THE SYSTEMATICS
OF THE FRESHWATER SCULPINS
OF BRITISH COLUMBIA

by

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We accept this thesis as conforming to the
required standard

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ABSTRACT

A systematic study was made of the genus *Cottus*, emphasizing the species of British Columbia. Some five thousand specimens from the Institute of Fisheries museum were used to construct distribution maps. Intensive examination before and after clearing and staining with alizarin or X-raying was made of 745 B.C. specimens and several exotic species. Color pattern, sex body proportions, prickles and the number of fin rays, lateral line pores, operculomandibular pores, caudal vertebrae, and preopercular spines were noted. Specific descriptions employing these characters were constructed. A new species found by Bailey is reported and described; *philonips* is synonomized with *cognatus*. Intraspecific variation in meristic characters showed modification with habitat, distance from the sea, altitude, latitude, populations and in some cases with sex. Interspecific comparisons revealed differences which were evaluated and made into a key of B.C. species. Supraspecific study showed the existence of three species groups having different counts of caudal vertebrae and other characteristics. A key is given to the species groups.

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INTRODUCTION

The genus Cottus is a closely-knit group of small fish inhabiting the fresh and brackish waters of the holarctic region. For several reasons they have been a challenge to the systematist. Convergent and divergent evolution in characters, such as dentition and number of pelvic fin rays, have been misleading. The variability of populations has led to the naming of invalid species. Phenotypic and genotypic variation is so great that characters normally used in definition of species cannot be applied.

This thesis attempts to clarify the definitions of B.C. species of Cottus, to determine their relations with other species, and to find species groups within the genus. An intensive study has been made of the variation, particularly clinal, of British Columbia species. Literature research has enabled suggestion of possible causes of variation. Differences between B.C. species have been determined and summarized in a key. Some exotic species were examined and this and the literature has allowed determination of relationships of species and species groups.

ORGANIZATION

This thesis is concerned with the variation of taxonomic characters within a single species, between species, and between groups of species. There are five main sections. The first reviews the literature on how and why meristics (serially repeated parts) vary. The second describes methods. The third section describes each B.C. species and its variation. The fourth deals with interspecific differences and the relations of B.C. species, and presents a key to B.C. species. The last section discusses the species groups in Cottus - all species, and terminates in a key.

LITERATURE ON MERISTIC VARIATION

One of the problems in taxonomy of Cottus has been the lack of knowledge of the variability, and the causes of variability in taxonomic characters. Since experiments on raising sculpins under different conditions failed, the possible causes of variation must be derived mainly from the literature on other genera. The discussion which follows is limited to serially repeated or meristic characters.

Experiments on Variation

The raising of fish eggs under constant environmental conditions has revealed two major controls of meristics. Environmental differences during development may modify meristic characters. Differences in factors such as temperature may result in different numbers of fin rays in lots of young from the same parent. Likewise, heredity may influence the number of parts in the progeny, for when offspring from different parents are raised under identical conditions the characters of the progeny are found to be similar to those of their parents. Literature on experiments on meristic variation is summarized in Table I.

Heredity

Schmidt (1917, 1919) (see Table I) showed that the tendency for the number of dorsal fin rays can be inherited. Gabriel (1944) found that high parental numbers of vertebrae were associated with high vertebral numbers in the offspring. According to Taning (1952) late determined characters - dorsal and pectoral rays are less subject to genetic control than are early determined characters such as vertebrae. Lindsey (1952) stated that every meristic character studied in Gasterosteus aculeatus showed genetic differences.

Environmental Effects

Table I lists the species in which certain environmental factors have been shown to produce differences in the serial characters. It is evident that average temperature, changes in temperature, salinity, oxygen and carbon dioxide pressure and light intensity have been able to modify certain characters during development. Scales, total vertebrae, caudal vertebrae, dorsal, anal, caudal and pectoral fin rays, dorsal and anal spines, the basals of dorsal and anal rays have shown themselves modifiable.

Temperature

Most investigators have reared fish at only two temperatures.

TABLE I
EXPERIMENTAL STUDIES OF MERISTIC VARIATION

AUTHOR	SPECIES	MERISTIC	OBSERVED CORRELATION
Temperature			
Bailey and Gosline, 1955	Etheostoma nigrum	Vert.	Negative
Dannevig, A. 1950	Pleuronectes platessa	Vert.	Negative
Fox, W. 1948	Snake - Thamnophis elegans atratus	Several scale series	Positive
Gabriel, M.L. 1944	Fundulus heteroclitus	Vert.	Negative, hereditary
Heuts, M.J. 1947b	Gasterosteus aculeatus Marine and freshwater populations	D, A, P.	Modified differently in two groups and at different salinities
Lindsey, C.C. 1952	Gasterosteus aculeatus	D_1 basals, D_2 and A basals, C Vert., P.	Positive Negative Lowest at intermediate temp. All hereditary
	Pygosteus pungitius	D_2 and A basals Vert.	Positive Lowest at intermediate temp.
	Macropterus opercularus	A Vert., A and D_2 basals, A spines	Negative Negative
Mottley, C.M. 1934	Salmo gairdneri	Lateral line scales	Negative
ibid 1937	Salmo gairdneri	Vert.	Positive and negative

TABLE I (continued)

AUTHOR	SPECIES	MERISTIC	OBSERVED CORRELATION
<u>Temperature</u>			
Schmidt, J 1917, 1919	<u>Lebistes reticulatus</u>	D_2	Positive and hereditary
ibid 1920	<u>Zoarces viviparous</u>	Vert.	Modified by salinity of temperature.
Tåning, A. 1952	<u>Salmo trutta</u>	Vert. D_2,A,P.	Lowest at intermediate temp. Highest at intermediate temp. All hereditary.
<u>Temperature Change</u>			
Tåning, A. 1946	<u>Salmo trutta</u>	Vert.	Radical effect at 100 day-degrees
<u>Light Intensity</u>			
McHugh, J.L. 1954	<u>Leuresthes tennuis</u>	Vert.	Negative
Vibert, R. 1953	<u>Salmo salar</u>	Vert.	Partial darkness produced most
<u>Salinity</u>			
Heuts, M.J. 1947b	<u>Gasterosteus aculeatus</u> Marine and freshwater populations	D_2A,P.	Modified differently in two groups and at different temperatures.
<u>Other Factors</u>			
Oxygen concentration			
Tåning, A 1952	<u>Salmo trutta</u>	Vert.	Negative
Carbon dioxide concentration			
Tåning, A 1952	<u>Salmo trutta</u>	Vert.	Positive

D_1 = dorsal spines
D_2 = dorsal rays
A = anal rays
P = pectoral rays
Negative = negative correlation with factor

Frequently unwarranted conclusions have been drawn; e.g., that vertebrae increase with developmental temperature. Schmidt, Tåning, and Lindsey have shown, using three or more temperatures, that the relationship between temperature and vertebrae is "V" shaped, with the highest or lowest vertebral number at intermediate temperatures. Furthermore, Tåning (1952) found that moderate temperature changes during a certain sensitive period of development could cause large differences in the number of vertebrae. This effect and the effects of sustained temperature during development suggest great caution be used in the application of meristic characters in taxonomy. If populations from locals of quite different temperatures are meristically different, it should not be assumed that the difference is genetic. Ideally, eggs from the two populations in question should be raised under identical conditions before they are declared to be taxonomically distinct.

Salinity

Experiments by several workers (see Table I) have shown that salinity may modify meristic characters. Heuts found that nitrates and phosphates had no effect. It seems likely that the chlorides are the ingrediant causing the differences. Freshwater species might possibly be affected similarly by other dissolved solids.

Light

McHugh (1954) found that light intensity could influence the number of vertebrae in the grunion, *Leuresthes tennuis*. Light was found to be more important in determining vertebrae than were temperature and temperature and salinity, the results of which were too variable to analyze. Work done by the author under C.C.Lindsey indicated that the rate at which the vertebrae were ossified could be influenced by the intensity of light in Catostomus catostomus, and the number of somites was affected by light-duration. These experiments are significant because they determine the effect of two factors (day-length and light intensity) which change with latitude. Latitudinal clines in meristic characters, often observed in fish, might be the result of change northward in either of these two factors or both.

Interaction

It is quite probable that the number of parts a fish has are not the result of the single effect heredity, or temperature, or salinity, or light or other factors. Probably variability and clines are the products of interaction of two or more of these factors. Lindsey (1952) found that temperature modified the effect of salinity. Other factors also probably interact.

Biological Complications

Generally speaking, it becomes colder away from the equator. It is quite possible, however, that fish at different latitudes spawn at the same temperature rather than at the same time of the year. These fish would be exposed to different light conditions. The conditions in which fish "select" to spawn may have a large influence upon the environment to which the developing egg is exposed.

It may be seen that a changing complex of factors change latitudinally. The effect of biological factors, genetic characters and environmental influences need to be determined before meristic clines are understood.

GEOGRAPHIC VARIATION

Meristic characters can be correlated with several geographic features. Meristic characters have been shown to change with altitude, latitude, distance from the sea, salinity and habitat. These features do not necessarily cause the differences, which may be the result of associated environmental factors (such as temperature).

Latitudinal Variation

Clines in meristic characters with latitude are shown to occur in several species of several families of teleosts in Table 2. These are merely a sample of numerous instances in the literature. Clines exist in several meristic characters such as dorsal spines, dorsal, anal and pectoral rays, vertebrae and caudal vertebrae. In the majority of cases there is an increase in meristic parts away from the equator (see Vladykov, 1934 and Hubbs, 1926). Clines may also occur in which parts increase towards the equator or in which they may increase both north and south. Bailey and Gosline (1955) have found increases in vertebrae from east to west. Some workers, such as Sato and Kato (1951) and Egami (1954), have found no relationship between meristic characters in fish and latitude.

TABLE 2

EXAMPLES OF LATITUDINAL VARIATION IN MERISTIC CHARACTERS

CLASSIFICATION	CHARACTER	CLINE	LOCALITY	SOURCE
CLASS TELEOSTOMI				
Clupeidae *Clupea pallasi*	vert. A & P	↓	35-60°; sw west NA.	McHugh, J.L. 1954
Engraulidae *Engraulis mordax*	vert. D & A	↓↑	30-50°; sw west N.A.	McHugh, J.L. 1941
Salmonidae *Oncorhynchus tshawytscha*	vert.	↓	38-41°; fw west N.A.	McGregor, E.A. 1924
Osmeridae *Thaleichthys pacificus*	vert.	↓	49-56°; fw west N.A.	Hart & McHugh 1944
Cyprinidae *Notemigonus crysoleucas* *Richardsonius balteatus*	 anal rays anal rays	↑ ↓	28-43°; fw east N.A. 49-55°; fw west N.A.	Schultz, L.P. 1926 Lindsey, C.C. 1953
Ictaluridae *Ictalurus nebulosus*	anal rays	↑	east N.A.	Hubbs, C.L. 1940
Gadidae *Cheragra chalcogramma*	D 1, 2 & 3 A 1 & 2	↓	49-60°; sw west N.A.	Schultz & Wel- ander 1935
Syngnathidae *Syngnathus californiensis*	D	↑↓	28-60°; sw west N.A.	Herald, E.S. 1941
Atherinidae *Menidia beryllina*	D_2	↓	26-41°; sw. east N.A.	Gosline, W.A. 1948
Percidae several species	vert.	↓	fw; east N.A.	Bailey & Gos- line 1955
Clinidae *Gibbonsia elegans*	A & D spines	↓	sw; west N.A.	Hubbs, C.L. 1927
Stichaeidae *Anoplarchus purpurescens*	D spines	↓	sw; west N.A.	Hubbs, C.L. 1927
Cottidae *Leptocottus armatus* *Cottus asper* [illegible] *Cottus rhotheus*	 D_2 & A D & caud.vert. D & caud.vert.	↓ ↓ ↓ ↑	sw; west NA. 37-50°; fw west N.A. "	Hubbs, C.L. 1921b Northcote, T.G. 1950 "
Cyclopteridae *Liparis liparis*	A	↓	Spitzbergen to Norway; sw	Vladykov, V. 1934
Pleuronectidae *Platichthys stellatus*	D	↓	sw; Alaska to California	Townsend, L.D. 1937
CLASS REPTILIA				
Thamnophis megalops	D scales	↓		Ruthven, A. 1908
Opheodrys vernalis	caudal scales	↑		Grobman, A. 1941
Thaleophis 4 sp.	ventral scales	↓		Oliver, J. 1949
Cnemidophorus sexlineatus	parietal "	↓		Hoffman, R. 1949

Arrow points in direction of decrease of character, north being top, south bottom of page.

vert. = vertebrae
caud. = caudal
D = dorsal rays
A = anal rays
P = pectoral rays

fw = breed in fresh,
sw, in salt water.
N.A. = North America
35-60° = degrees of latitude north of the equator.

all differ geographically and it is possible that they are the cause of geographic variation in meristics. Geographic clines might well be explained in terms of environmental clines. Average temperature, rate of change of temperature, light intensity, day-length, and light quality all change with latitude. All could theoretically affect meristics.

It is also possible that geographic clines are hereditary. Lindsey (1953) believed that the latitudinal clines in anal rays of Richardsonius balteatus were genetic. Clines could be due to change in gene composition from one end of the range to the other. These genetic clines could be due to chance mutation and slow transmission of hereditary factors from one end of the distribution to the other. Because of their frequency and because they are usually in the same direction in different groups, it is likely that they are the result of selection, rather than chance. For instance, it might be advantageous to have more fin rays in colder water because of its greater density. Possibly metabolic rates or other internal factors are clinal, and these indirectly result in production of meristic clines.

METHODS

Some 5000 specimens of sculpins from the collections of the Institute of Fisheries, U.B.C. were identified or checked. New collections were made (see acknowledgements). Specimens were then selected for study from the larger collections of each species. An attempt was made to cover the range of each species in B.C. as well as the collection permitted. A few exotic species were also studied to determine relationships between species. Both external and internal characters were studied.

External Characters

The external characters were determined first. Certain body proportions were measured using vernier calipers accurate to .1 mm. Head length was measured from the anterior tip of the upper lip to the posterior tip of the opercular bone. Caudal peduncle depth was the least depth of that part. Standard length was taken from the most anterior portion of the body to the posterior edge of the hypural.

Color and tubularity of the posterior nostril were noted. The lateral line pores were counted commencing behind the operculum and ending where the lateral line ceased. In some specimens slight interuptions occurred at the end of the lateral line, leaving small sections of lateral line past the end of the completed portion (which are not mentioned by Robins (1954). These extra portions were not counted.

Internal Characters

To determine internal characters the specimens were stained in alizarin and cleared in KOH under ultraviolet radiation and glycerine by the method given by Hollister (1934). Some were x-rayed. From cleared specimens and x-rays plates counts were made under a binocular microscope. Dorsal spines, dorsal, caudal, anal, ventral, pectoral and branchiostegal rays, preopercular spines, caudal vertebrae, the presence of palatine teeth, and the degree and extent of prickling were determined. Occasionally fins were damaged in clearing and counts could not be made. This is the reason why some counts of different characters in a sample are not equal.

All of the dorsal spines were counted, even though in some species there were two spines on the first basal. The number of spines on the first basal (no basals existed in front of the fin) were noted - one or two. The spines could be distinguished readily from the rays by their slenderness and lack of annulae.

The last two rays of the dorsal and anal fins were counted as one when they sat on the same basal. This method was used so that counts from the literature would be comparable. This procedure is open to some objection, as it is actually a basal count rather than a ray count. This would be an understandable method in groups of fishes where the last ray is actually branched, but does not differentiate between forms having one or several rays on the last basal. In some species of Cottus cognatus only one ray occurred on the last basal. The counting method does not separate these fish from fish having two rays on the last basal.

As one spine was always present in each of the ventral fins it was not designated in counts. This and the outermost ray are bound together and can only be distinguished in cleared or dissected fins. Except for two or three specimens with 2 or 5 rays, the ventral fin always contained 3 or 4 rays. In Cottus cognatus the fourth ray was absent or of varying length, and its length was visually estimated as a small fragment 1/5, ¼, 1/3, ½, 2/3, 3/4 of the longest ray. The left fin was always counted. The number of rays in the pectoral fin and in the branchial membrane (branchiostegals) was also enumerated.

Counts of caudal vertebrae were made using the method given by Schultz (1930). Wherever vertebrae are mentioned in this paper, caudal vertebrae are referred to, unless otherwise designated. A few counts of abdominal vertebrae were also made. Following McHugh (1941) columns containing abnormal vertebrae were not counted. The number of spines on the left preopercle was counted. Unless the preopercle erupted into a sharp elevation it was not considered a spine; low bumps were not considered spines. Unless the two inner and outer plates composing the preopercle fused together to form a point a spine was not enumerated.

Scales are absent in Cottus; small spines, termed prickles (see fig. 3) are present in the skin. The amount of the body prickled varied between different species and within species. To evaluate differences in extent of prickling the body was divided into areas (see fig. 1) which were designated as a-----j. The intensity of prickling, that is how close the prickles were to one another, was also determined. The intensity was estimated and given a value of from 1 to 4, 1 being the lowest; 4 being the highest intensity. At intensity 4 the bases of the prickles were in contact; at 1 they were widely dispersed, only about half a dozen prickles being present in an area.

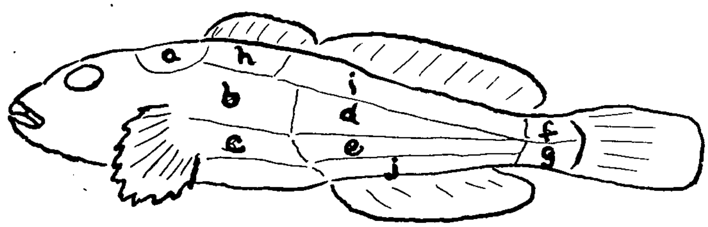


Figure 1.

Areas of prickling.

Sex was determined by dissection on some individuals. Ovaries are round in cross-section and covered by a definite membrane. On breaking the membrane eggs can often be seen. Testes are triangular in cross-section and have a white granular composition throughout. Differences are also found in the length of the anal papilla, but this was not used in sex determination.

Ecology

An indication of the ecology of different species has been obtained from the data on the field record sheets of the collections of the Institute of Fisheries (see following sample). As the sampling method for these collections was largely seining there are certain limitations to the data. Seining is probably less efficient in fast deep water with rocky bottom. The fact that waders were mainly used while seining to secure specimens limits the depth of collecting. Since collections were made mainly in the summer with a few in the fall and spring and none in the winter, the data represents only a portion of the year. Since these prejudices were probably random with regard to the species, the information is nevertheless of comparative value. It indicates relative ecological differences. Ecological differences are hence discussed under interspecific relationships. Sometimes collections occurred in mixed habitats - rocky and sandy bottom. These collections were entered under both categories.

UNIVERSITY OF BRITISH COLUMBIA
Institute of Fisheries
Field Record

Province or Country .... **Field No.** ....

County: .... **Map:** ...., 1...............

Locality: ....

....

.... **Lat.** .... **N., Long.** .... **W.**

Water: ....

Vegetation: ....

....

Bottom: ....

Cover: .... **Temp.:** ....

Shore: .... **Current:** ....

Dist. offshore: .... **Stream width:** ....

Depth of capture: .... **Depth of water:** ....

Collected by ....

Tide: .... **Date:** ....

Method of capture: ....

Orig. preserv.: .... **Time:** ....

Synonomies

Synonyms were obtained mainly from Jordan and Evermann,(1898), Schultz and Delacy (1936), Hubbs (1919). Only names different from present useage were included.

Drawings

Drawings showing important external features were made with the aid of a camera lucida. These were photographed on 35 mm. film and reduced to about 2/3 of the original size in the prints.

DESCRIPTIONS OF AND

VARIATION IN INDIVIDUAL SPECIES OF B.C. SCULPINS

INTRA SPECIFIC VARIATION

Cottus asper Richardson 1936 prickly sculpin

Figure 9

Synomymy
Cottus asper Richardson, Fauna Bor. Amer., Fish., 295, 1836 Columbia River at Ft. Vancouver.
Trachidermis richardsoni, Heckel, Ann.Wiener Mus., 162, 1840
Centridermichth asper, Richardson, Voyage Sulphur, Icth., 74, 1845; Gunther 1860.
Cottopsis asper, Girard, U.S. Pacific R.R.Surv., X, Fish., 51, 1851, 1858; Suckley 1860; Jordan and Jouy 1882.
Cottopsis parvus, Girard, ibid 1854, 1857 and 1858.
Uranidea aspera, Jordan and Gilbert, Synopsis, 694, 1883
Cottus gulosus, Girard, in Jordan, Bull. U.S. Fish. Comm. 141, 1894; Jordan and Evermann 1898 in part

DESCRIPTION

Color

Olive brown sometimes tinged with yellow or plum. Black mottlings on back and sides, often in six vertical saddles, two below spinous dorsal, three below rayed dorsal (see Fig. 9). Dark bar at base of caudal fin. Narrow dark bands on second dorsal passing posteriorly and ventrally. Irregular wide dark bands on caudal and pectoral fins. Chin and often abdomen covered evenly with fine speckles. Short dark bar under eye bordered by lighter zone. First dorsal with faint dark central band; prominent characteristic dark spot in posterior portion; posterior dorsal edge with thin band of orange. Little difference in color of sexes except in the spawning season when male becomes very dark on head, body and fins. See Fig. 9 for the color patterns and external morphological features.

Morphology

The maximum recorded size is 300 mm. The usual maximum is 150 mm. The head is large and the mouth is only smaller than that of Cottus rhotheus (of B.C. species) (discussed by Northcote 1954). The caudal peduncle is of medium depth. Strong teeth are present on the palatine bones but these do not come into contact with the vomerine patch of teeth. As in all other B.C. sculpins villiform teeth are present on the vomer, premaxillaries, dentaries and the upper and lower pharyngials. Four to eight, usually five pyloric cacae are present, usually two short and three long. The posterior nostrils usually are not tubular, but some preserved large specimens have semitubular nostrils. The anal papilla of the female is a small bump, while that of the male is a large flattened "v". Most authors record one large spine at the angle of the preopercle and one smaller below. Clearing and dissection revealed that there are more often two smaller spines below (27 specimens) than one (9 specimens). Prickling is very variable in extent and intensity. Some have only a few in the axil under the lateral line, while others are covered densely with coarse prickles except on the head and thorax. Usually they occur on the sides and back and on the dorsal side of the caudal peduncle. They may occur in all regions in Fig. 1 (regions a - j). Generally they are most dense in regions b to e and decrease in intensity outwards. The prickles themselves are generally large and strong, have a long sharp shaft and a flat or tridentat base (see Fig. 3). One pore is usually present on the tip of the chin (see Fig. 5).

Meristic values (vertebrae and fin rays) may be obtained from the section on interspecific comparisons or from Fig. 7. Statistical significance of meristic differences in the graph (Fig. 7) may be determined visually (graphical method from Hubbs and Hubbs (1953). The first two dorsal spines are usually placed on the first dorsal basal. Usually the last spine and the first dorsal ray are placed on their own basal (67 specimens), occasionally they are on the same basal (9) and rarely an unrayed basal exists (6). The ventral fin almost invariably contains 4 rays, only two specimens being found with 5 and two specimens with 3 rays out of many examined. The innermost ray is about $\frac{3}{4}$ the length of the longest. The lateral line is usually complete in specimens over 60 mm. in length. Sometimes the lateral line is missing on the caudal peduncle and in specimens from Buttle Lake it extends only to the middle of the rayed dorsal. The number of pores in specimens over 60 mm. may vary from 32 to 43 but is usually about 38. No external scales exist. Internal scales were apparent between the lateral line pores in cleared specimens of all species. These internal scales are hollow tubes which surround and presumably support the lateral line canal. Tiny holes appear at the bottom of these tubes which may transmit nerves or blood vessels. Internal scales develop as the lateral line forms and are usually about equal to the number of pores. Illustrations of similar structures may be seen in Bolin (1952).

Distribution

Figure 8 gives the distribution of Cottus asper. The range is quite wide, extending from Chilkoot Lake in southeastern Alaska - 59°30'

(Nichols 1908) to Ventura River lagoon in California - 34°20'. Most Pacific drainages between these two points contain Cottus asper. It is present also in the upper waters of the Peace River in the Mackenzie River system into which it has gained entrance from either the Fraser or the Skeena. In B.C. it is found in the Peace, Stikine, Nass, Skeena, Fraser and Columbia River systems, as well as many coastal lakes and streams.

GEOGRAPHIC VARIATION

The number of body parts in C. asper have been found to vary with geographical factors. As the number of parts is taxonomically significant it is important to know the existance and extent of effects geography may have on meristic characters.

Habitat

Plasticity often exists in the characters of species having wide ecological valency. The habitat may be found to modify the organism phenotypically or genotypically.

Prickling was found to be one of the most variable characters in the prickly sculpin. Some individuals are so densely prickled that the bases of the prickles are almost in contact, while in others the prickles are far apart. The extent as well as density varies widely. To determine if habitat had any influence on the variability, the intensity of prickling was tabled for three general types of habitat. Rivers, lakes and brackish waters (streams a mile or less from the sea) formed the criteria for habitat classification. Following are tabled the means for intensity of prickling for each region on the body. The percent of individuals which possessed prickles in each region is also tabled. The number of individuals and number of collections is included.

TABLE 3
MEAN INTENSITY OF PRICKLING IN DIFFERENT HABITATS (in *Cottus asper*)

HABITAT			AREA PRICKLED										
	N	M	a	b	c	d	e	f	g	h	i	j	Mean
River	16	7	.60	1.1	3.1	2.8	3.1	1.2	.71	.62	2.2	.49	1.6
Lake	94	28	.571	1.68	2.53	2.22	2.47	1.32	.692	.531	1.82	.391	1.42
Brackish	15	3	.00	1.5	2.4	2.3	2.2	.47	.07	.00	1.9	.00	1.18

N = number of individuals
M = number of samples

TABLE 4
PERCENT OF INDIVIDUALS PRICKLED IN EACH AREA FROM DIFFERENT HABITATS (*Cottus asper*).

HABITAT			AREA PRICKLED										
	N	M	a	b	c	d	e	f	g	h	i	j	Mean
River	16	7	56%	94%	100%	100%	100%	88%	50%	44%	94%	38%	76.4%
Lake	94	28	48%	100%	100%	94%	94%	86%	57%	53%	89%	35%	75.6%
Brackish	15	3	0%	100%	100%	100%	93%	47%	7%	0%	93%	0%	54.0%

The preceding tables indicate differences in prickling between habitats. Six out of eight of the areas on river sculpins were more heavily prickled than those on lake sculpins. All but one of the zones on the brackish sculpins are less prickled than those of the lake forms. The averages indicate that a much greater difference exists between the sculpins from brackish and those from freshwater habitats than between those from the two freshwater habitats. Table 4 shows that the lake specimens are prickled over less of the body than the river specimens, while the brackish specimens are much less prickled than either. A large difference between both lake and stream and the brackish sculpins is that the brackish ones lack prickles on the head, beside the rayed dorsal, and below the lateral line on the caudal peduncle. Robins (1954) found similar differences in Cottus carolinae which was less densely prickled in lakes and most densely prickled in torrential rivers.

Differences also exist in the number of meristic parts in specimens from streams and lakes. Table 5 shows the differences in dorsal spines and rays, anal and pectoral rays, branchiostegals, and vertebrae, in lacustrine and fluviatile populations.

TABLE 5

MERISTIC DIFFERENCES BETWEEN LAKE AND STREAM POPULATIONS OF COTTUS ASPER
The mean of the number of parts is followed by the sample size in parentheses.

HABITAT	NO. LOCALS	DORSAL SPINES	DORSAL RAYS	ANAL RAYS	PECTORAL RAYS	VERT.	BRANCH
Rivers	16	9.08(88)	20.69(77)	16.92(78)	16.44(81)	26.00(101)	6.12(88)
Lakes	94	8.98(217)	20.70(214)	16.60(204)	16.59(203)	25.81(240)	6.30(181)

It will be noticed that there is almost no difference in the number of dorsal spines or rays between individuals from lakes and those from streams. River forms do have more anal rays, few pectoral rays, more vertebrae, and fewer branchiostegals. River forms may possibly not require as many branchiostegals to support their gill membranes. Stronger gill membranes might be required of lake forms which have to pump the still water through their gills. Alm (1952) found that heritable differences were present between lake and stream populations of Salmo trutta. It is also possible that the differences between lake and stream sculpins are caused by differences in developmental conditions, rather than environmental selection.

Coastal and Non-coastal populations

It will be noted that the greatest morphological differences occurred between brackish and freshwater populations. This classification of environments is very coarse, only separating those individuals living close to or in brackish water and all interior forms. Since great climatic differences exist between the interior and the coast, large morphological differences might also be expected to exist. Therefore, a closer comparison between coastal and non-coastal individuals was made. Coastal specimens were arbitrarily designated as those 10 miles or less from the sea and non-coastal as those 10 to 65 miles. In order to secure a large enough sample, specimens from Oregon to Prince Rupert were included. About equal number in the two groups were chosen from different latitudes. Table 6 below gives differences in prickling. As differences between the two groups were very small in b and c, these are not tabled.

TABLE 6
PERCENT OF INDIVIDUALS PRICKLED IN DIFFERENT AREAS OF THE BODY FROM COASTAL AND NON-COASTAL POPULATIONS (in <u>Cottus asper</u>)

HABITAT	AREA PRICKLED								
	a	d	e	f	g	h	i	j	Mean
Coastal (52)	0%	83%	77%	35%	29%	23%	63%	13%	40.3%
Non-coastal (35)	69%	91%	94%	91%	77%	86%	91%	77%	84.5%

Sculpins living near the sea are evidently less commonly prickled in several body areas than sculpins living away from the sea. This is highly significant statistically. The prickles were also observed to be closer together in the non-coastal forms. Probabilities of the significance of difference of prickling in different areas is given below.

Area	P	Area	P
a	<.001	g	<.001
d	.2-.1	h	<.001
e	.05-.01	i	.01-.001
f	<.001		

Meristic differences between coastal and non-coastal populations of the prickly sculpin were also analyzed. Data is presented in the following table.

TABLE 7
FREQUENCY DISTRIBUTION OF MERISTICS OF COASTAL AND NON-COASTAL
COTTUS ASPER

LOCAL	DORSAL SPINES			DORSAL RAYS					ANAL RAYS				PECTORAL RAYS			VERTEBRAE				
	8	9	10	19	20	21	22	23	15	16	17	18	15	16	17	24	25	26	27	28
Coastal	4	69	7	2	22	47	7	1	0	14	50	16	12	49	19	1	11	55	14	0
Non-Coastal	10	53	5	3	15	33	17	0	3	9	43	12	2	23	42	0	2	28	32	2

Chi square tests showed that the probability that the differences were due to chance in dorsal spines was 0.2-0.1; in dorsal rays, .05-.01; in pectoral rays, .001; and vertebrae, -.001. Because of the similarity of anal ray counts they were not tested. The differences between coastal and non-coastal populations in dorsal rays, pectoral rays and vertebrae are too great to be attributed to change.

It has been shown that differences in extent and intensity of prickling and in numbers of dorsal rays, pectoral rays and vertebrae, between coastal and non-coastal prickly sculpins are significant. What has caused these differences? Biological data must be considered before this can be answered. According to Shapovalov and Taft (1954), prickly sculpins migrated downstream to spawn through a counting fence close to the sea at Waddell Creek, California. Sumner (1952) reports that *Cottus asper* were caught in their downstream trap, which was just below the head of tidewater, in spring and early summer - the spawning period at Jewell Creek, Oregon. Hunter (pers.comm.) states that *Cottus asper* moves into the intertidal regions to spawn at Hooknose Creek, Port John, B.C. This information would indicate that coastal populations move down at least to within tidal influence to spawn. Often salt water, because of its greater density, moves in under fresh water in the intertidal zones of rivers. It is thus possible that the eggs of coastal populations are subject to brackish water. On the other hand, it is unlikely that inland sculpins would migrate long distances to the coast to spawn, and it is known that populations 50 miles from the sea spawn in fresh water.

Two possible explanations exist for the morphological differences. Firstly, the differences could be caused by the environment. Salinity differences during development may exist and these could modify meristics. Possibly temperature differences also exist. Secondly, the differences could be heritable. Coastal forms migrate downstream to the sea. One would also expect several necessary adaptions to accompany this behaviour. Physiological adaptions would be necessary in the parents, fry and eggs to withstand the salinity. Behaviour patters allowing return of the adults and fry upstream would also be required. These differences in spawning habit would also produce isolation which would permit genetic selection to take place and further differences to be developed. The threespined stickleback, Gasterosteus aculeatus, has been found to have marine and inland populations with physiological, behavioral and morphological differences. All these items would tend to suggest that Cottus asper also has two genetically different forms, a brackish, lightly prickled one with fewer dorsal and pectoral rays and vertebrae, and an inland freshwater form. As the morphological differences overlap it is unlikely that they are completely reproductively isolated.

Altitude

All specimens for which altitude information was available were grouped under the categories: 0 feet (above sealevel), 200 feet, 1000 feet, 2000 feet, 3000 feet, and 4000 feet above sealevel. The means and sample sizes of the counts are presented in Table 9, below.

TABLE 9
RELATION OF ALTITUDE TO MERISTICS IN COTTUS ASPER
Mean is followed by sample size in parentheses.

ALTITUDE	DORSAL SPINES	DORSAL RAYS	ANAL RAYS	PECTORAL RAYS	VERTEBRAE
0'	8.97(36)	20.81(37)	17.00(36)	16.19(36)	26.29(31)
-200'	9.00(18)	20.77(18)	17.12(17)	16.36(19)	26.26(19)
-1000'	9.10(10)	20.78(9)	16.82(11)	16.54(11)	25.92(13)
-2000'	8.89(29)	20.54(26)	16.56(32)	16.78(28)	25.27(33)
-3000'	9.14(69)	20.30(70)	16.54(61)	16.49(69)	25.14(69)
-4000'	8.76(34)	21.18(33)	16.76(34)	17.03(34)	25.84(33)

Altitude would appear from Table 9, to have a considerable effect upon meristics. The average number of caudal vertebrae, dorsaland anal rays behave similarly and decrease with increasing altitude up to 4000 feet, above which they increase. Pectoral rays, on the other hand, tend to show a positive increase with altitude, varying irregularly from one level to the next.

The correlation with altitude may be spurious. However, temperature tends to decrease with altitude at an average rate of 3.3°F. per 1000 feet

(6°C. per 1000 m.). The intensity of insolation increases with altitude. Changes in the components of light also take place, with ultraviolet and infrared intensity increasing upward. The differences in meristics at different altitudes could be attributed to developmental or selective effects of these factors.

Temperature

Temperature has been shown experimentally to modify meristic characters. It was decided to test its effect in nature. Unfortunately temperature data are not available in the most desireable form for correlation. Ideally spring temperatures - those during spawning times, would be the most logical to correlate with meristics. However, the only available isotherm maps are July or January. July was chosen as the most suitable. It is assumed that July temperatures are related to those in the spring and that there is a direct relation between air temperature and water temperature. Table 10 gives mean July temperature and the means of vertebrae and fin ray counts.

TABLE 10
INFLUENCE OF TEMPERATURE ON MERISTICS
Mean July Temperature, meristic mean and sample size (in parentheses) of B.C. Cottus asper

AVERAGE JULY ISOTHERM DEGREES F.	DORSAL SPINES	DORSAL RAYS	ANAL RAYS	PECTORAL RAYS	VERTEBRAE
70° +	8.87(31)	20.41(32)	16.56(32)	16.81(27)	25.28(29)
70° -	8.92(12)	21.00(12)	16.85(13)	16.75(12)	25.93(14)
65° -	8.94(140)	20.89(134)	16.98(130)	16.54(133)	26.21(131)
60° -	9.15(118)	20.48(115)	16.74(111)	16.32(117)	25.59(121)
55° -	8.86(43)	20.93(42)	16.73(37)	16.89(38)	25.64(50)

The above data shows an increase in dorsal spines with increase in temperature, except at the lowest temperature. Pectoral rays show an opposite relationship. Vertebrae and anal rays are highest at intermediate temperatures. V-shaped relationships to temperature were found in other species by Lindsey (1952) and Tåning (1952). Although several of the differences are probably statistically different, no simple pattern is apparent.

Latitude

Below is a table showing how ray and vertebrae counts change with latitude from California to British Columbia. Counts were taken from Snyder, (1905, 1908 and 1914), Rutter, (1908), Gilbert and Evermann (1895), Gilbert (1893) and Evermann and Goldsborough (1907). Vertebral means for Washington, Oregon and California were taken from Hubbs and Schultz (1932).

TABLE 11
LATITUDINAL VARIATION IN FIN RAY AND VERTEBRAL COUNTS, _COTTUS ASPER_
Means and sample sizes

LATITUDE	DORSAL SPINES	DORSAL RAYS	ANAL RAYS	PECTORAL RAYS	VERTEBRAE
38°N	8.34(59)	19.78(59)	16.36(59)	16.05(59)	
40	8.70(20)	19.80(20)	16.67(20)	16.1 (10)	25.30(59) (California)
42	8.73(49)	20.34(50)	16.78(49)	15.80(44)	
44	8.98(46)	20.98(46)	17.20(46)	16.33(46)	26.06 (Oregon)
46	9.03(29)	21.04(28)	17.14(28)	15.89(19)	
48	8.92(25)	20.40(25)	16.72(25)	15.53(15)	26.00 (Washington)
50	8.84(121)	20.88(205)	16.83(199)	16.69(205)	26.01(208)
52	8.86(29)	20.75(28)	16.77(30)	16.86(28)	25.77(26)
54	9.15(41)	20.48(44)	16.63(43)	16.95(39)	25.49(57)
56	9.11(71)	20.23(60)	16.68(65)	16.44(73)	25.50(64)
58	9.0 (4)	22.2 (4)	17.5 (4)	16.5 (4)	26.8 (4)

Table 11 shows a tendency towards an increase in dorsal spines towards the north. Large differences at different latitudes occur in pectoral rays but the oscillations are so great that the tendency to increase northward is probably not significant. In caudal vertebrae, anal rays, and dorsal rays, the highest values are found at intermediate latitudes.

Correlations Between Parts

In comparisons between lake and river populations, and between populations from different temperatures, altitudes and latitudes, it will have been noticed that some characters displayed similar reactions. Generally dorsal and anal rays responded similarly, and usually these two responded like vertebrae. Pectoral and dorsal spines responded differently from each other and from the preceding characters. Because of their morphological relationships, one would expect similar reactions from dorsal and anal rays and vertebrae, and dissimilar reactions between these and pectoral and dorsal fins. The dorsal and anal rays are each, through their basals, associated with the caudal vertebrae. The pectoral rays and dorsal spines bear no such relationship. To determine if correlation existed between the vertebrae and other characters, correlation tests were performed from a random sample of 24 collections of *Cottus asper*. The correlation coefficients (r), sample sizes (n) and probabilities (p) follow.

Correlation	r	sample size	p
dorsal spines x vertebrae	-.00956	188	$>$.05
dorsal rays x vertebrae	.278	187	$<$.01
anal rays x vertebrae	.172	179	.05-.01
pectoral rays x vertebrae	.0332	180	$>$.05

The above indicates that there is little relationship between dorsal spines and vertebrae and between pectoral rays and vertebrae. A significant positive relationship exists between the number of dorsal rays and the number of vertebrae, and between the number of anal rays and the number of vertebrae. In other words, when a high caudal vertebrae count is found, a high dorsal or anal ray count can usually be expected.

The association between anal rays and vertebrae, and between dorsal rays and vertebrae could be explained by gene linkage, or by vertebral influence on the number of rays in development by similar effects of environmental factors on these characters.

Comparative Variability of Characters.

It is convenient in taxonomy to know which characters are the most variable. The standard deviation gives a measure of the variability of measurements and counts. The standard deviation (for all B.C. Cottus asper) of dorsal spines is .508, for dorsal rays .704, for anal rays is .722, for pectoral rays is .686, principal caudal rays .208 and for vertebrae .729. The size of the standard deviation depends upon the size of the mean, however. A comparable measure of dispersion is obtained if one multiplies the standard deviation by 100 and divides by the mean. This is called the coefficient of variation. The coefficient of variation for dorsal rays is 5.66%, for anal rays 3.39%, pectoral rays 4.14%, vertebrae 2.8% and caudal rays 1.73%.

Variability differences might be allotted to two causes. One, that organs developing at a later period might be subjected to more environmental changes. Two, the degree of constancy is genetic. Here, the low variability of some characters is advantageous and has been selected for. Selection could make characters less variable by favouring development of the character at an earlier stage in morphogenesis.

Vertebrae probably develop earliest of meristic characters. The probable order of development of rays in Cottus bairdi kumlieni (Marie Fish

1932) is first the caudal, then the pectoral, anal, and second dorsal, and lastly the first dorsal. This bears some relationship to the variability of the parts, caudal rays being less variable than vertebrae, than dorsal rays, than pectoral rays, than anal rays, than dorsal spines in <u>Cottus asper</u>. The characters which develop earliest, assuming same developmental sequence, are usually less variable. Caudal rays and vertebrae which develop earliest have the lowest variability. It is possible that dorsal rays (and not pectoral rays) are less variable than their developmental order would suggest because they are partly determined by the number of vertebrae which have preceded them.

It is also interesting to note that the caudal rays and vertebrae which are probably most important in locomotion develop earliest and are least variable. The spinous dorsal fin, which probably has mainly a behavioral function, develops last and is the most variable.

Year Class Variation

No comparisons were made of year classes. Northcote (1950) found no difference between year classes zero and one in dorsal spines and rays. A significant difference was found in the number of anal rays.

Sex Differences

Northcote (1950) found no significant differences in dorsal spines, dorsal rays, and anal rays between males and females in <u>Cottus asper</u>.

DISTINGUISHING CHARACTERISTICS

The prickly sculpin is distinguished from all other B.C. forms by its complete lateral line, palatine teeth, single symphysial pore, 24-28 caudal vertebrae and distinct round black spot in the posterior part of the spinous dorsal fin.

Cottus cognatus Richardson 1836

Figure 10

slimy sculpin
(common sculpin,
mottled sculpin)

Synonymy

Synonyms of eastern species may be obtained from Robins (1954). See also discussion in text.

DESCRIPTION

Color

Highly mottled grey-yellow coloration. Frequently orange flashes on lower flanks and under pectorals. Remainder underparts white, except for fine speckles on chin. Three or sometimes two mottled saddles under second dorsal. Second dorsal, caudal and pectoral with bands on rays forming bars. The spinous dorsal of male in spawning season dark to black, particularly anteriorly and posteriorly, with broad orange edge. Male generally dark all over in spawning season. Dark patch beneath eye and between eye and preopercle. (see Fig. 10).

Morphology

Maximum size in British Columbia 120 mm. Head small, 3.0-3.9 into standard length; mouth small. Caudal peduncle deep, 3.2-4.4 in head, usually 3.5-4.2. Posterior nostrils not tubular. Anal papilla begins to be longer in male after a total length of about 60 mm., until at 80 mm. it is twice as long as female's - about 2 mm. It has a long flat "V"-shape in the male while in the female it forms a small round extension. One, two or three preopercular spines may be present. Prickles are restricted to a weak patch in the axil. The prickles are usually of intensity 1 above the lateral line and of 1 or 2 below. The number of prickles above the lateral line varies from 0 to 5, usually 1 or 2, and varies from 0 to 86 below, usually about 40 to 50. The prickle shaft is equal or longer than the length of the base. The base of the prickle is oval (see Fig. 3). The skin is slippery, hence the name slimy. Two pores are present on the tip of the chin, one on either side of the symphysis.

Usually (in 46 specimens) there is only one spine on the first dorsal basal, sometimes (5) there are two. Often but one ray sits on the last anal basal or one tiny ray is bound to the larger so as only one is discernable in the uncleared fish. This is not found in other B.C. sculpins. The number of ventral fin rays varies from three to four. The lateral line is always incomplete and usually ends before the second third of the rayed dorsal. It usually contains 18-22 pores (rarely 12-25) in specimens over 60 mm. total length.

DISTRIBUTION

Cottus cognatus is the most widely distributed of North American freshwater sculpins (see distribution, Fig. 8). It occurs on the eastern seaboard as far south as Virginia, in the Labrador Peninsula, the Great Lakes, in northeastern Iowa and Minnesota. It is apparently absent from most of the Saskatchewan system, but is present in the North West Territories and Alaska from the Arctic Ocean to Kenai Peninsula. In British Columbia it occurs in the Yukon, Stikine, Mackenzie, Fraser and Columbia River systems. Distribution records were obtained from Eddy and Surber (1947), Livingston (1952), Hubbs and Laglar (1949), Dymond (1947), Walters (1955), Lindsey (1956), Carl and Clemens (1953), Miller and Paetz (1953), Rawson (1951), and the museum specimens of the Institute of Fisheries.

GEOGRAPHICAL VARIATION

Geographic variation of <u>Cottus cognatus</u> was studied only in relation to latitude and river systems.

Latitudinal variation

Table 12 presents data showing variation associated with latitude. Two sets of data are presented for 70°. The sample of five is from museum samples from the Colville River system, Alaska, the second sample of 12 is taken from Walters (1955). The remainder of specimens are from collections in the Institute of Fisheries Museum.

TABLE 12
LATITUDINAL VARIATION IN COTTUS COGNATUS
Mean and sample size (in parentheses)

LATITUDE	DORSAL SPINES	DORSAL RAYS	ANAL RAYS	PECTORAL RAYS	VERTEBRAE
50°N.	8.53(51)	16.65(51)	11.82(50)	13.92(49)	22.56(45)
52	8.18(11)	17.00(11)	11.80(10)	14.11(9)	21.90(10)
54	8.61(18)	17.22(18)	11.56(18)	14.12(17)	22.71(14)
56	8.24(25)	16.44(25)	10.96(25)	14.08(25)	22.35(23)
58	8.35(17)	16.83(18)	10.67(18)	13.67(18)	22.61(18)
60	8.26(34)	16.62(34)	10.57(35)	13.86(36)	22.04(23)
70	8.2 (4)	15.6 (5)	10.4 (5)	13.4 (5)	-
70	8.3 (12)	15.5 (12)	11.3 (12)	13.3 (13)	21.7 (9)

The foregoing table demonstrates several clines. An unidirectional cline is found in anal rays in which the number of parts decreases towards the north. The two samples at 70° confirm one another except in the anal ray count where a difference of nearly a whole ray is found. Walters' anal ray count is the only one which does not fit into the cline. The remainder of the counts, dorsal spines, dorsal rays, pectoral rays and vertebrae all tend to show a double cline, decreasing away from 54°. The condition over most of the range (from 54-70°) is a decrease northward. The significance of the double clines is discussed under river systems.

River System Variation

The greatest differences in meristics between latitudes occurred from 54° to 56° (Table 12). These latitudes coincide with the Peace and Fraser Rivers. To determine the amount of variation attributable to river systems the data were reclassified. The mean dorsal spine, dorsal, anal, ventral and pectoral ray counts for the major river systems of B.C. are given in Fig. 2.

Lindsey (1956) noticed that Peace River forms had only four ventral rays, unlike those of more southerly B.C. specimens which had three to four. Figure 2 shows that the means of ventral ray counts of the lower Peace (defined as below the Ne-parle-pas Rapids which are shown on Figure 2a) the Liard and the Stikine are consistantly higher than those of the upper Peace, Fraser and Columbia Rivers. The Ne-parle-pas Rapids are probably impassable to fish. It is interesting to note that *Cottus ricei*, *Percopsis omiscomaycush*, *Stizostedion vitreum* and *Platygobio gracilis* have not yet been recorded in the upper Peace, although they are found in the lower Peace and Liard. The lower Peace, Liard and Stikine specimens (referred hereafter as Northern) never have three ventral rays, while the upper Peace, Fraser and Columbia (hereafter referred to as Southern) frequently have three ventral rays. None of the Alaskan specimens have three ventral rays. Figure 2 shows that the greatest difference between adjoining systems in many meristics occurs between the upper and lower Peace. Frequently the differences are smaller within the Southern or Northern classes than between them. The fact that the upper and lower Peace are not climatically different would suggest the differences between them are not the result of environmental influences. The small sample size of the lower Peace collection should be noted. The constant presence of a fourth ventral ray, however, would confirm the low alliance of the lower Peace to the Northern.

Body proportions were also examined in northwestern specimens of Cottus cognatus. Following is a list of the means of the head/caudal peduncle ratio in Cottus cognatus from the different river systems.

	Mean	Range	Sample Size
Alaska	4.13	3.8-4.8	7
Liard River	3.93	3.4-4.7	18
Lower Peace	3.89	3.6-4.4	10
Upper Peace	3.63	3.3-4.1	20
Fraser River	3.59	2.9-4.3	17
Columbia River	3.70	3.4-4.2	16

It will be seen again that there is a break between the upper and lower Peace and that this difference is greater than that between the upper Peace and the Fraser. In fact, the mean of the lower Peace is closer to that of Alaska than it is to the upper Peace. Chi square tests show that the difference between the upper and lower Peace is significant

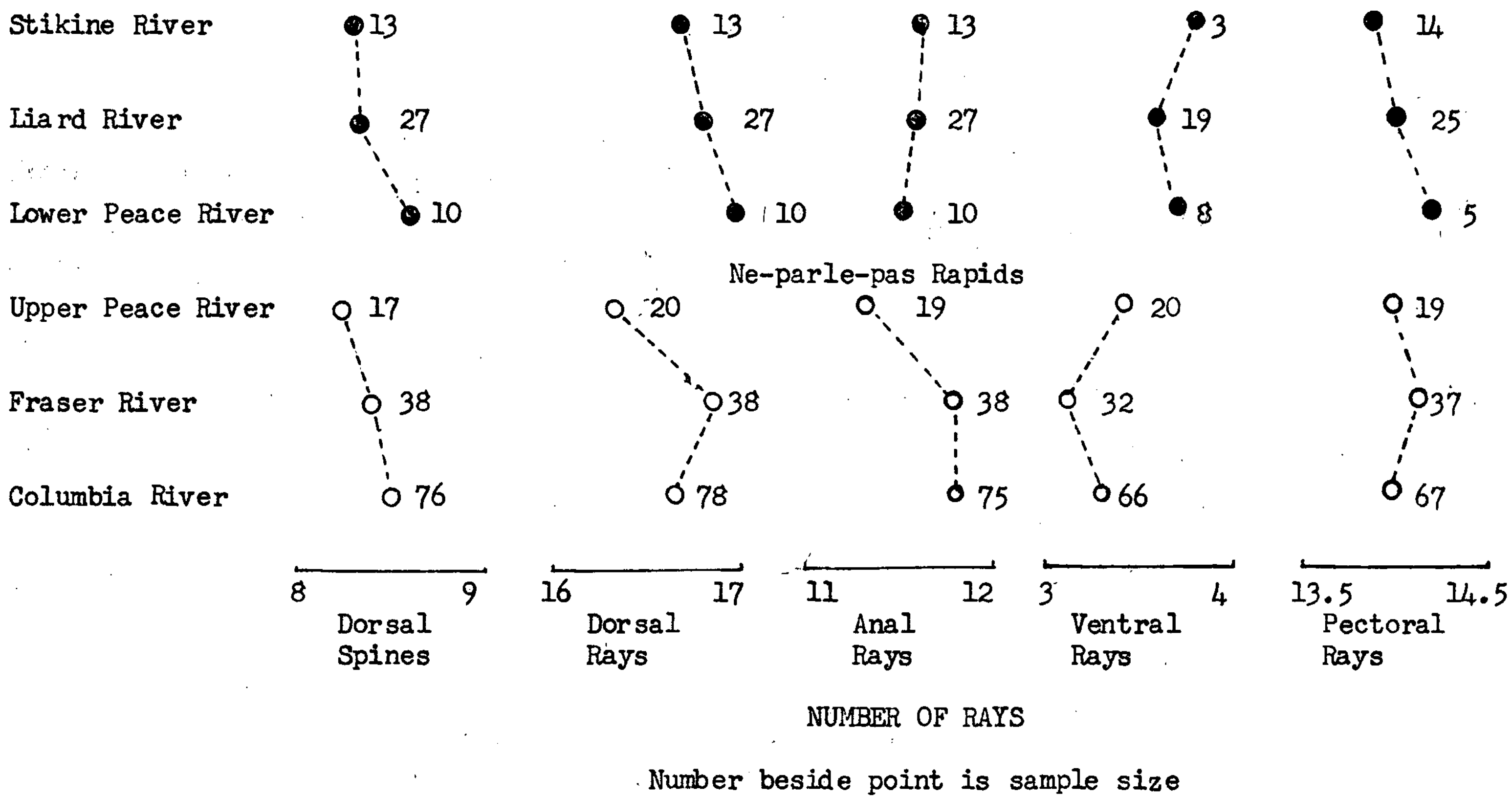


FIGURE 2. Means of Fin Ray Counts in Cottus cognatus from Different River Systems

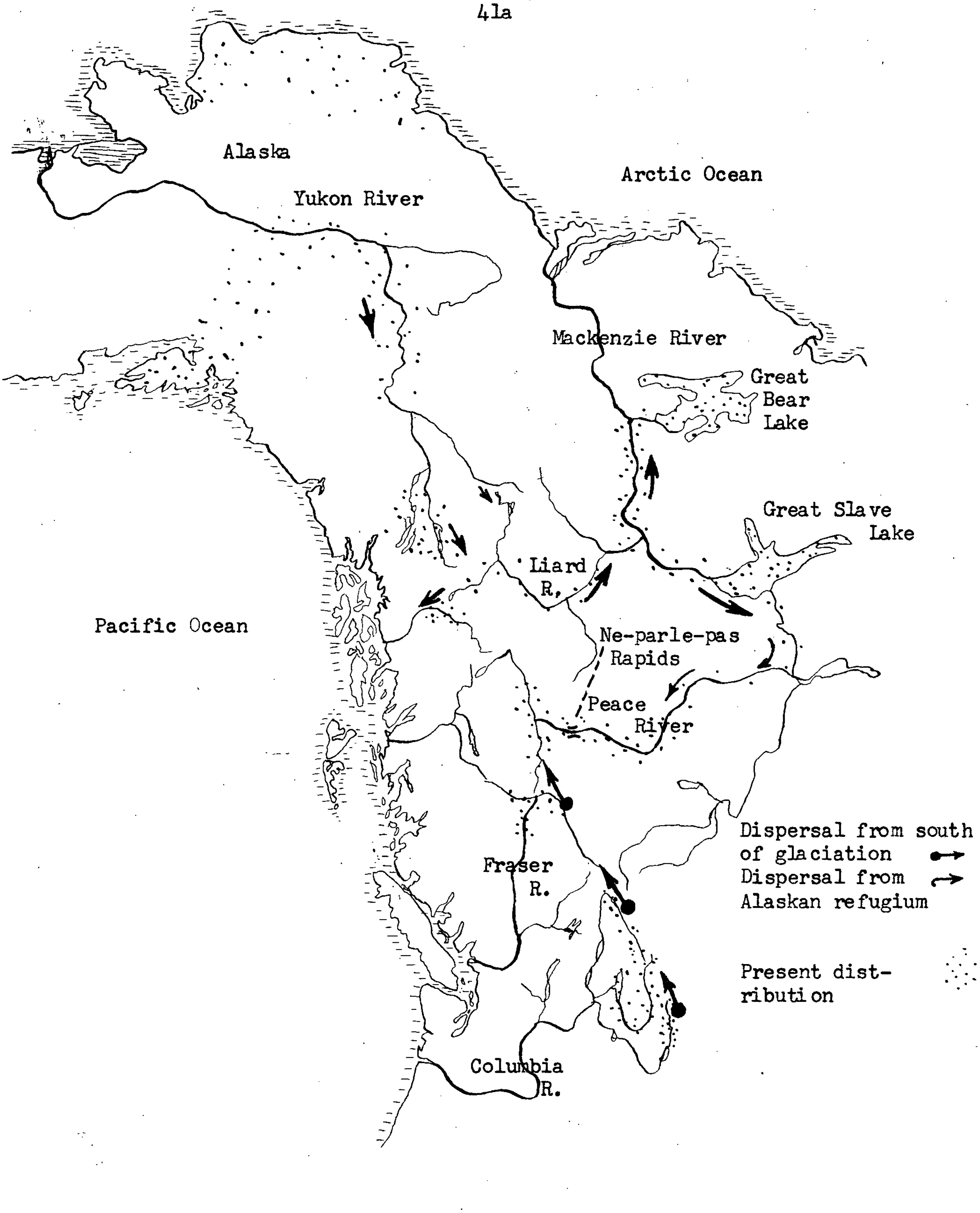


Figure 2a. Probable redispersal of Cottus cognatus from two centres following the Wisconsin glaciation.

($p < .05$) while that between the upper Peace and the Fraser is not significant.

What accounts for the dissimilarities of the adjacent upper and lower Peace and the similarities within the Northern and Southern groups? Glacial history provides a good explanation of these similarities and differences. During the last glacial period, parts of Alaska were icefree (Walters 1955), probably permitting cognatus to survive there. Walters considers cognatus to have been present in Alaska since the Bering land bridge. Probably cognatus was also present south of the ice sheet. Progression of the ice sheet would have resulted in the southward displacement of these sculpins until they were present in the Columbia River system. As the ice moved no farther south than about 49°, the slimy sculpin could well have survived the duration of the glacial period in the Columbia system. When the glaciers retreated, cognatus might well have followed northward. It is likely that in the wake of the glacier the upper bend of the Fraser and the Big Bend of the Columbia were connected. Dispersion could thus have occurred into the upper Fraser, where the species exists today (see distribution map). As no collections have been made in the bend of the Fraser it is unknown whether present day distribution would support the entrance of cognatus into the Fraser from the Columbia. On the basis of known distribution elsewhere, this is apparently the only likely means of transmission between the two systems (see Figure 2a).

From similarities between the upper Peace and the Fraser, it would seem likely that Fraser cognatus repopulated the upper Peace. Geological evidence shows that the upper Fraser flowed into the upper Peace at the end of the last glaciation. That such a transmission is possible is demonstrated by the presence of Cottus asper in the upper Peace, where its present restricted distribution strongly suggests entrance from the Fraser. Probable movements of cognatus following glaciation in B.C. are given in Figure 2a.

Figure 2a also compares Stikine populations with other systems. The differences would indicate that the Stikine is more dissimilar to the Fraser than to the Mackenzie. The Stikine has the high ventral fin ray count of the Northern forms. It seems likely that Stikine populations originated from headwater capture, probably from the Liard, the Stikine being very close to Dease Lake, or from the Yukon.

The constancy of the ventral rays in Alaskan derived types, the continuity of meristics and proportions in the Northern and in the Southern groups, the sharp break between the adjacent populations, and the absence of climatic isolines conforming with this distribution, all support the hypothesis of glacial segregation and subsequent redispersal from two sources.

Sex Differences

The means and sample sizes of meristic counts for males and females are given in Table 13, below. The sample includes specimens from the Liard, Fraser and Columbia.

TABLE 13
SEX DIFFERENCES IN MERISTICS OF B.C. COTTUS COGNATUS

SEX	D_1	D_2	A	P	VERTEBRAE
Male	8.46(26)	16.79(24)	11.42(26)	14.12(25)	22.38(21)
Female	8.44(27)	15.59(27)	11.52(27)	13.78(27)	22.56(23)

Chi square tests were performed on those characteristics showing the greatest difference, pectoral rays, dorsal rays and vertebrae. No significant differences were found. It is possible that the variation from different river systems obscured differences and that a larger or more homogeneous sample might reveal sexual dimorphism.

The Systematic Position of Cottus philonips Eigenmann and Eigenmann

In 1892 Eigenmann secured 17 specimens of Cottus in the snow waters of the Kicking Horse River (Columbia system) in southeastern B.C. These were named in the same year as Cottus philonips. With further knowledge of the distribution and variability of Cottus cognatus it now appears that philonips is synonomous with cognatus. The following table compares descriptions of philonips with measurements of B.C. cognatus.

TABLE 14

	Cottus philonips	Cottus cognatus
Head into standard length	$4-4\frac{3}{4}$ or 3.8	3.0-4.0
Depth	6.0	4.6-6.2
Dorsal spines	8 - 9	8-9 (rarely 7-10)
Dorsal rays	16-18	16-18 (15-19)
Anal rays	11-13	10-13
Palatine teeth	Absent	Absent
Preopercular spines	1	1-3

The description of color in Eigenmann (1892) and Jordan and Evermann (1898) agrees very well with that of cognatus. According to the key in Jordan and Evermann the skin is smooth or nearly so and Carl and Clemens describe the skin as without prickles. Specimens of cognatus from the Flathead River (Columbia system) of southeastern B.C. have been found to lack prickles and it is common to have the prickles reduced to less than a dozen. The prickling of philonips is not, therefore, outside the range of that of cognatus. The position of the tip of the maxilla, tip of the pectoral and of the anus mentioned in the original description do not serve to differentiate the two. The last six of the characters in the preceding table do not show reason for differentiation.

Eigenmann's statement about the head is the only one not in agreement with cognatus. Eigenmann (1892) states, "Head proportionately longer in adult, about $4\frac{3}{4}$-4 in head." Usually head proportion is indicated by how many times it enters standard length. Eigenmann writes as if some part, not mentioned, enters the length of head $4\frac{3}{4}$-4 times, which is illogical. Standard length does not enter $4\frac{3}{4}$-4 times into the head length; the reverse would be true. Jordan and Evermann (1898) describe one of the type specimens having head length such that the standard length is 3.8 times its length. Their key states the head of philonips enters $3\frac{1}{2}$-4 times in standard length, so they must have been sure of this character.

Although fairly extensive collections have been made in the upper Columbia River, and one in Emerald Lake near the type locality (about 5 miles from it) no sculpins have been found having 4 to $4\frac{3}{4}$ into standard length.

For the above reasons I believe that Eigenmann was describing the number of times some other part, such as eye, enters the head, or some other measure of the head (snout to preopercle) or made an error in describing the head. Hence, because no other differences have been found, I would consider philonips synonomous with cognatus. Cottus cognatus has priority. In the event that philonips should prove to be a distinct form, it will require a new name for reasons given by Hubbs and Schultz (1932).

Cottus N. Sp. shorthead sculpin

Figure 10

DESCRIPTION

Color

Light clay colored background with dark mottlings. Three light mottled saddles under second dorsal. Chin evenly speckled. Pectoral, dorsal, and caudal fins with mottled crossbars. Dark medium band in first dorsal fin, more intense anteriorly and posteriorly. Edge of fin light in preserved males. Trapezoidal bar beneath eye and stripe passing backwards from eye to preopercle. Orange flash may be present on flank. Chin evenly speckled.

Morphology

Total length up to 105 mm. Body stouter than other B.C. species. Head short, round from above, 3.2 - 3.7 times into standard length of B.C. specimens. Tail short. Caudal peduncle deep, 3.2 - 3.6 times into head. Palatine teeth present, but weak, not in contact with vomerine teeth. Posterior nostrils semitubular. Anal papilla longer in male. Preopercular spine at corner of preopercle with one below and sometimes a small projection underneath (2 below in some U.S. specimens according to pers. comm. from Bailey). Prickles in weak patch behind pectoral fins or absent. Two sympheseal pores are present.

One spine on the first dorsal basal in all five specimens examined. Inter-dorsal spines and rays each on own basal with no empty interdorsal basals in those examined. Ventral fins I4 in all examined, except one having 5 rays on one side. Lateral line extends up to 2/3 of the way past the origin of second dorsal and contains 20 - 24 pores in specimens over 60 mm.

About a dozen of this species were collected in the Flathead River of the Columbia system in southeastern British Columbia, along with Cottus cognatus (which was more numerous). It was designated as Cottus bairdi punctulatus (Gill) with which it agreed in several characters and disagreed in others. It also showed some similarities to Cottus bairdi semiscaber. Several specimens were sent to Dr. R.M. Bailey of the University of Michigan who has been working on the group for several years. Dr. Bailey informs me that these specimens were of a new species he had collected in Idaho, northeastern Oregon and eastern Washington. He intends to give a brief synopsis of American representatives of Cottus within the year, in which he will name the new species. Because of its small head, it will be referred to as the shorthead sculpin in this thesis.

As the shorthead sculpin is present in only one river system in British Columbia and as no other published data exist on it, no discussion of its variation will be given.

DISTRIBUTION

The shorthead sculpin occurs in the Salmon River in Idaho, in the Columbia system in northeastern Oregon and in eastern Washington. In British Columbia it has been found only in the Flathead system.

DISTINGUISHING CHARACTERISTICS

The shorthead sculpin is distinguished by its 2 chin pores, incomplete lateral line ending before the termination of the second dorsal, palatine teeth and its short head and one or two preopercular spines. It is not a highly differentiated form and further investigation may indicate it to be a coldwater variant of *Cottus bairdi* or *hubbsi*.

Cottus hubbsi Bailey and Dimick 1949 Columbia sculpin

Figure 10

Synonomies

The nomenclators stated that *Cottus hubbsi* has been confused with *Cottus rhotheus*. Literature references were not given, however.

DESCRIPTION

Color

Light to dark brown with dark markings. Three dark saddles under the second dorsal fin. Rays of dorsal, caudal, pectoral and often anal with broad dark bands. Dorsal fin in breeding male possesses a dark median band; in preserved fish the edge is devoid of pigment, but possibly it may be colored in fresh specimens. Orange flash on flanks. In non-breeding males and females the median band is reduced to dark areas in the anterior and posterior parts of the fin. The chin and less so the abdomen is sprinkled with fine black spots. Two eye bars, similar to those in *Cottus asper*, are present.

Morphology

The maximum size yet found is 122 mm. The head and mouth are of medium size, the former entering standard length about 2.9 to 3.2 times. The chin is unwrinkled. The caudal peduncle is of medium depth, entering the head 3.7 to 4.6 times, entering the standard length about .072 to .085 times. The strong palatine teeth are separated from the vomerine patch of teeth. Posterior nostrils semitubular. Anal papilla longer in adult male. Three preopercular spines present. Prickles usually present behind pectoral fin, stronger below lateral line. Occasionally prickles extend onto in front of the dorsal, beside the rayed dorsal or onto the dorsal surface of the caudal peduncle. The unprickled portion of the skin is slippery. Each prickle has a short shaft about equal to the length of the round or oval base.

Of 40 specimens, 39 had one spine on the first dorsal basal and one had two spines. Twice as many individuals (26/13) had the last spine and first ray on their own basal as had an empty basal. The lateral line is nearly always incomplete, missing on the caudal peduncle. It contains about 28 to 36 pores, rarely 23 to 38 in specimens over 60 mm.

DISTRIBUTION

Cottus hubbsi is limited, as far as is known, to the Columbia River system. It is found in Idaho, Washington and British Columbia. Its distribution in B.C. may be seen on Figure 8. Distribution in U.S.A. is given by Bailey and Dimick (1949).

GEOGRAPHIC VARIATION

To determine if latitudinal changes exist, Bailey and Dimick's data from Washington and Idaho were compared with British Columbia material. Dorsal spines, dorsal rays, anal rays and pectoral ray counts from U.S.A. and Canada are contrasted in Table 16.

TABLE 16
MERISTIC DIFFERENCES IN CANADIAN AND AMERICAN COTTUS HUBBSI

LOCAL	D_1		D_2			A				P			
	7	8	16	17	18	11	12	13	14	13	14	15	16
British Columbia	8	13	1	16	4		10	10	1		5	21	16
Washington & Idaho	13	27	2	30	8	4	19	15	1	1	9	27	3

Chi square tests were applied on the two characters which appeared most different, anal and pectoral rays. The difference between anal rays was not found to be significantly different, (p=0.3-0.5), while that between pectoral rays was significant, (p=0.01-0.001). This would indicate that the greater number of individuals with higher pectoral rays counts in U.S.A. is significant. Bailey and Dimick included counts of both right and left pectoral rays, while mine included only those of the left. It is possible the difference is attributable to bilateral differences.

DISTINGUISHING CHARACTERISTICS

The Columbia sculpin is distinguished by 2 symphisial pores, evenly speckled chin, palatine teeth, axillery prickles and lateral line extending past the rayed dorsal.

Cottus rhotheus (Rosa Smith) 1882 the torrent sculpin

Figure 11

Synonomy

Uranidea rhothea Rosa Smith (Mrs. Eigenmann), Proc. U.S.Nat.Mus.5:347, 1882 Spokane Falls, Washington; Jordan and Gilbert, Synopsis, 1883.
Cottus rhotheus (Rosa Smith) Gilbert and Evermann 1895; Syder 1908a.
Cottus rhothea (Rosa Smith) Jordan, Evermann and Clark 1930; Dymond 1935.

DESCRIPTION

Color

Color grey brown with black specklings. Two sharp saddles sharply outlined and angled forward from underneath the second dorsal; occasionally small saddle between. Orange flashes often present on the lower flank and between the pectorals. Dorsal fins, caudal fin and often anal fin with bars on rays forming bands. Speckles on the pectorals may form vague bands. The rim of the spinous dorsal fin is thickened and colored orange in the spawning male; the base may be dark. The chin, unlike other B.C. species is strongly mottled (see Figure 11). Often the ventral surface of the body is speckled.

Morphology

Total length up to 160 mm. Head long and wide, entering 2.65-3.0 times into standard length. Mouth large, width about 5.7 times into total length (when about 42 mm long), largest of B.C. species (Northcote 1950). Caudal peduncle narrow, depth contained 4.8 to 6.4 in head. Strong palatine teeth, band usually in contact with the vomerine teeth.

Pyloric cacae 4-5. Posterior nostril semitubular. Anal papilla long and narrow in male, short and tubular in female. Three preopercular spines. Strong prickles are usually found on the head, sides, beside the dorsal fins, on the upper part of the caudal peduncle and beside the anal fin. Occasionally, according to Bailey and Dimick (1949) the prickles are much reduced. Each prickle has a large oval base which is equal to or greater than the height of the spine (see Figure 3). The proximal portion of the base is usually serrated. Two symphysial pores are present. The skin of the lower mandible is wrinkled.

Usually one spine is found on the first dorsal basal. The interdorsal basal may be rayless (15 specimens) or occupies by a spine or ray (10). The lateral line is usually complete and often extends onto the caudal fin. It is usually complete on individuals over a total length of 70 mm., and bears 32 to 38 pores. (Several points of the preceding description have been derived from Bailey and Dimick (1949).)

DISTRIBUTION

The torrent sculpin is reportedly found in British Columbia, Washington, Oregon and Idaho, in the Columbia and Kootenay Rivers, and in Puget Sound drainages south to Nehamlem River, Oregon. This is the distribution given by Schultz and Delacy 1936. It is possible their localities contain <u>Cottus hubbsi</u> with which <u>C. rhotheus</u> has been confused. For this reason I have only given B.C. distributions, where identity is certain, on Figure 8.

SEX DIFFERENCES

The following table combines Northcote's (1950) and my data on sex differences in Cottus rhotheus.

TABLE 15
SEX DIFFERENCES IN COTTUS RHOTHEUS, A COMPARISON OF MERISTICS.

SEX	D_1			D_2				A			P		Vertebrae		
	7	8	9	14	15	16	17	11	12	13	15	16	21	22	23
Male	-	6	16	-	6	13	2	4	17	1	-	7	7	8	1
Female	2	9	23	2	8	17	6	12	22	1	2	11	14	16	-

A chi square test on the largest difference between sexes in the table, anal rays produced a chi square which was not significant. Northcote also found no significant difference between dorsal spines, dorsal rays, anal rays and caudal vertebrae between sexes.

GEOGRAPHIC VARIATION

Northcote (1950) found the difference in dorsal rays between samples from both Idaho and the Columbia River and the Arrow Lakes was significantly different. The increase in vertebrae from Oregon to B.C. was significant. Correlations between dorsal rays and dorsal spines and between dorsal rays and anal rays were not found to be significantly correlated.

Bailey and Dimick (1949) state that Cottus rhotheus exhibits considerable geographic variation. Specimens from coastal Washington and Oregon were found by them to have a somewhat shorter head, the lateral line not extending onto the caudal fin base, and the prickles on the body much reduced or sometimes completely absent. The last condition is similar to that found in coastal populations of Cottus asper. Cottus rhotheus has not been recorded as entering brackish or salt water, however.

DISTINGUISHING CHARACTERISTICS

Cottus rhotheus is distinguished by its 2 sharp dark dorsal saddles, its highly mottled chin, its strong palatine teeth which touch the vomers, and the two pores on the tip of its chin.

Cottus aleuticus Gilbert 1893 Aleutian sculpin

Figure 9

Synonomy

Uranidea microstoma Lockington, Proc. U.S.Nat.Mus., III, 58, 1880, St.Paul, Kodiak Island; name preoccupied in Cottus.
Cottus aleuticus Gilbert, Rept. U.S.Fish.Com.,XIX, 418, 1893, streams at Unalaska; also in Departure Bay, Vancouver Island.

DESCRIPTION

Color

Color grey with dark blotches, underparts white. Three mottled saddles under second dorsal. Rays of dorsals, caudal, and pectorals covered with series of crossbars forming bands. Male darker, nearly black, with a broad orange band on edge on first dorsal fin when spawning. Chin covered evenly with fine speckles, unwrinkled. Often orange splotch at base of pectoral fin and white bar at end of second dorsal across top of caudal peduncle. White v with base at front of dorsal with arms pointing forward, as in asper but much more intense.

Morphology

Total length up to 115 mm. Head and mouth small. Caudal peduncle deep. No teeth on palatine bones. Posterior nostrils distinctly tubular, inclined posteriorly. Anal papilla longer in male than in female. Only one preopercular spine, at corner of preopercle. Prickles restricted to small area behind pectoral, occasionally absent. Rarely a few weak prickles above lateral line, usually restricted to below. Prickles of distinctive shape (see Figure 3), with long broad shaft and base which is reduced to a slight enlargement on end of shaft. Only one symphysial pore.

All forty-eight Aleutian sculpins examined possessed two spines on the first dorsal basal, the most constant species in this regard. Ten of forty-six had an empty basal between the dorsal fins, the remainder bore one ray or one spine on the interdorsal basals. After a total length of 60 mm. has been reached the lateral line is complete, bearing 34-44 pores, usually 38.

DISTRIBUTION

The Aleutian sculpin occurs in Pacific drainages from Carmel River, just south of Monteray Bay, California - 36° 50' N, to Unalaska, Alaska at the western tip of the Aleutian Peninsula, north to Kodiak Island and the Bering Sea - about 60° N (Wilimovsky 1954). Although mainly coastal, it occurs as far inland as 300 miles in the Skeena system. See Figure 8 for distribution.

GEOGRAPHIC VARIATION

Coastal and Non-coastal

As coastal population of Cottus aleuticus have shown downstream spawning migrations in Waddell Creek, Californis (Shapovalov and Taft 1954) similar to those in Cottus asper, it might be expected that "coastal" groups exist. Table 16a, below, gives the counts for meristic characters in Cottus aleuticus 10 miles and less from the sea and 10 to 50 miles from the sea.

TABLE 16a
COMPARISON OF MERISTICS OF COASTAL AND NON-COASTAL COTTUS ALEUTICUS

LOCAL	D_1		D_2			A				P				VERTEBRAE			
	8	9	18	19	20	12	13	14	15	13	14	15	16	24	25	26	27
Coastal	5	17	4	14	3	0	11	9	1	3	12	7	0	1	4	9	1
Non-Coastal	9	17	5	22	3	1	12	12	2	2	8	15	2	0	2	17	3

Chi square tests applied to the characters which showed signs of difference, vertebrae and pectoral rays. The difference between the pectoral rays yielded a probability of .05-.02, vertebrae .3-.2. Since only one character differs significantly and since one would expect several differences to arise if separate populations existed, the differences could be attributed to environmental factors. Data on 35 specimens indicates no difference in extent or degree of prickling.

Latitudinal Variation

Comparisons of meristics were made every 4°. Hubbs and Schultz (1932) give the data on number of vertebrae for California and Washington specimens. Table 17 below shows latitudinal variation of Cottus aleuticus.

TABLE 17
LATITUDINAL VARIATION IN VERTEBRAE OF COTTUS ALEUTICUS

Latitude	Number of Caudal Vertebrae				Mean
	24	25	26	27	
57-60° N	1	6	11	2	25.70
53-56	-	2	7	7	26.31
57-52	1	11	32	5	25.84
Washington	1	12	25	5	25.79
California	1	5	5	-	25.36

Table 17 shows an obvious tendancy for vertebral means to increase northward. A drop, which appears significant, occurs at 57-60°N. Ungrouped data show this to take place starting at 56°.

SEX DIFFERENCES

Table 18 below compares the meristics of males and females

TABLE 18
COMPARISON OF MERISTIC FREQUENCIES IN MALES AND FEMALES OF COTTUS ALEUTICUS

SEX	D_1			D_2			A				P				VERTEBRAE			
	8	9	10	18	19	20	12	13	14	15	13	14	15	16	24	25	26	27
Male	3	11	1	3	10	2	0	6	9	0	2	5	4	4	-	1	9	3
Female	10	25		14	23	2	2	23	13	2	3	29	6	1	1	4	10	

Chi square tests were applied to the data which showed signs of differences - vertebrae, pectoral and anal rays. Only pectoral rays were found significantly different. The males had significantly more pectoral rays, p.05-.02. The explanation of this might be found in the behavior of the male. The male in <u>Cottus gobio</u>, the English sculpin, has been found to fan the eggs with undulations of his pectoral fins. This activity occurs during incubation until just after hatching. Similar behavior has been observed in <u>Cottus asper</u> by the author. Possibly the increased number of rays is associated with egg-fanning activity in <u>Cottus aleuticus</u>. It is interesting to note that, although the differences were not significant, more pectoral rays were found in male <u>Cottus cognatus</u> and <u>rhotheus</u>.

DISTINGUISHING CHARACTERISTICS

<u>Cottus aleuticus</u> may be distinguished by its tubular nostrils, single preopercular spine, 24 to 27 caudal vertebrae and single symphysial pore.

Cottus ricei (Nelson) 1876 spoonhead sculpin

Figure 11

Synonomy

Cottopsis ricei Nelson, Bull.Ill.Lab.Nat.Hist.,I, 40, 1876, Lake Michigan off Evanston.
Uranidea pollicaris Jordan and Gilbert, Proc.U.S.Nat.Mus., V, 222, 1882, Lake Michigan off Racine, Wisconsin.
Uranidea ricei Jordan and Gilbert, Bull.U.S.Nat.Mus., 16, 953, 1883
Uranidea spilota Jordan and Gilbert, Synopsis, 694, 1883, not of Cope.
Uranidea ricei, Jordan and Gilbert, Synopsis, 953, 1883.
Cottus pollicaris Jordan and Evermann, Bull.U.S.Nat.Mus., 47, 1954, 1898.
Cottus ricei Jordan and Everman, Bull.U.S.Nat.Mus., 47, 1952, 1898.

DESCRIPTION

Color

Light brown with dark markings. Two to four dark saddles, usually three, under second dorsal. Narrow bands on rays of dorsals, caudal and pectorals. Chin evenly covered with fine speckles.

Morphology

Head small, about 3.5 times into standard length. Mouth small, head wide, widest at preopercle where width equals length. Caudal peduncle narrow. Chin wrinkled. No teeth on palatines. Four pyloric cacae. Posterior nostrils semitubular. Upper preopercular spine curved upwards and inwards in an arc resembling the horn of a bison. One to three, usually two, smaller spines below. Prickles highly variable, may cover whole body (even on head and abdomen) or be reduced or absent. Strongly prickled individuals often have more preopercular spines. The prickle has an oval base which is longer than the spine. The long base is strongly serrate on the side distant from the spine (see Figure 11). One symphysial pore is present.

Meristic variation in Figure 7 includes specimens from over the whole North American range (other species counts just from B.C.). Twelve specimens had one spine on the first dorsal basal, two had two. Out of 15 specimens one had three empty basals between the dorsals, one had two empty basals, four had one empty basal and in six all the interdorsal basals were occupied by a spine or a ray. The lateral line is usually complete at a total length of 55 mm. When complete it contains from 35 to 37 pores.

DISTRIBUTION

The spoonhead muddler is found in the Great Lakes system, in James Bay drainages, in the North Saskatchewan River, in Lesser Slave Lake and tributaries, in Lake Athabaska, in Great Slave Lake, in the Peace River and in the Muskwa River of the Liard system (last two in B.C.) and in the main Mackenzie River to the delta. The distribution map shows a divided distribution, with no records from all of Manitoba and most of Saskatchewan. It may be that insufficient collecting has been done in these areas.

GEOGRAPHIC VARIATION

As only two collections of Cottus ricei have been made in British Columbia, the literature and museum collections from other locals have been relied on. Table 19 shows latitudinal variation in Cottus ricei from southeast to northwestern North America. Data from Lake Erie were obtained from Marie Fish (1932), Lakes Michigan, Huron and Superior from Hubbs (1919), Lake Nipigon Dymond (1926) and some Lake Michigan and the remainder from Institute of Fisheries material.

Only about thirty specimens are involved in Table 19. Despite this small sample size trends are apparent. The number of anal rays decline northward. The pectoral and dorsal rays probably also decline northward, while the dorsal spines perhaps increase northward.

The distribution of Cottus ricei is,disjunct, a northwest and a southeast region being populated. Significant differences probably exist in the characters of the two groups. However, they should not be given taxonomic status. Clinal groups, unless they contain sharp zones of change, should not be given subspecific or specific status. Bailey, Winn and Smith (1954) discuss the clinal problem in taxonomy.

The distribution of ricei looks almost as if the original distribution was continuous and had been cleaved by glaciation. If this is so, where did the northwestern group survive? It is not known to be present in Alaska (Walters 1955). It is possible that the northwestern group followed the glaciers southward, then north on glacial retreat. This does not explain the absence of an intermediate group, however. It is possible that the spoonhead sculpin has remained undiscovered in the intermediate regions.

TABLE 19
CHANGES IN THE MERISTICS OF <u>COTTUS RICEI</u> FROM SOUTHEAST TO NORTHWEST IN NORTH AMERICA.

	DORSAL SPINES				DORSAL RAYS				ANAL RAYS						PECTORAL RAYS				VERTEBRAE		
	7	8	9	10	16	17	18	19	11	12	13	14	15	16	14	15	16	17	23	24	25
Lake Erie		1					1						1			1					
Lake Huron and Lake Michigan	5	5	1		1	6	3	1			3	7		1		2	7	1			1
Lake Superior		1					1				1						1				
Lake Nipigon	c	c	r			c	c				c										
North Saskatchewan	1					1					1					1				1	
Peace River	1	1				1	1			1	1				1	1			1	1	
Muskwa River		7	1	1	1	6	2			8	1				8	1			4	5	
Lesser Slave Lake		2					1	1			2						1	1		1	1
Great Slave Lake		2				2			1	1						2			1	1	

c = common
r = rare

COMPARISON OF SPECIES AND INTERSPECIFIC VARIATION

RELATIONSHIPS OF SPECIES TO ONE ANOTHER

The following briefly summarizes the closest relatives of a species, why and to which species it is most closely related.

C.asper seems to be most closely related to C.princeps because of similarities in vertebral counts, chin pores and the number of spines on the first basal of the spinous dorsal fin.

C.cognatus appears to be most closely related to the shorthead sculpin and C.hubbsi and other members of the bairdi group. Sexual dimorphism, coloration, vertebral counts and chin pores relate the two. C.aleuticus resembles cognatus in body proportions, dentition, coloration of spinous dorsal of spawning male and prickling. Probably this resemblance is secondary - an example of the common convergent evolution in the group.

The shorthead sculpin resembles hubbsi and cognatus in several respects. It differs from cognatus in dentition, in which it resembles hubbsi. The opercular mandibular pores in cognatus agree in number and pattern with the shorthead and differ from hubbsi. More study will be required to determine the exact relationships.

C.aleuticus bears many affinities with C.chamberlini and protrusus which are discussed in Schultz and Spoor (1933) in which reference protrusus was named. The similarities are numerous and the differences few and investigation might show synonomy.

C.rhotheus has many affinities with C.ricei. Their wrinkled chin, prickling and prickles, narrow caudal peduncle, wide flat head, preopercular armature, complete lateral line and semitubular nostrils are common features. C.rhotheus is distinct from ricei in its fewer caudal vertebrae (21-22 instead of 23-25); longer head and larger mouth, palatine teeth, 2 instead of 3 to 4 (rarely 2), saddles under the second dorsal, and two instead of one symphisial pore. It is possible that rhotheus is a modified relict of ricei from some past glaciation. C.rhotheus is somewhat similar to C.carolinae in mottling and wrinkling of the chin, speckling on the pectoral fins, and two sharp saddles under the second dorsal, in having the vomerine and palatine teeth in contact, and in having two symphysial pores. It differs from carolinae in prickling and possession of a reddened dorsal in the spawning male, in having a complete lateral line. C.rhotheus is probably also similar to the unpublished new species of Robins, C.girardi, having the same characters in common that carolinae has, except the number of symphysial pores. C.rhotheus is geographically quite isolated from carolinae and girardi, both being eastern forms. C.rhotheus seems to have more characters similar to carolinae than to ricei, hence should be considered most closely related to it. It is interesting to note that the characters in ricei that are similar to rhotheus are not usually those in carolinae that are similar to rhotheus; each is more similar to rhotheus than to one another.

As mentioned before, the spoonhead muddler seems distantly related to C.rhotheus. The spoonhead sculpin also seems related to two forms in the U.S.S.R. described by Berg (1949), C.sibiricus and C.spinulosus. The flat heads, shallow bodies, small darkbands on the dorsal fins in Berg's illustrations appear very similar to ricei. A dorsal view of the head of sibiricus shows the same wide head and hornlike upper preopercular spine as in C.ricei, as noted by Wynne-Edwards (1952). The following table gives meristic counts of the three species.

TABLE 20
MERISTIC COMPARISON OF COTTUS RICEI, SIBIRICUS AND SPINULOSUS

SPECIES	DORSAL SPINES	DORSAL RAYS	ANAL RAYS	PECTORAL RAYS	LATERAL LINE PORES
ricei	7-10	16-19	11-16	14-16	35-37
sibiricus	7-8	17-19	12-14	15-16	
spinulosus	7-8	16-18	12-14	14	32-35

The pectoral ray counts of sibiricus are taken from illustrations, and hence may not be accurate. It will be seen that none of the meristic ranges has sufficient distinctiveness to provide separation, except lateral line pores. This demonstrates their close relationship. It is interesting to note that C.ricei keys down to C.sibiricus in Berg's key (translated by Marie Jerkela of the Institute of Oceanography). C.sibiricus and spinulosus are differentiated by the following section of the key:

13(14) Tail stem more than 11% of the entire body length. Minimum body height not more than 40% of the length of tail stem. Pelvic fins generally reach anus .... C.sibiricus Kessler.

14(13) Tail stem less than 11% of the entire body length. Minimum body height more than 50% of the length of tail stem. Pelvic fins do not or scarcely reach anus .... C.spinulosus Kessler.

It would seem that ricei is a close relative of sibiricus. The wide separation (neither species in Alaska and sibiricus only as far west as the Kolyma River in western Siberia) raises the question of how, if related, they arrived at their present distribution.

INTERSPECIFIC DIFFERENCES

Interspecific differences will be dealt with by discussing differentiating characters and evaluating their taxonomic worth.

Relative Growth

Body proportions have been utilized little in this paper because insufficient time was available to develop this aspect. Relative growth characteristics have the disadvantage that they are modified by condition, size and developmental conditions. They are not constant as meristics are; as the organism enters different stages or "stanzas" proportions may alter. Nevertheless proportions of various body parts to one another are often useful in separating forms such as hubbsi and rhotheus. A sufficient series of representative measurements must be utilized, unlike has been done in the past where single specimens have sufficed. Ths position of the ventrals relative to the anus, often used in the past, does not seem to be a valuable character in B.C. species. The proportion of depth into length does not seem a valuable one as it is modified by fullness of stomach, starvation and reproductive condition. The length of the head and the depth of the caudal peduncle were found to be useful.

Color

Generally color is not held to be a good taxonomic character since it often fades on preservation. However, some colors do survive alcohol and formalin, and color is useful in the field. As color differences are often associated with behavioral difference (which are considered constant characters) they may be quite useful; use should be avoided, of course, of those colors modifying with the background. Color differences in Cottus surviving preservation and useful in species separation were, number of saddles under the second dorsal, patterns of black marks on the spinous dorsal, presence of wide bands or flecks on pectoral fin, and mottling on the chin. Sexual differences in coloration of edge of spinous dorsal and black infusion of the male were found to be less well preserved.

Morphology

The presence, absence or form of several characters designatable as morphological are useful in differentiation. The absence or presence of teeth on the palatine bones proved useful in separating British Columbia forms. Robins (1954) found palatine teeth to be present in some populations of cognatus and absent in others. Whether the palatine tooth patch was in contact with the vomerine teeth was found to be a good character. The number of pyloric cacae in the species examined was not found to be diagnostic. The tubularity of the nostrils was variable. Some species with a non-tubular nostril occasionally had semi-tubular nostrils. Sometimes species like C. ricei with a non-tubular nostril possess tubular ones. The character is usually valid in separating those with non-tubular and tubular nostrils, however.

Preopercular spines are a highly modifiable character in the genus Cottus and within some of its species. In asper and the shorthead sculpin, variation of one spine occurred, in cognatus and ricei, two spines. This character may be useful if the extent of its variation is appreciated. Robins (1954) found it to vary with habitat.

The extent of prickling was found to be too variable to be useful. Frequently specimens of a species would be prickled all over or only in a small patch behind the pectoral fin or not at all. Prickling, when extending over the whole body, can be useful as a confirming character, but if reduced, little can be deduced from it.

The shape of the prickles themselves can be used in sculpin taxonomy. This new character is not applicable to field identification, since it is not visible in uncleared fish. It can, however, be applied in determining the relationships of fish. The following illustration shows the shapes of prickles in species examined. The shape and proportions of the shaft - the vertical portion and the base - the round or oval portion at the base of the spine should be noted.

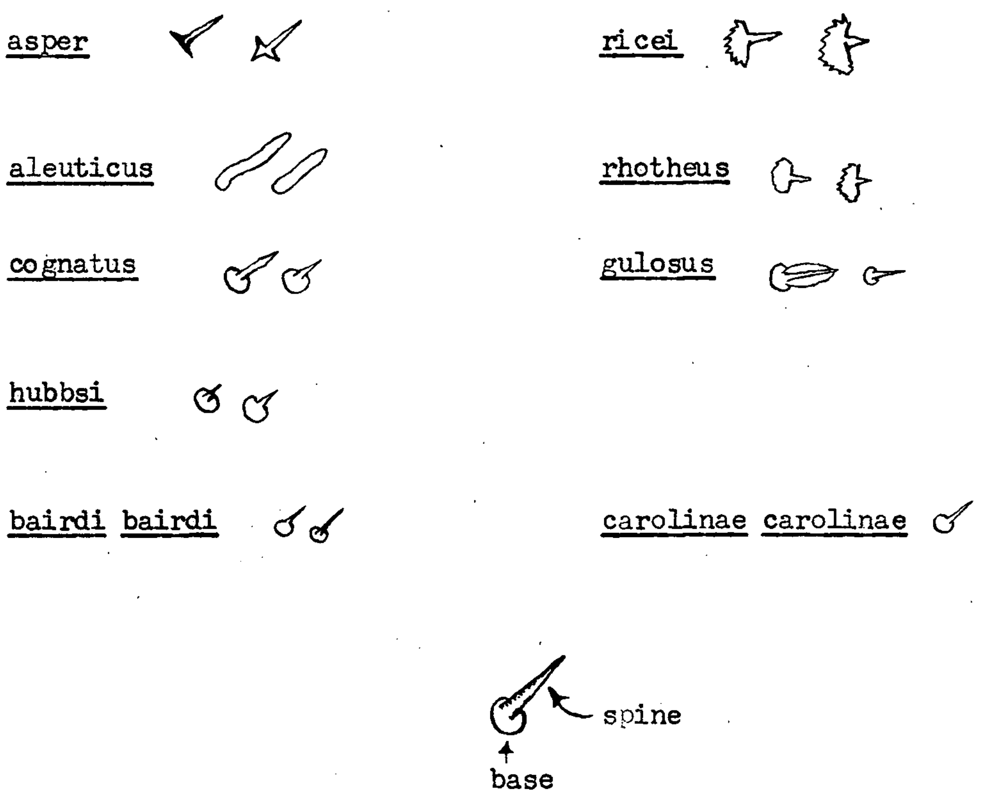


Figure 3. Shapes and proportions of cottine prickles drawn from cleared specimens.

Variability does occur in the shape of the prickles within a species. The typical shape is found in the centre of the prickle patch; it may vary at the perimeter. The shape of prickle is described under individual species. The odd vanes beside the spine in gulosus are peculiar, making the spine appear feather-like.

It was found that some species possessed two pores on the tip of the chin (see illustrations of ventral surface of head of different species), while others possessed only one. Robins (1954) noted this character previously. Dr. R.M.Bailey (pers.comm.) states that in some species the fusion or lack of fusion of pores is subject to marked variation. The following table shows that the amount of variation in this character in B.C. species is small and that it is a good identification feature. The specimens were a random sample (those individuals used for clearing). A second sample from the collection is present for Cottus cognatus. A few non-British Columbia species are also included.

TABLE 21
NUMBER OF CHIN OR SYMPHYSIAL PORES

SPECIES	ONE PORE	TWO PORES
asper	400	5
aleuticus	135	2
princeps	6	0
bairdi shasta	10	0
gobio	4	0
ricei	21	0
bairdi punctulatus	1	7
bairdi semiscaber	0	3
shorthead sculpin	0	9
hubbsi	0	35
cognatus	1	462
rhotheus	0	33

Another previously unreported character found in this study was the number of spines on the first pterygiophore of the spinous dorsal. In some species there were characteristically two spines on the first basal of the dorsal, in other species only one. Table 23, on the following page presents the variability found in this character in different species. Determination wasmmade on cleared specimens from British Columbia.

The exact function of differences in the number of spines on the first dorsal basal is unknown. It appears unrelated to habitat. Species bearing higher spinous dorsal counts(C.asper and aleuticus) usually possess two spines, while those having low spinous dorsal counts have only one spine on the basal. It is possible that the possession of two spines strengthens the leading edge of the fin. The chief function of the fin would seem to be behavioral, however, not locomotory.

Even in uncleared fish the number of spines on the first basal can be determined with fair accuracy. When two are present the bases of the spines are in contact and form a "V"; when only one is present the bases of the first and next spine are separated by the width of at least one spine.

In some species, such as cognatus and ricei, a high degree of variation in the number of spines on the first basal occured, amounting to 10% in cognatus. In such species the character may not be used for identification, although it may be used for indicating relationships. In other species it might be used for an accessory character in keys. As it is not the simplest character to describe or determine perhaps it should only be used in determining the relationships of species.

TABLE 23
NUMBER OF INDIVIDUALS IN VARIOUS SPECIES HAVING ONE OR TWO SPINES ON FIRST DORSAL BASAL

SPECIES	ONE SPINE	TWO SPINES
<u>asper</u>	3	82
<u>aleuticus</u>	0	48
<u>princeps</u>	46	0
<u>cognatus</u>	46	5
shorthead sculpin	25	0
<u>rhotheus</u>	22	2
<u>hubbsi</u>	39	1
<u>ricei</u>	12	2
<u>carolinae</u>	7	0
<u>bairdi bairdi</u>	4	1
<u>hypselurus</u>	5	0

When the number of spines on the first basal is away from the norm the number of spines is usually abnormally high or too low. Hence two spines on the basal where there are usually one may result from crowding. One spine where there are usually two may result when there are fewer than the usual total number of spines.

<u>Meristic Characters</u>

Meristic characters have been often used in the past for differentiation of forms. Increasingly it has been shown that their high variability in many cases excludes their use for specific differentiation. The preceding studies on intraspecific variation have shown that meristic characters may change with several factors such as latitude, altitude and temperature. It is only when the full effect of these on variation is known that serial characters should be used in identification and naming.

Most of the meristic characters in Figure 7 show significant differences in means. Although this establishes that the species involved are different, it doesn't necessarily enable one to differentiate them. However, reference to the graph will show that some characters do not overlap. That meristic characters in some cases are useful in separation of species should not be obscured. Also the overlap that occurs in the extremities of the ranges may occur so infrequently that the character may be used for separation with a fair degree of certainty. The utility of characters shown on Figure 7 can be obtained directly so that no discussion of these characters will be given.

Branchiostegals

The usual number of branchiostegals in *Cottus* is six. Occasionally seven are found. The frequencies with which sevens occur in different species varies but not sufficiently to be diagnostic.

Basals

The number of basals in the anal fin equals the number of rays, but the number of basals under the dorsal fin may differ from the number of spines and rays. Between some species the ranges, and between others, the modes, serve as a means of distinguishing. The table following summarizes the number of basasl under both dorsal fins.

TABLE 24
NUMBER OF BASALS BELOW THE DORSAL FINS

SPECIES	NUMBER OF BASALS									
	23	24	25	26	27	28	29	30	31	32
asper					2	20	43	17	1	
aleuticus				9	21	8				
princeps					1	3	2			
cognatus	1	6	21	22	1	1				
shorthead sculpin			1	1	2					
rhotheus		17	7	1						
hubbsi		4	26	10						
ricei			1	6	2	2				
carolinae c.		1	3	1						
bairdi b.			2							

Caudal rays

The number of major caudal rays (attached to the two hypural plates) is so constant in the genus that, like the number of branchiostegals, it is of no specific taxonomic importance. The minor rays (not attached to hypural plates, above and below the major rays) vary greatly, in fact more than any other count. In most cases the variation is so great that they are unuseable. The fact that they cannot be readily counted without clearing decreases any value that they might have. Table 25 below gives the frequencies of minor caudal counts for several species. It will be noted that the dorsal minor caudal counts are usually higher than the ventral.

TABLE 25
VARIATION IN MINOR CAUDAL RAYS

SPECIES	DORSAL MINOR CAUDALS						VENTRAL MINOR CAUDALS										
	6	7	8	9	10	11	4	5	6	7	8	9	10	11	12	13	14
<u>asper</u>		1	4	32	10	3		1	2	3	19	19	8	1			1
<u>aleuticus</u>	1	5	8	4					3	8	6	1					
<u>bairdi</u> <u>shasta</u>		3	2					2	1	1	1						
<u>cognatus</u>	5	13	14	9	2			5	6	16	11	2					
shorthead sculpin		1	2	2						3	2						
<u>hubbsi</u>	3	8	5	1				3	7	6	1						
<u>rhotheus</u>	4	8	4	1				5	11	1							
<u>ricei</u>	1	5								2	1	2	2				
<u>carolinae</u> <u>c</u>.		1	1	3				1		1	3						
<u>hypselurus</u>	3	2						3	2								
<u>bairdi</u> <u>b</u>.	4						1	2	1								

Lateral line

Lateral line pores are a highly useful character. Their numbers may be seen under the description of each species. The length of the lateral line is quite closely proportional to the number of pores. The position of the end of the lateral line relative to the dorsal fins or caudal peduncle may, therefore, substitute, and as it is more easily determined is a better character. One disadvantage of the lateral line as a taxonomic character is that it is not usually complete until a size of about 60mm. (total length) has been attained. As mentioned in the descriptions, exceptions in the completeness of the lateral line, i.e., incomplete when normally complete, do occur.

Reproduction

Time of reproduction does not lend itself to identification of specimens in hand, but it does to the finding of the relationships of species.

Two types of spawners would appear to exist in British Columbia. Table 26 gives spawning time of B.C. sculpins. It is known that Cottus asper, aleuticus, hubbsi, and rhotheus spawn in the spring. The eggs in these species are large just before they spawn. Limited observations would indicate that they are not large in the winter. This, and the presence of large (1.0-17) eggs in Cottus cognatus from August to November (no specimens collected later), seems to indicate they are fall spawners. Whether cognatus spawns in the fall or not, the earlier development of eggs (when none are present in others) indicates a definite physiological difference from asper, aleuticus, hubbsi and rhotheus. Specimens of Cottus ricei from Lake Michigan collected on 11 June possessing eggs 0.8 mm. in diameter might indicate summer or fall spawning. These differences are of taxonomic importance. If changes in spawning time exist, deep-seated behavioral and physiological differences in the adults and young hence might be expected.

Ecology

Modern systematics utilizes other than morphological characters. Physiological, ethological and ecological characters are also employed. Table 26 summarizes relative differences in ecology of B.C. species of Cottus. Insufficient data were available to draw conclusions from ecology of the spoonhead and shorthead sculpin. Their data are included only for the sake of completeness.

The data are subject to the limitations given in the methods. Since the ecological data are of comparative value only, no description was given under individual species. To evaluate ecological differences statistical tests were performed on the differences between the species. Tests cannot be performed on all the differences since there are too many combinations. Only certain differences will be pointed out.

It will be noted in Table 26 that Cottus asper and Cottus aleuticus have been recorded as occurring in brackish water in 2% of the collections. Doubtless they occur fairly frequently in brackish or even salt water. Snyder (1908a) stated that the two were able to tolerate salt water. C.L.Hubbs (1921a) records the prickly sculpin from two brackish lagoons in California. Clark Hubbs (1947) recorded C.asper as venturing downstream into chlorinities of .57 in Salinas River, California. Gilbert (1895) found C.aleuticus in brackish water in Alaska and was able to keep one for several days in a saltwater aquarium. The only other instance of a British Columbia species of Cottus being in saline water is given by Dunbar and Hidebrand (1952). They found the C.cognatus in brackish water in Ungave Bay, northern Quebec. This, the only instance I know of in this species may merely be another instance of freshwater fish entering the sea in the northern parts of their distribution (such as Prosopium cylindraceum). It does not seem to be a normally salt water inhabiting species.

To test the significance of habitat difference between Cottus asper and aleuticus a chi square test was run on the distribution of numbers of collections taken in lakes, streams and brackish water. The difference was found to be significant, $p < 0.02$. The difference is chiefly attributable to the more common occurrence of asper in lakes. Another test was run of the width of streams in which asper and cognatus were collected. This difference was found to be significant, $p < 0.05$. When differences between the slimy and torrent sculpin were tested as to current, the difference was found attributable to chance ($p=.3-.2$). The above tests indicate that habitat differences exist in B.C. species and that these may be statistically significant.

The prickly sculpin seems to be ecologically distinct from other B.C. species by its more common occurrence in lakes than streams, and its more common occurrence on sandy bottoms. The Aleutian sculpin is distinguished by its high degree of preference for narrow, swift, clear streams. Frequent occurrence on gravel or mud bottoms, in clear narrow streams characterize the slimy sculpin. The Columbia sculpin would seem to usually inhabit swift or slow clear wide streams and frequently lakes. The torrent sculpin is, as its name indicates, an inhabitant of strong currents. It has been recorded in three lakes; but two of these, the Upper and Lower Arrow Lakes, possess a definite current. The third collection was made within the influence of an entering stream. All collections have therefore been made in some current.

Differences in food also occur. Northcote (1954) discusses differences in food of asper and rhotheus. The larger size of mouth in rhotheus permits it to utilize larger food items at an earlier age than asper. Present information would indicate that cognatus is not piscivorous, while asper and rhotheus are. Palatine teeth are present in asper and rhotheus and absent in cognatus. Possibly these food preferences and morphological characters, fish diet and palatine teeth, are correlated.

TABLE 26

COMPARATIVE ECOLOGY OF B.C. SCULPINS - Figures in parentheses and percentages refer to the number of collections.

SPECIES	HABITAT	DEPTH	STREAM WIDTH	CURRENT	WATER COLOR	TEMPERATURE	PREDATORS
Cottus aleuticus	Streams 68% Lakes 30% Brackish 2% (41)	Streams 1 ft. or less usually, up to 4 ft. (10)	11-20 ft. 50% 6-20 ft. 25% + 50 ft. 25% (12)	Swift 75% Mod. 13% Slow 12% (8)	Clear 72% Glacial 14% Cloudy 14% (7)	Cold	Game fish and Dolly Varden
Cottus asper	Lakes 55% Streams 43% Brackish 2% (140)	Streams usually 1-5 ft.; lakes 1-10 ft. (23)	+ 50 ft. 31% 21-50 ft. 25% 11-20 ft. 25% 6-10 ft. 13% 1-5 ft. 6% (16)	Swift 50% Slow 43% Mod. 7% (14)	Clear 47% Cloudy 43% Muddy 13% Glacial 7% (15)	Warm	American Merganser, lake and Dolly Varden char, cutthroat and brown trout, squawfish, ling and sculpins.
Cottus cognatus	Streams 69% Lakes 31% (54)	Streams 1-3 ft., up to 5 ft.; lakes ½-6 ft. (23)	11-20 ft. 55% 6-10 ft. 18% 21-50 ft. 18% + 50 ft. 9% (22)	Swift 45% Slow 27% Mod. 18% Still 9% (22)	Clear 58% Cloudy 26% Muddy 16% (19)	Cool	Lake char, pike and ling.
Cottus n. sp.	Streams 100% (3)		+ 50 ft. 50% 1-5 ft. 50% (2)	Swift 100% (2)	-	Cool	-
Cottus hubbsi	Streams 60% Lakes 40% (10)	Streams 1-3 ft., usual, range ½-5 ft. (5)	21-50 ft. 50% + 50 ft. 25% 11-20 ft. 25% (4)	Swift 43% Slow 43% Mod. 14% (7)	Clear 80% Glacial 20% (5)	Cool	-
Cottus rhotheus	Streams 84%	Streams 1-3 ft., rarely 1-5 ft. (6)	+ 50 ft. 50% 21-50 ft. 38% 11-20 ft. 12% (8)	Swift 38% Mod. 38% Slow 24% (16)	Clear 50% Glacial 33% Cloudy 17%	Cool	-
Cottus	Streams 100% (2)	Streams 1-3 ft. (1)	+ 50 ft. 100% (2)	Mod. 100% (1)	Muddy 100% (1)	-	-

TABLE 26 continued

SPECIES	BOTTOM	REPRODUCTION	FOOD
Cottus aleuticus	Boulder 36% Gravel 36% Rocks 18% Sand 10% (11)	Spawn from Feb. to mid-June in creeks under boulders. Eggs orange, 1.5-2.0 mm.	-
Cottus asper	Sand 35% Detritus 9% Gravel 26% Silt 4% Mud 13% Boulder 4% Rock 9% (54)	Spawn from mid-Feb. to June in streams under boulders. Yellow or orange eggs. Down-stream spawning migrations in coastal streams	Fry - plankton and aquatic insect larvae; Adults - insect larvae, fish, crustacea, molluscs.
Cottus cognatus	Gravel 32% Boulders 6% Mud 25% Clay 6% Rocks 17% Silt 2% Sand 10% Detritus 2% (48)	Ovaries are ripe from August to at least November. Eggs 1.5 to about 2 mm.	Aquatic insect larvae
Cottus n. sp.	Rocks 66% Boulder 34% (3)	-	-
Cottus hubbsi	Gravel 40% Boulder 20% Rocks 17% Sand 10% (10) Mud 10%	Probably spawn from April to June.	-
Cottus rhotheus	Gravel 45% Rocks 12% Boulders 19% Sand 12%	Probably spawn from April to June	Fry - plankton, midge larvae; Adults - insect larvae and fish.
Cottus ricei	Mud 100% (1)	Ripe individual on 11 June from Lake Michigan.	

Part of habitat data from Carl and Clemens (1953). Food data in part from Northcote (1954) and Munro and Clemens (1937)

KEY TO THE FRESHWATER SCULPINS OF BRITISH COLUMBIA

In order to summarize the differences between species of British Columbia, a key containing most of these differences is provided below.

1 (12) Upper preopercular spine not long and shaped like buffalo horn and head not greatly flattened as in Figure 4.

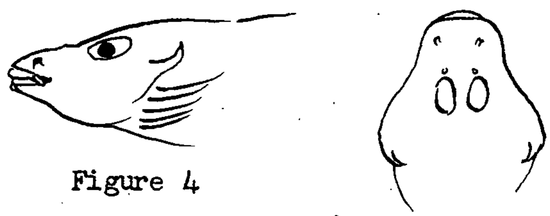


Figure 4

2 (5) One pore on midline of tip of chin (see Figure 5); caudal vertebrae 24-28; 2 spines on the first dorsal basal; dorsal spines usually 8-10; 26-31 basals under the dorsal fins; commonly enter brackish water; lateral line always past second dorsal in specimens over 60 mm. total length.

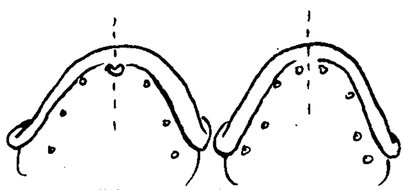


Figure 5

Figure 6

3 (4) Posterior nostrils not tubular (Figure 6); anal rays 15-19; palatine teeth present; black spot present on the posterior portion of the first dorsal and then orange border along dorso-posterior edge; 2-3 spines on preopercle (skin must be removed); prickles usually present on back and sides, occasionally reduced to patch in axil; pectoral rays 15 to 18.

prickly sculpin - Cottus asper

4 (3) Posterior nostrils tubular (Figure 6); anal rays usually 12-14 (rarely 15); no palatine teeth; no black spot present on the posterior portion of the first dorsal fin; wide orange band present on first dorsal of only spawning male; one spine at corner of preopercle; prickles in axil only or absent, skin slippery; pectoral rays usually 13-15 (occasionally 16)

Aleutian sculpin - *Cottus aleuticus*

5 (2) One pore on either side of midline of tip of chin (see Figure 4); 20-24 caudal vertebrae; usually one spine on first dorsal basal; dorsal spines usually 7-9; dorsal basals usually 23-26 (occasionally to 28); never enter brackish water in B.C.; lateral line complete or incomplete.

6 (7) Usually strong prickles on back and sides; two sharp dark saddles under second dorsal; strong mottling on chin; lateral line complete in specimens whose total length is over 60 mm.; pectorals with speckles rather than wide crossbars on rays; 24 or 25 (rarely 26) basals under the dorsal fins; usually 15 to 16 dorsal rays (rarely 17); caudal peduncle enters head 2.65-3.0 (as opposed to 2.19-4.5); head large 2.9-3.2 into standard length (as opposed to 3.0-3.9); palatine teeth in contact with the vomerine patch of teeth; dark median band absent in first dorsal.

torrent sculpin - *Cottus rhotheus*

7 (8) Prickles reduced to a weak patch behind pectoral fin (rarely extending onto sides and back past area covered by pectoral fin; usually three, sometimes two, mottled crossbars across back under

second dorsal; chin evenly speckled; lateral line not complete except sometimes in <u>hubbsi</u>; pectorals with bars on rays forming bands; basals under dorsal fins usually 25-27 (rarely 24-28); usually 16-18 dorsal rays (rarely 15-19); head entered 2.9-4.5 times by depth of caudal peduncle; head small, entering standard length 3.0-3.9 times (2.9 occasionally); palatine teeth, if present, not in contact with the vomer; dark marks in first dorsal often forming median band.

8 (11) Palatine teeth present; anal rays 12-14 (rarely 11); ventrals with 4 rays.

9 (10) Three preopercular spines; lateral line extends past second dorsal; 7-8 dorsal spines; head 2.9-3.2 times into standard length; caudal peduncle 3.7-4.6 times into head; usually 14-15 pectoral rays (13-16).

Columbia sculpin - <u>Cottus hubbsi</u>

10 (9) One to two preopercular spines; lateral line does not extend past second dorsal; 8-9 spines in first dorsal fin; head 3.2-3.8 times into standard length; caudal peduncle 3.2-3.6 times into head; usually 13-14 pectoral rays.

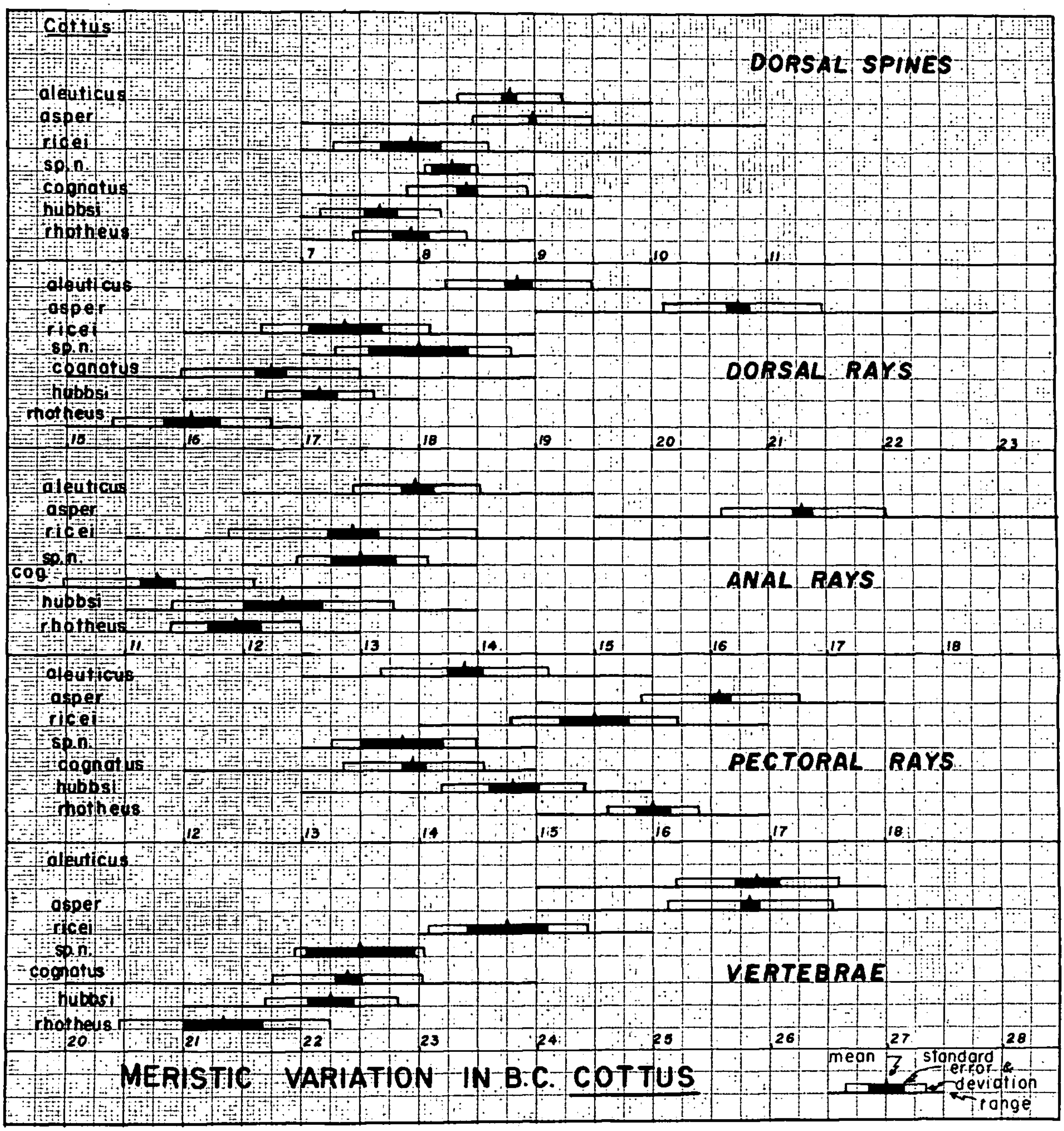
Shorthead sculpin - <u>Cottus n.sp</u>.

11 (8) Palatine teeth absent; anal rays 9-12 (occasionally 13); ventrals with 3-4 rays; lateral line not extending past second dorsal fin.

slimy sculpin - <u>Cottus cognatus</u>

12 (1) Upper preopercular spine long and resembling buffalo horn; head greatly flattened; lateral line complete; caudal vertebrae 23-25; one pore on midline of tip of chin.

spoonhead sculpin - _Cottus ricei_


Cottus
DORSAL SPINES
aleuticus
asper
ricei
sp. n.
cognatus
hubbsi
rhotheus
7
8
9
10
11
aleuticus
asper
ricei
sp. n.
cognatus
hubbsi
rhotheus
DORSAL RAYS
15
16
17
18
19
20
21
22
23
aleuticus
asper
ricei
sp. n.
cog
hubbsi
rhotheus
ANAL RAYS
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hubbsi
rhotheus
VERTEBRAE
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28
MERISTIC VARIATION IN B.C. COTTUS
mean
standard error &
deviation
range

Figure 7

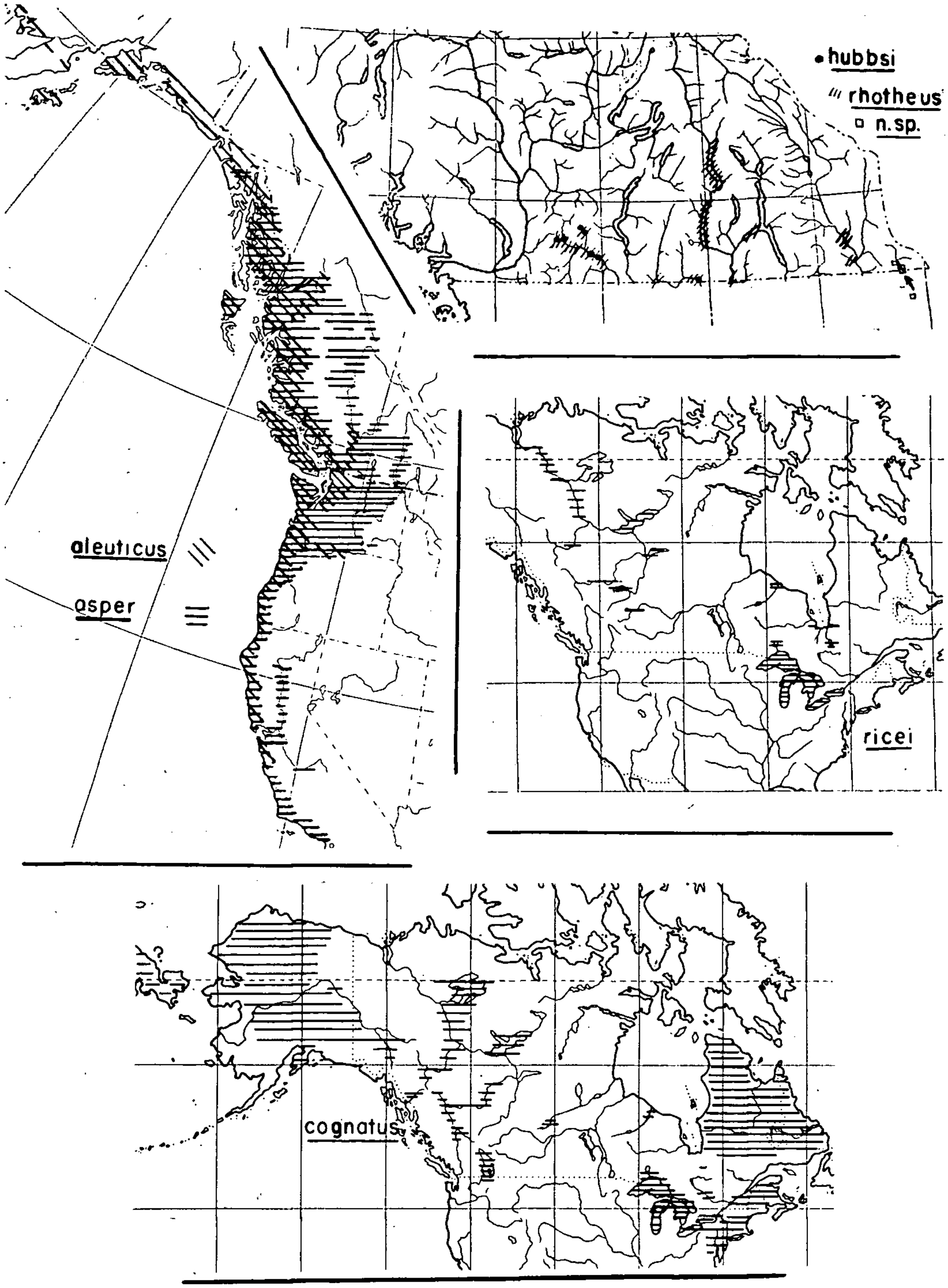


Figure 8. Distribution of B.C. species of Cottus

SUPRASPECIFIC RELATIONS IN COTTUS

The classification of species within the genus Cottus has varied. In 1842 DeKay placed those cottines bearing 3 ventral rays in the genus Uranidea. This character has been shown to very within the species level; his generic distinction has therefore been recognized as invalid. Several other now invalid genera for cottins were erected since this date which will not be discussed (see synonyms of Cottus). Jordan and Evermann (1898) divided Cottus into three subgenera, Pegedictis (short preopercular spine at corner and palatine teeth), Cottus (same but lacking palatine teeth) and and Tauridea (preopercular spine very large, as large as eye and spirally hooked). The first two of these subgenera are not now considered as valid since palatine teeth may very within species and probably occur in unrelated groups. The last was retained by Robins (1954) as a species group. Jordan, Evermann and Clark (1930) retained and confused several old and invalid sub-genera.

Robins (1954) thoroughly revised the systematics of eastern cottins (excepting Cottus cognatus). He divided them into three groups: the banded sculpin, the redfins sculpins and a group containing Cottus ricei.

Some western species studied in this thesis did not fit Robins' key to species groups. Examination of some western and some eastern sculpins and Robins' thesis suggests that there are three major species groups, one of which sub-divides in two. Group I includes Pacific forms, group II holarctic species, the eastern American forms of which break into IIa (sexually dimorphic) and IIb (non sexually dimorphic species), and lastly group III in which are placed ricei and perhaps related palearctic forms. It is likely that examination of Soviet species will require the addition of another group to these three, if not modifications to the grouping. As the required information was not available on all North American species, and as insufficient specimens were available, modifications of species groups may well be required on addition of this information. The existence of three species groups will be established in the following discussions.

CHARACTERISTICS OF SPECIES GROUPS

Caudal Vertebrae

The number of caudal vertebrae is the principal character on which the three species groups are based. Caudal vertebrae were first used taxonomically by Schultz (1930) who used them to separate western Washington species of Cottus. He divided them into two groups, those with 21-24 and those with 25-29 caudal vertebrae. In 1936 Schultz produced a key to the fish of Washington and Oregon. Palatine teeth were the main character used in this key, caudal vertebrae were used in separating small species groups. Schultz and Spoor (1933) also used caudal vertebrae. Hubbs and Schultz (1932) present a table showing two groups of Cottus, one having 20-23 and the other 24-28 caudal vertebrae. Despite the obvious dimorphism, no comment was made on the existence of two species groups. Robins (1954) made no mention of caudal vertebrae in his thesis on eastern sculpins.

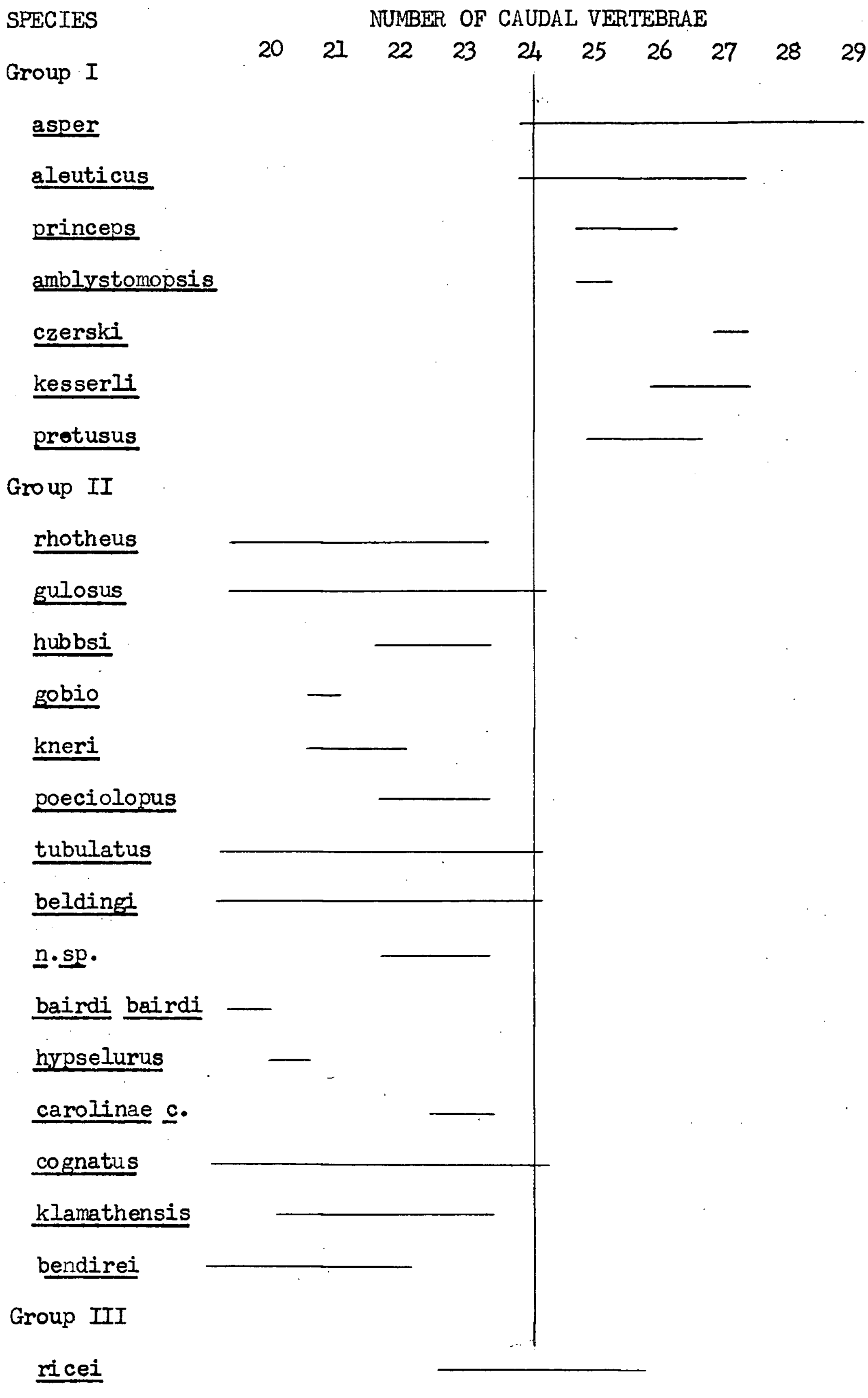
Table 27 presents all data obtainable on ranges of caudal vertebrae. In order to make comparisons of species, worldwide counts were obtained from several sources. The total number of vertebrae in Soviet species was translated from Berg (1949). To convert his total counts to caudal vertebrae counts, 12 was subtracted. Twelve abdominal vertebrae was the greatest number of vertebrae usually found in seven species of Cottus examined (counts ranged from 9 to 13). Counts were also obtained from Schultz (1936) and Hubbs and Schultz (1932).

Table 27 indicates the existence of three groups - 24-29, 20-24, and 23-25 caudal vertebrae. It might be argued that the number of vertebrae does not separate the species into two groups, that overlap occurs at 24 vertebrae and that one species straddles the 24 count. However, ricei is the only species straddling the 24 count out of twenty-five species. If the distribution of vertebral counts was chance one would expect more cases of overlap across the separating line. The amount of overlap occurring in other species than ricei (both other groups extend to 24) is small, 24 being an unusual count in these species. Other evidence for the existance of three groups will be dealt with under the headings of the characters that separate them.

Dorsal Spines

Table 28 gives the ranges of the dorsal spines in groups I and II. Unfortunately means and statistical measures of deviation are not available for most of the species dealt with. "t" tests therefore cannot be used to test the significance of difference between numbers of spines in groups I and II. In most species, as may be seen from the graphs in Figure 7, the midpoint of the range would be a fair indication of the mean. A chi square test on the differences in distribution of midpoints above and below 8.75 in the two groups yield a chi square value having a probability of less than .01.

TABLE 27
RANGE OF CAUDAL VERTEBRAE



Differences in the number of dorsal spines might possibly be attributable to a correlation between the number of dorsal spines and dorsal rays. If this were the case the dorsal spine differences would not be increasing the differentiation between groups I and II. To find if the higher number of spines was related to having more vertebrae, chi square tests were applied to each group. Chi square tests showed that there was not significant association between the number of caudal vertebrae and the number of dorsal spines within each group. The significantly higher tendancy in group I to have more dorsal spines is then dissociated from their having a higher vertebral count. The higher number of dorsal spines in group I then confirms the existence of two groups. Table 28 gives dorsal spine counts in the two groups.

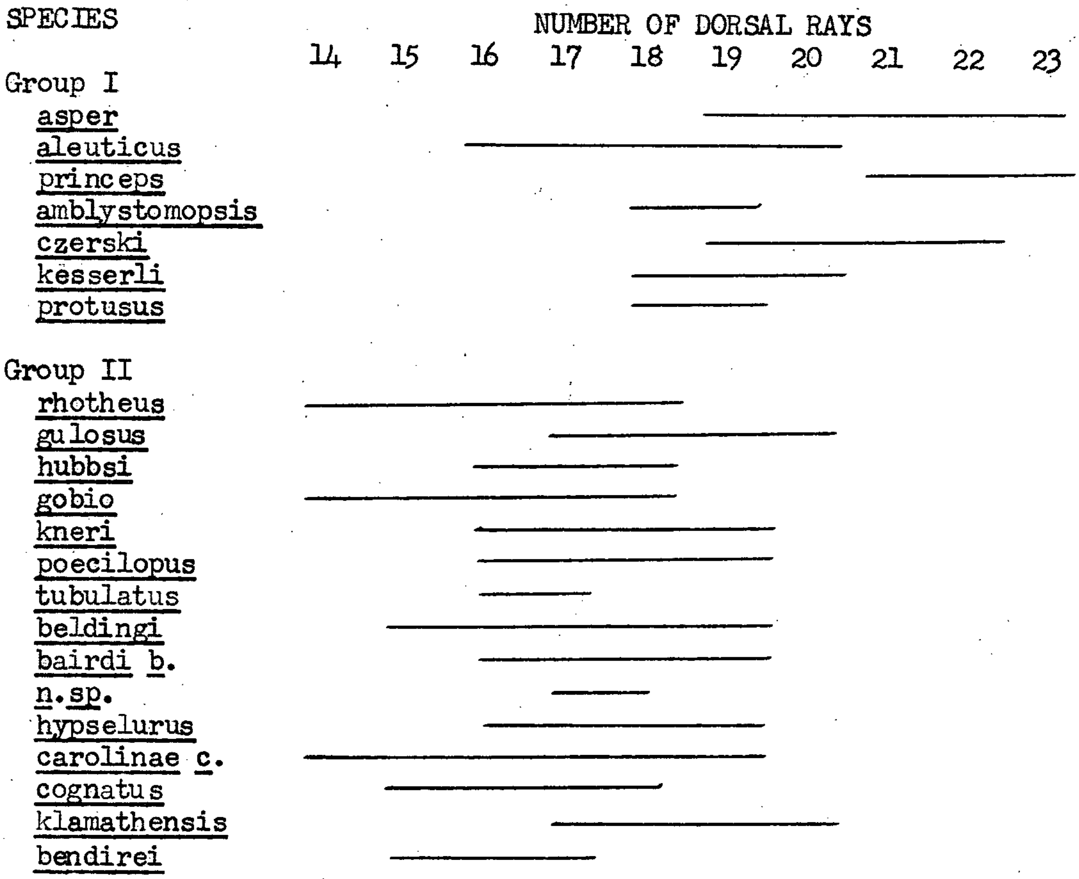
TABLE 28
DORSAL SPINE RANGE IN GROUPS I AND II

SPECIES	NUMBER OF DORSAL SPINES						
	5	6	7	8	9	10	11
Group I							
<u>asper</u>			—	—	—	—	—
<u>aleuticus</u>				—	—	—	
<u>princeps</u>		—	—				
<u>amblystomopsis</u>				—	—		
<u>czerski</u>				—	—	—	
<u>kesserli</u>				—	—		
<u>protusus</u>					—	—	
Group II							
<u>rhotheus</u>		—	—	—	—		
<u>gulosus</u>			—	—			
<u>hubbsi</u>			—	—			
<u>gobio</u>		—	—	—	—		
<u>kneri</u>				—			
<u>poecilopus</u>				—	—		
<u>tubulatus</u>			—				
<u>beldingi</u>		—	—	—			
<u>bairdi bairdi</u>		—	—	—	—	—	
<u>n.sp.</u>				—	—		
<u>hypselurus</u>	—	—	—	—	—		
<u>carolinae c.</u>		—	—	—	—		
<u>cognatus</u>			—	—	—	—	
<u>klamathensis</u>			—				
<u>bendirei</u>			—	—			

Dorsal Rays

Table 29 gives the ranges of dorsal rays in group I and group II. It may be seen that the ranges are usually higher in group I than group II. A chi square test shows that the difference is significant ($p < .01$). Chi square tests also show that no relationship exists between the number of rays and vertebrae in group I ($p=0.5-0.3$) or group II ($p=0.1-.05$). The number of dorsal rays then aids in the definition of groups, although the high overlap makes separation difficult on this basis. It must be remembered than in many species, particularly where the range is small, large series of specimens have not been examined. Therefore, one expects that, in the future, ranges may be extended, which may increase the degree of overlap.

TABLE 29
RANGES OF DORSAL RAYS IN GROUP I AND II



Anal Rays

Table 30 gives the ranges of the number of anal rays in groups I and II. Group I[illegible] was found to have significantly more of the midpoints of its ranges above those of group II (p= -.01).

TABLE 30
RANGES OF ANAL RAYS IN SPECIES GROUP I AND II

SPECIES	NUMBER OF ANAL RAYS 9	10	11	12	13	14	15	16	17	18	19	20	21
Group I													
asper							—	—	—	—	—		
aleuticus				—	—	—	—	—					
princeps								—	—	—			
amblystomopsis						—							
czerski						—	—	—					
kesserli										—	—	—	—
protusus					—	—							
Group II													
rhotheus			—	—	—								
gulosus						—	—	—					
hubbsi				—	—	—							
gobio		—	—	—	—								
kneri					—	—							
poecilopus					—	—	—						
tubulatus			—	—									
beldingi			—	—	—	—							
n.sp				—	—								
bairdi b.			—	—	—	—							
hypselurus				—	—								
cognatus	—	—	—	—	—								
klamathensis					—	—	—						
bendirei			—	—	—	—							

Ventral Rays

There seems to be a higher frequency of forms having 3 ventral rays in group II than in group I. Only one of six group I species ever had 3 ventral rays, while 6 out of 13 of group II species at least sometimes had 3 ventral rays.

Pectoral Rays

A chi square test on the midpoints of the ranges of the pectoral fin rays of the two groups showed they were not statistically different in this respect.

Lateral Line

Only one out of seven species in group I normally had an incomplete lateral line, while 7 out of 11 of group II normally had an incomplete lateral line. A greater tendency in group II exists to have incomplete lateral lines.

Symphysial pores

All three of the species examined in group I (asper, aleuticus and princeps) normally possess one pore on the tip of the chin. According to Robins and according to my own data, seven out of eight species of group II possess two pores on the tip of the chin, Cottus gobio, the Eurasian species, possessing only one. Cottus girardi (manuscript name of Robins') has but one pore and probably belongs to group II. Possibly in the last two species the one pore has been secondarily derived by fusion. Cottus ricei, the only known member of group III, has but one pore.

Other Characters

Other characters such as palatine teeth, tubularity of the posterior nostril, prickling and preopercular armature seem to occur sporadically in both groups. Their ready gain or loss is presumably the result of convergent and divergent evolution.

Distribution

All species of group I are found in Pacific drainages except kesserli which is found in Lake Baikal, U.S.S.R. of Nearctic and Palearctic. Species of group II are holarctic in distribution. The homogeneity of distribution of group I would confirm the common origin of its members. There are indications that group I is more tolerant of saline water than is group II. Cottus asper and aleuticus of group I are known to enter salt water and the presence of several others of this group in maritime islands would also suggest this. Of group II, cognatus (Dunbar and Hildebrand 1952) and poecilopus (Splastenenko 1955) have evidenced ability to enter slightly saline waters. Most of the latter group are found away from the coast, however.

SPECIES GROUPS

The morphological differences and distribution of the high and low vertebrae groups (I and II) would suggest them to be natural taxons. The characters of ricei would, at present, differentiate it from I and II (see key). Further information on its anatomy and that of other freshwater cottids may indicate its derivation which is not clear. Robins' groupings have not been deeply examined; they have been adopted as subgroups of II to which they belong without critical examination since specimens of most eastern species were not available for study.

The relationships of the different species groups are indicated in the following key. The species in each group are listed following each group, the probable members are in parentheses.

KEY TO SPECIES GROUPS IN *COTTUS*

1 (4) Upper preopercular spine not longer than eye and not buffalo-horn-like; head not greatly flattened; caudal vertebrae 20-24 or 24-28, not 23-25; lateral line complete or incomplete; one or two pores at symphysis.

2 (3) Caudal vertebrae 24-29; one chin pore; 4 ventral rays; lateral line usually complete; dorsal spines usually 8-10 (rarely 6-11); anal rays usually 14-18 (rarely 12-19); dorsal rays usually 18-23 (rarely 16-23); found, with one exception, on Pacific slope of North America and Asia.

Group I - *Cottus asper*, *protusus*, *aleuticus*, *princeps*, *amblystomopsis*, *czerski*, *kësserli*, (*asperimus*)

3 (2) Caudal vertebrae 20-24; usually 2 symphysial pores; 3-4 ventral rays; lateral line incomplete or complete; dorsal spines usually 6-9 (rarely 5-10); anal rays 11-15 (rarely 10-16); dorsal rays 15-19 (rarely 14-20); holarctic.

Group II - *Cottus rhotheus*, *gulosus*, *hubbsi*, *gobio*, *kneri*, *peecilopus*, *tubulatus*, *beldingi*, *bairdi*, *hypselurus*, *carolinae*, *cognatus*, *klamathensis*, *bendirei*, *n.sp.*, *baileyi girardi*.

a (b) Sexual dimorphism in breeding features; breeding male characterized by a general black suffusion on body, a well developed and enlarged anal papilla which extends to the anal base as a flat triangular process, blackish fins, a broad red or orange border on the first dorsal fin, chin uniformly pigmented;

palatine teeth weakly developed (the palatine patch shorter than the width of the vomerine patch and separated from it or absent).

Group IIa Redfin sculpins, Cottus bairdi, hypselurus, baileyi, cognatus, (hubbsi).

b (a) Sexual dimorphism in breeding features lacking; males and females similarly colored, anal papilla a small rounded protuberance in both sexes. Fins never black, the spotting restricted to the surfaces of the rays. Chin characteristically mottled. Red border on first dorsal fin reduced or absent.

Group IIb Cottus girardi, carolinae (rhotheus).

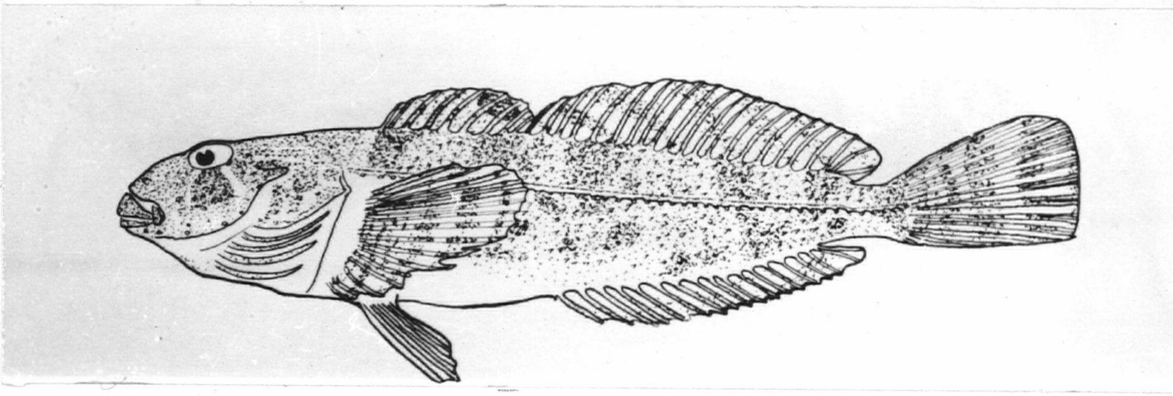
4 (1) Upper preopercular spine longer than diameter of eye; buffalo-like head greatly flattened; caudal vertebrae 23-25; lateral line complete; bones of head cavernous; one chin pore. Do not occur on Pacific slope

Group III - Cottus ricei (sibiricus, spinulosus).

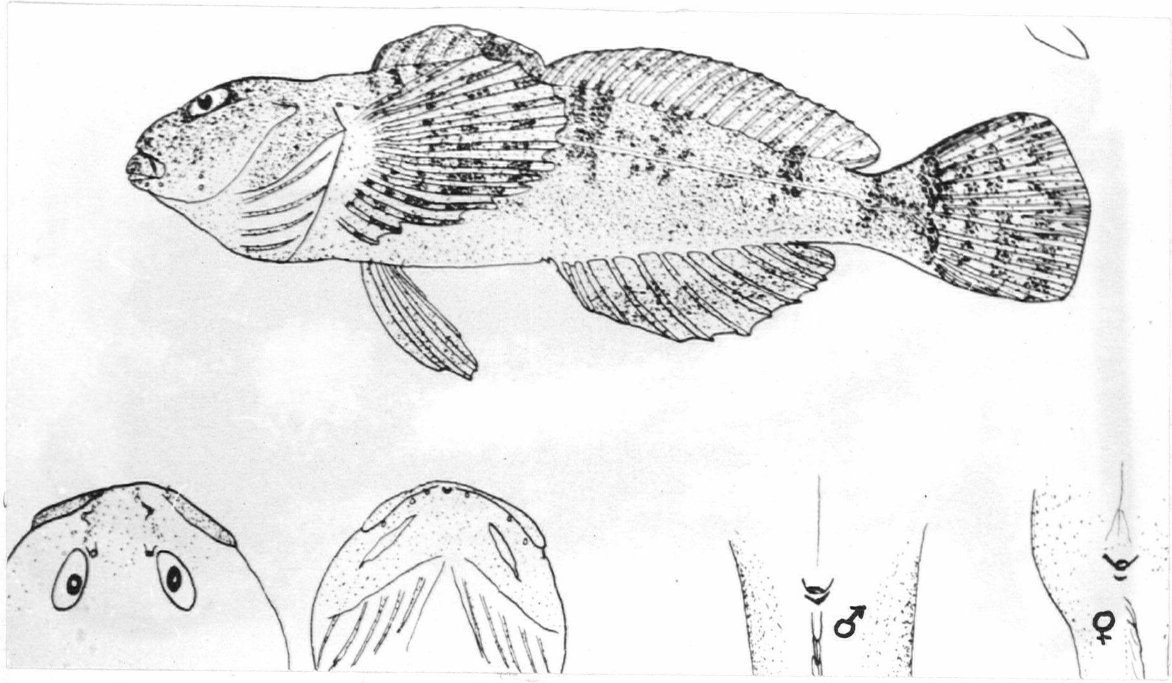
CONCLUSIONS

1. Differences were found in extent and degree of prickling between lake, stream and brackish Cottus asper. River asper possessed more anal rays, fewer pectoral rays, more vertebrae and fewer branchiostegals than lake.
2. Populations of C.asper in or near brackish water near the coast were found to be significantly different than those just inland, in extent of prickling and number of dorsal rays, pectoral rays, and vertebrae.
3. Populations, altitude, isotherms and latitude were shown to be related to meristic variation in C.asper.
4. Significant correlations exist in C.asper between dorsal rays and vertebrae and between anal rays and vertebrae. Pectoral rays and dorsal spines showed no significant correlation with vertebrae.
5. Differences in variability of dorsal spines, dorsal rays, anal and pectoral rays and vertebrae were shown to exist in C.asper.
6. Body proportion and meristic differences were found in river systems and at different latitudes in Cottus cognatus.
7. No significant sex differences in dorsal spines, dorsal rays, anal rays, pectoral rays and vertebrae were found in C.cognatus.
8. C.philonips was found to be synonomous with C.cognatus.
9. No sex differences in dorsal spines, dorsal rays, anal rays, pectoral rays and vertebrae were found in C.rhotheus.
10. Significant differences exist between B.C. and Washington in pectoral rays of C.hubbsi.

11. Significant differences exist in pectoral rays of coastal and non-coastal C.aleuticus.
12. A latitudinal cline in vertebrae, increasing northwards, occurs in C.aleuticus.
13. Clines were shown to exist from southeast to northwestern North America in anal and pectoral rays in C.ricei.
14. Differences were shown to exist between B.C. species in coloration, body proportion, meristics, distribution and ecology.
15. The taxonomic characters used to classify Cottus were evaluated.
16. Three natural groups were found in cottines, based on caudal vertebrae and affirmed by other characters.

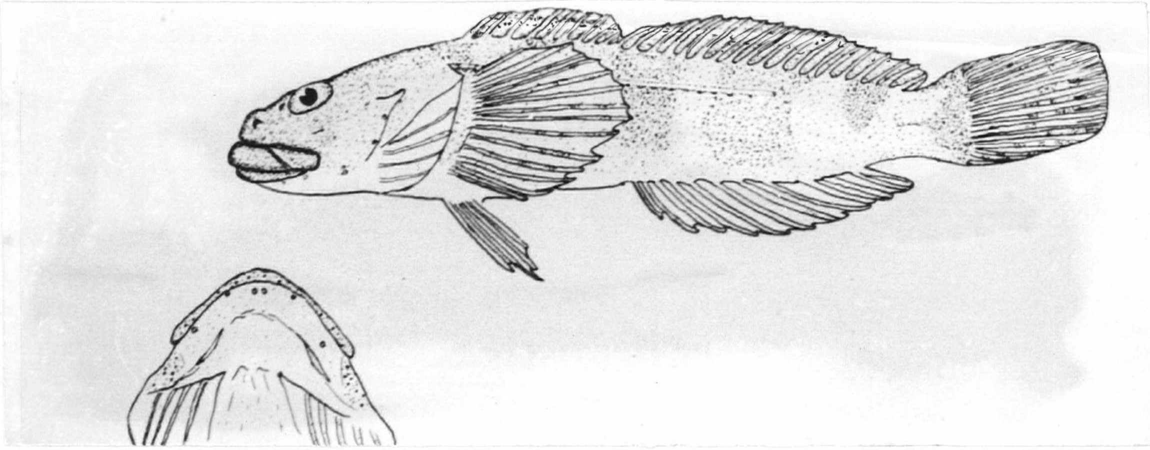


Cottus asper Richardson

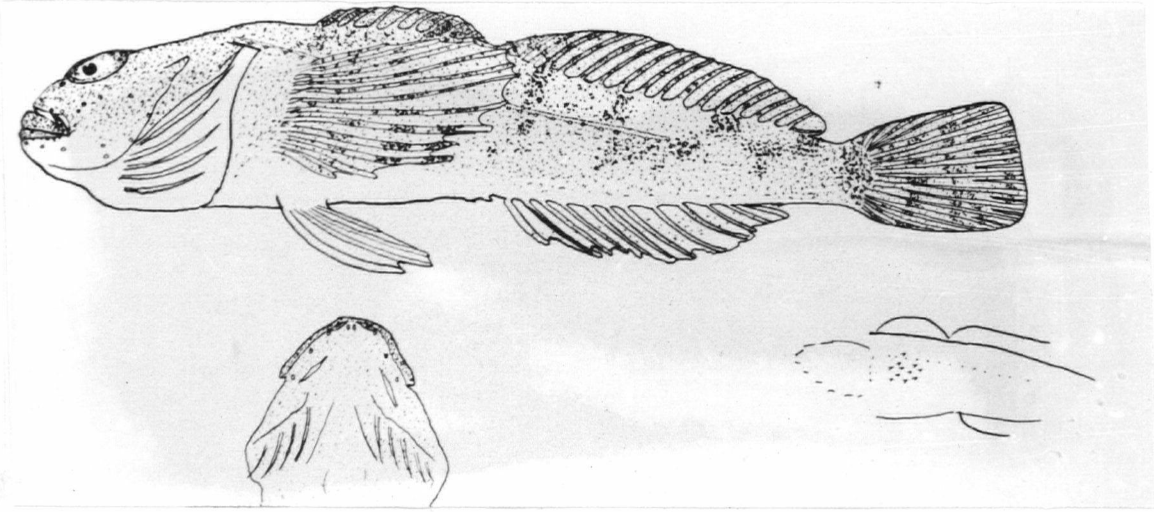


Cottus aleuticus Gilbert

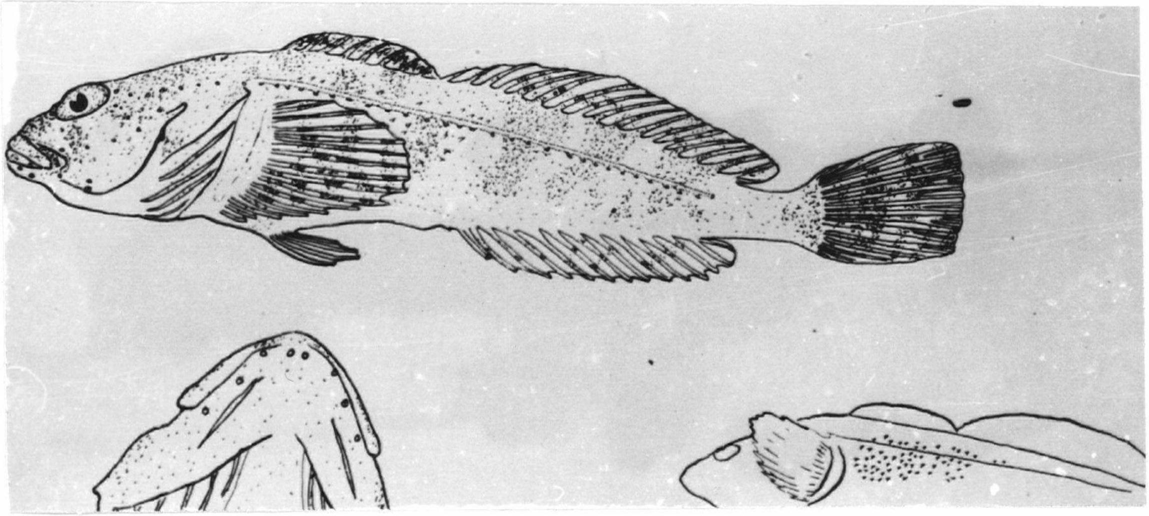
Figure 9



Cottus n.sp.

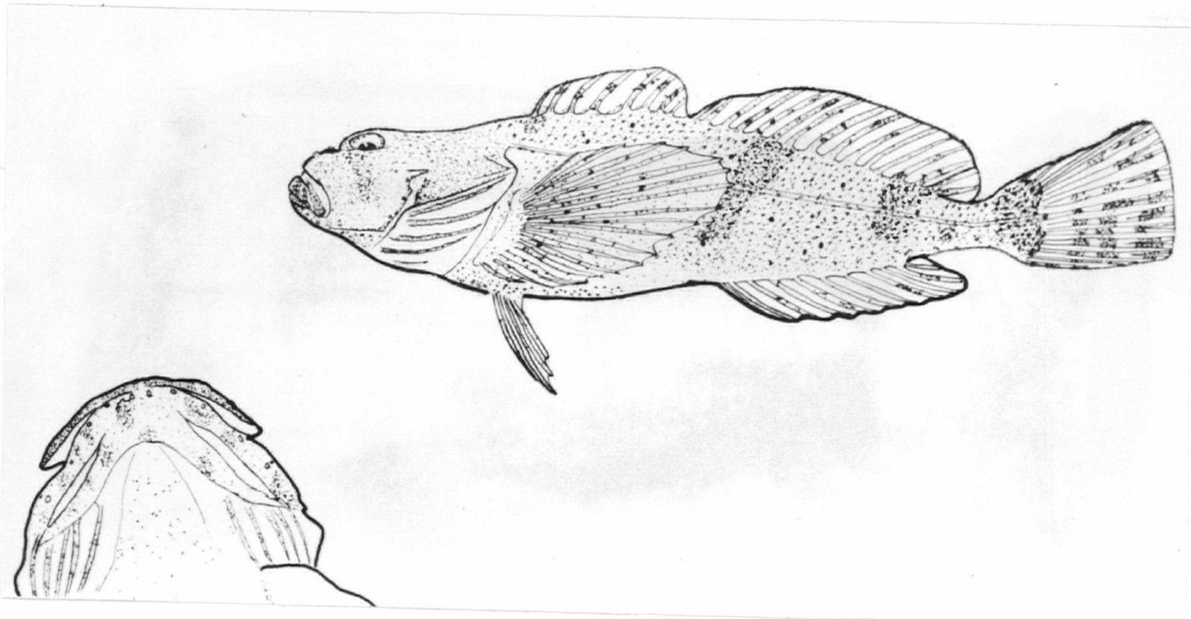


Cottus cognatus Richardson

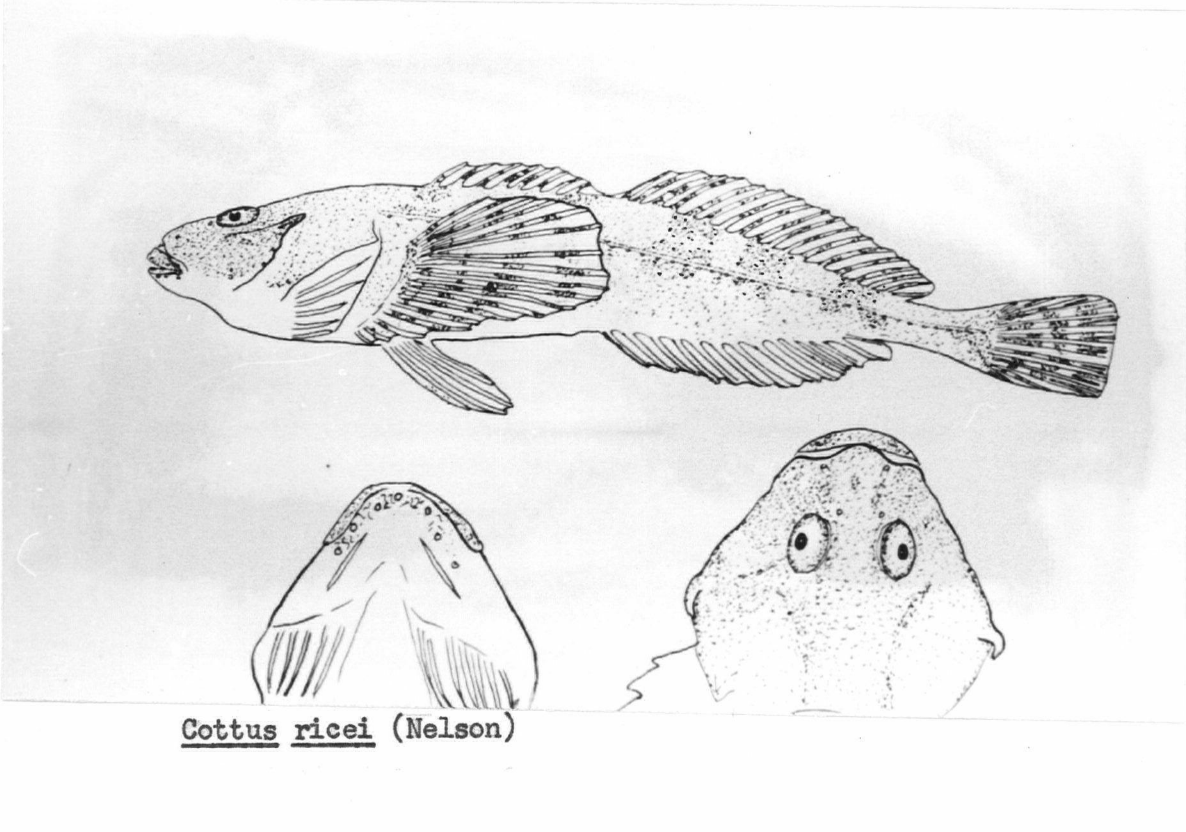


Cottus hubbsi Bailey and Dimick

Figure 10



Cottus rhotheus (Rosa Smith)



Cottus ricei (Nelson)

Figure 11

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