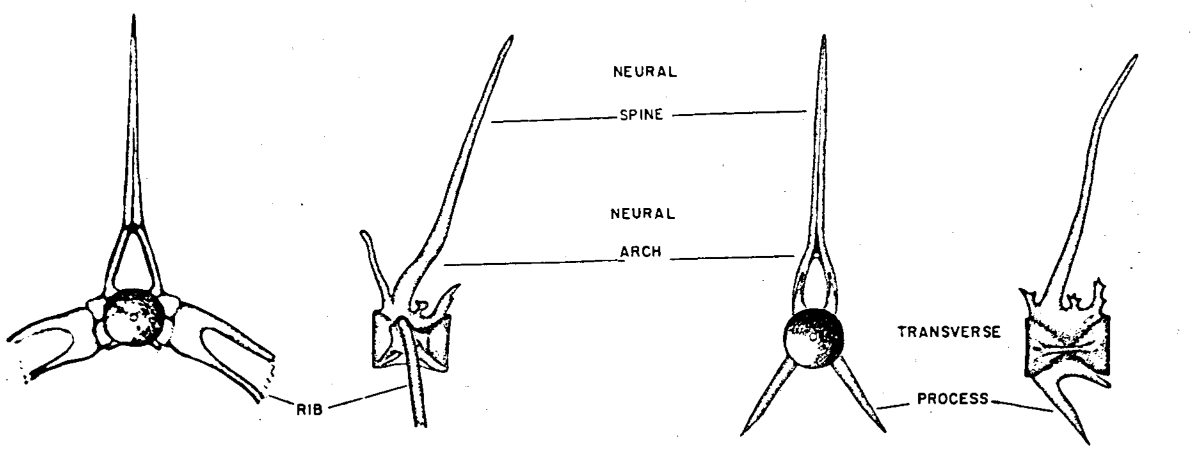


Plate I



Anterior View Left Side

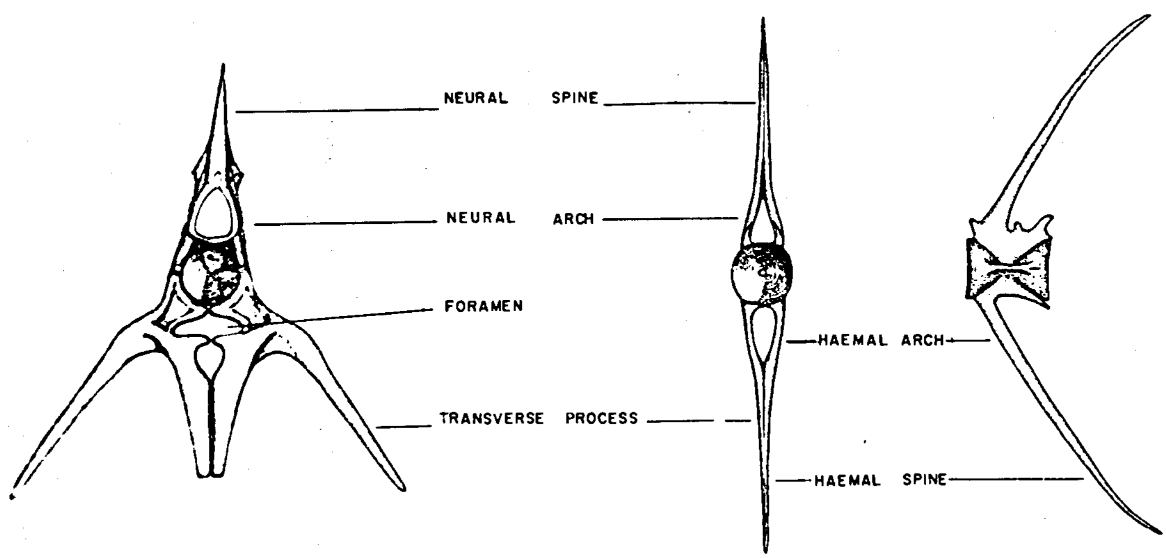
Fig. A.

Trunk Vertebra 5.

Anterior View Left Side

Fig. B.

Trunk Vertebra 18.



Posterior View

Fig C

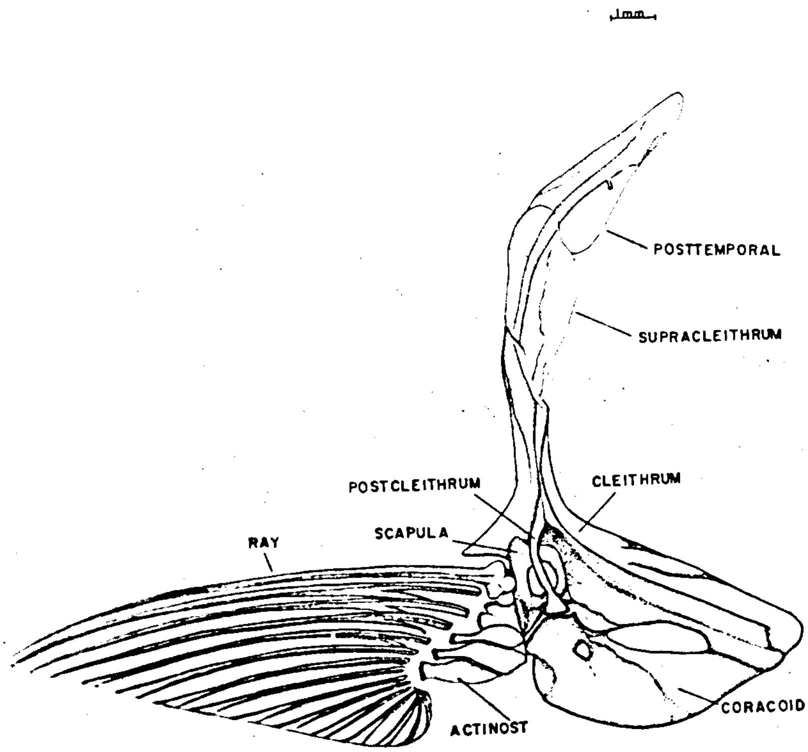
Trunk Vertebra 4.

Anterior View Left Side

Fig. D.

Caudal Vertebra 6.

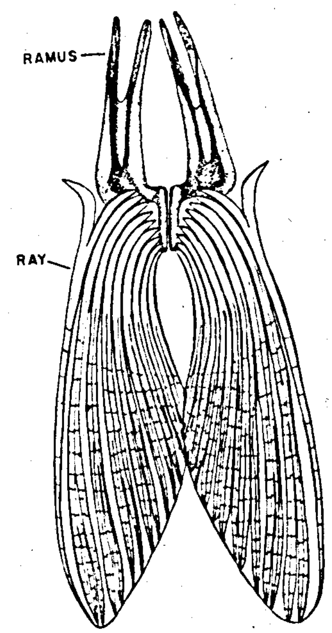
Plate II



Anterio-mesial View

Fig. A.

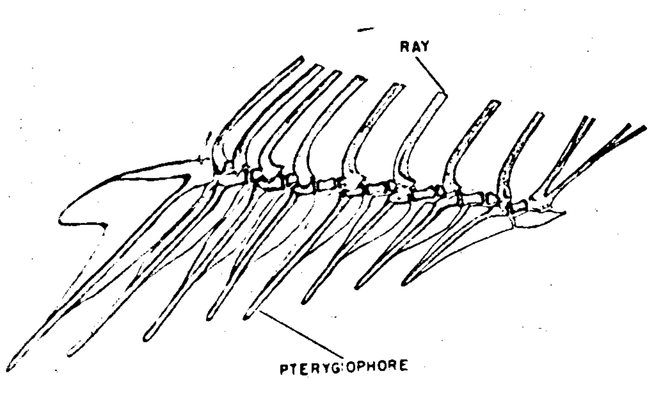
Left Pectoral Girdle and Fin



Ventral View

Fig. B.

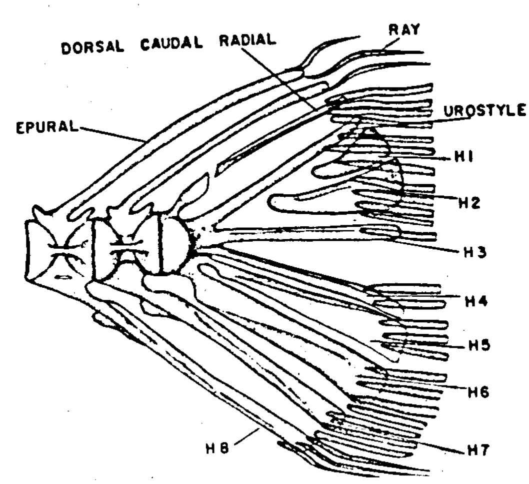
Pelvic Girdle and Fins



Left Side

Fig. C

Dorsal Fin



Left Side

Fig. D

Hypural Plate H= Hypural

Plate III

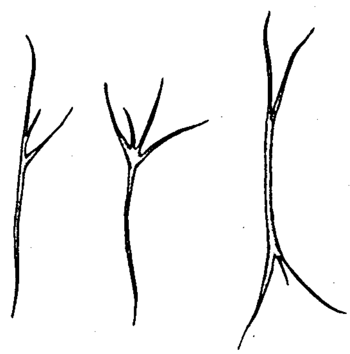
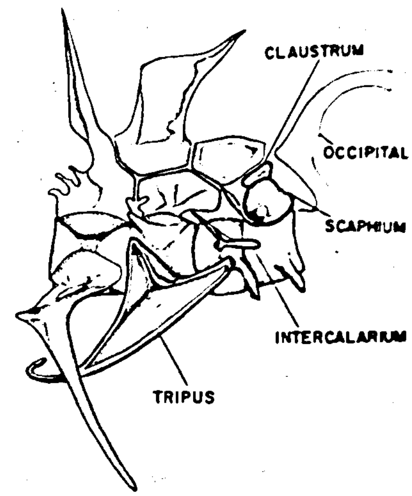


Fig. A.

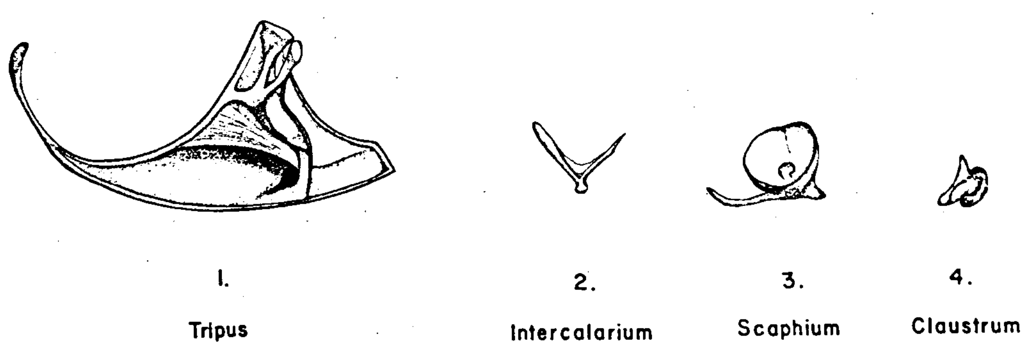
Intermuscular Ribs



Right Side

Fig. B.

Vertebrae 1-4



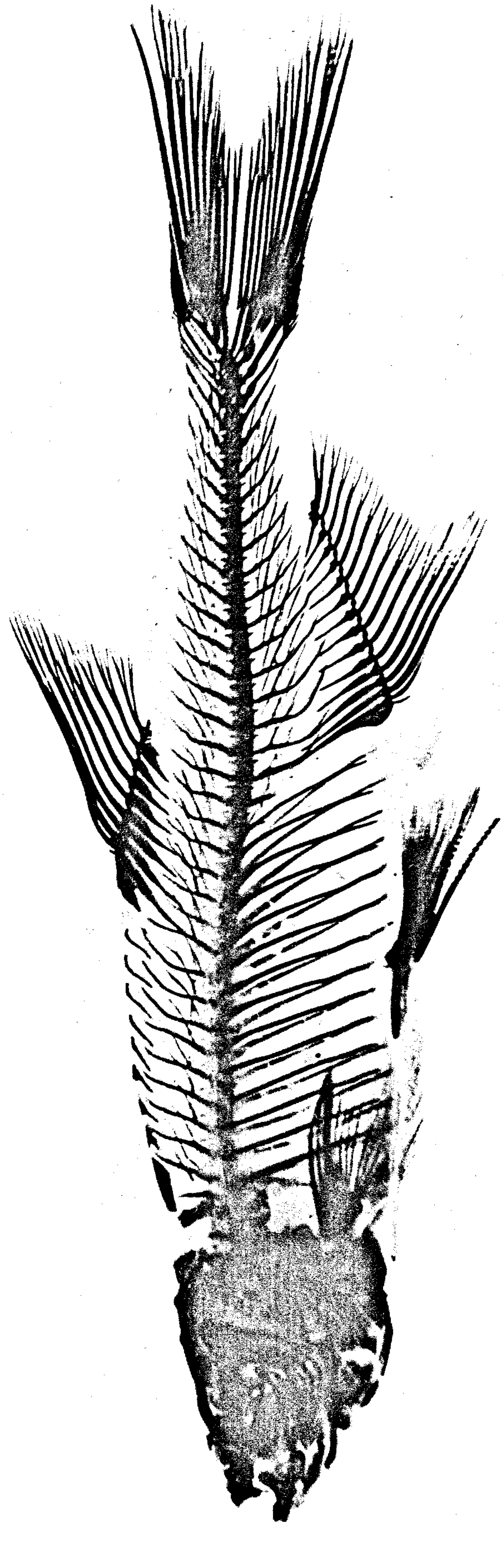
Median View

Fig. C.

Weberian Ossicles

A 70 mm. cleared specimen of _N. crysoleucas_

Plate IV



BIOGRAPHY

Aaron Hathaway O'Bier, Jr. was born June 24, 1926 at Miami, Florida. He attended public school in Northumberland and Westmoreland Counties in Virginia from 1932 to 1946. The interval from 1943 to 1945 was spent in service as a radio operator on a mine sweeper for the U. S. Navy. In 1947 he entered the University of Richmond and graduated in August 1951 with a B. A. degree. The following year was spent teaching in public high school in Dinwiddie County, Virginia, after which he re-entered the University of Richmond for graduate study. At the close of this first year of graduate school, June 14, 1953, he was married to Kathleene A. Cooke. In July of 1953 he went to the Medical College of Virginia as an instructor in biology for the school of Pharmacy. Part-time graduate study was pursued during this two and a half years. In February 1956 he returned to the University of Richmond to complete a program for the M. A. degree in biology.