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Morphological and Ecological Characteristics of Common Fishes in Ontario Lakes

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October 1988

Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1991

Fisheries and Oceans   Pêches et Océans

Canada

Canadian Manuscript Report

of Fisheries and Aquatic Sciences 1991

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MORPHOLOGICAL AND ECOLOGICAL CHARACTERISTICS OF COMMON FISHES IN ONTARIO LAKES

by

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Cat. No. Fs 97-4/1991 ISSN 0706-6473

Correct citation for this publication:
Portt, C.B., C.K. Minns, and S. W. King. 1988. Morphological and ecological characteristics of fishes common in Ontario lakes. Can. MS Rep. Fish. Aquat. Sci., 1991: vi +37p.

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ABSTRACT

Portt, C.B., C.K. Minns, and S. W. King. 1988. Morphological and ecological characteristics of fishes common in Ontario lakes. Canadian Manuscript Report of Fisheries and Aquatic Sciences 1991.

Measures of the morphological and ecological characteristics of 52 freshwater fish species common in Ontario lakes, were obtained and compiled. Relationships among measures and species were identified using factor and cluster analyses. Species were clustered according to morphological and size-age-fecundity using factor scores ,and feeding attributes using presence-absence information analysis. All three clusterings produced clearly defined groupings. Pair-wise contingency analysis of group memberships showed that the groupings were not independent. Features of the feeding ecology provided the simplest explanation of most groupings. Reproductive guilds were not as strongly associated with the other grouping criteria. These quantitative relationships among species can be applied to the analysis of fish assemblage structure in Ontario's lakes.

RESUME

Portt, C.B., C.K. Minns, and S. W. King. 1988. Morphological and ecological characteristics of fishes common in Ontario lakes. Canadian Manuscript Report of Fisheries and Aquatic Sciences 1991.

Des mesures de caractères morphologiques et écologiques ont été recueillies et compilées pour 52 espèces de poissons d'eau douce communément retrouvées dans les lacs de l'Ontario. Des relations ont été établies entre les données at les espèces par les méthodes d'analyse factorielle et d'analyse de grappes. Les diverses espèces ont été réparties en grappes à partir de mesures morphologiques et da la combinaison taille-âge-fécondité par l'établissement de scores factoriels, et à partir de caractéristiques d'alimentation par l'analyse de données de présence et d'absence. Ces trois répartitions en grappes ont données des groupements clairement définis. L'analyse de la contingence de la composition des groupements, en considérant deux à deux les répartitions, a montré que les groupements n'étaient pas indépendants. L'écologie de l'alimentation explique le plus simplement la plupart des groupements obtenus. Les guildes de reproduction n'étaient pas aussi fortement liées aux autres critères de groupement. Ces relations quantitatives entre les espèces peuvent être utilisées pour l'analyse da la structure des peuplements de poissons des lacs de l'Ontario.

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INTRODUCTION

The relationships between body form and function in fishes is known as functional design (Alexander,1974) or functional morphology (Gosline,1971). The relationship between body form and function, and 'niche' is referred to as ecological morphology (Gatz,1979a), or ecomorphology (Mahon,1981,1984;Watson and Balon,1984).

The ecomorphology of stream fishes has been explored quantitatively (Gatz,1979a,b; Mahon,1984; Watson and Balon,1984) but the examination of lake assemblages has been largely subjective, and restricted to relatively few species (i.e. Keast and Webb,1966; Keast,1978). This study was undertaken to compile and analyze data on morphological and ecological characteristics of 52 fish species commonly found in Ontario's lakes. The analyses were directed to developing measures of dissimilarity distance between species based on ecomorphological, life-history, and feeding characteristics. The concordance of species' groupings obtained using different criteria was assessed.

The results will be used elsewhere to develop and test predictive models of fish taxocene assemblage structure in Ontario's lakes.

METHODOLOGY

The Ontario Ministry of Natural Resources lake inventory database, which contains species lists for 9679 Ontario lakes, was examined and 52 species which were present in 50 or more of these lakes were selected for analysis (Appendix Table A). The morphometric characteristics for North American populations of 21 of these species were reported by Mahon (1984). We determined the characteristics of the remaining 31 species from preserved specimens following the methodology of Mahon (1981,1984) as closely as possible. Because we wanted to use Mahon's results, we restricted our choice of characteristics to the 11 used by Mahon (1984).

The descriptions of the morphometric characters and their functional significance which follow are adapted from Mahon (1984), Watson and Balon (1984), and Gatz (1979a):

1) Lateral compression index (CI): maximum body depth divided by maximum body width. Many pelagic fishes are laterally compressed while benthic species tend to be dorsoventrally compressed (see 5).

2) Relative depth (RD): Maximum body depth divided by standard length (SL). Standard length is defined as the distance from the most anterior point on the fish to the posterior of the vertebral column. Minimum drag occurs when the ratio of maximum radius to length is about 0.22 (Alexander,1974) and departure from this ratio implies reduced swimming efficiency.

3) Relative peduncle length (RPL): length of caudal peduncle divided by standard length. The length of the caudal peduncle is defined as the horizontal distance from a line at the posterior margin of the base of the most posterior median fin to the posterior end of the vertebral column. Fishes with long caudal peduncles are assumed to be good swimmers (Gatz,1979a).

4) Index of caudal peduncle compression (IPC): caudal peduncle depth divided by caudal peduncle width, measured at the midpoint of the peduncle. A compressed peduncle is typical of slow swimming species but may increase maneuverability(Gatz,1979a).

5) Index of ventral flattening (IVF): The proportion of the body occurring below the midline, defined as a straight line from the middle of the posterior edge of the hypural bones to the most anterior point on the head, at the point of maximum depth. Ventral flattening enables benthic fishes to maintain their position on the bottom without swimming in flowing waters (Hora,192 ; Hubbs,1941). It also reduces the lateral profile and hence susceptibility to predation of benthic species.

6) Relative area of pectoral fin (RPA): The area of the pectoral fin divided by body area, which is estimated by standard length times maximum depth. Large pectoral fins increase the maneuverability of slow swimming fishes which use them for braking and turning (Alexander,1974). Fishes that inhabit fast water use these fins to deflect water upward and thus force their body against the substrate, assisting them in maintaining their position without swimming (Keenleyside,1962; Jones,1975). Some species with large pectoral fins, such as darters and sculpins, use them for forward propulsion in short, rapid lunges.

7) Pectoral fin shape or pectoral aspect ratio (PAR): The length of the pectoral fin divided by its maximum width. Long narrow pectoral fins are expected in fishes which are actively swimming much of the time (Keast and Webb,1966; Lindsey,1978).

8) Relative caudal area (RCA): The area of the caudal fin divided by body area, which is estimated as for RPA. Lindsey (1978) reported that no observable trends in caudal fin area has been noted, however Webb (1977) stated that large caudal fins were important for rapid acceleration (fast starts), and Magnuson (1978) reported that, among scombroids, species with larger relative caudal area swam further per tail beat.

9) Caudal fin aspect ratio (CAR): the maximum height of the caudal fin divided by its area. Keast and Webb (1966) and Gatz (1979a) reported that fishes which have a high CAR swim more actively and/or continuously than those with a low CAR.

10) Eye position (EP): the proportion of head depth which occurs below the centre of the eye. The eyes of benthic species tend to be more dorsal than those of nektonic species.

11) Mouth orientation: the inclination of a plane tangential to the lips when the mouth is open, coded as 1 if the plane is above the vertical, 2 if it is vertical, 3 if the plane faces obliquely downward, and 4 if the plane is horizontal. The position of the mouth indicates where the fish feeds in the water column (Gatz, 1979a).

Ten individuals of each species were measured with the exception of lake whitefish (Coregonus clupeaformis), tadpole madtom (Noturus gyrinus), and ninespine stickleback (Pungitius pungitius) of which 9,9, and 8 individuals respectively were examined. Measurements of lengths less than 180 mm were made to the nearest .05 mm using vernier calipers. Measurements greater than 18 cm were made to the nearest mm. Fins areas were determined to the nearest mm^2 from tracings of fully extended fins using an electronic digitizing planimeter.

The mean morphometric values for the species which we examined were combined with the data from Mahon (1984) and a factor analysis by principal components was done using the SPSS and SPSS-X statistical packages (Nie et al 1975, Norusis 1985).

The ecological characteristics were taken largely from secondary sources. Where possible seven 'life history' parameters, maximum standard length, standard length at maturity, maximum age, age at maturity, fecundity, egg diameter, reproductive guild according to Balon (1975), and spawning habitat defined as either lotic, lentic, or both, were determined for each species. Where maturity data were available for both sexes the data for females was used. Where a characteristic was described by a range (i.e. length at maturity= 26-35 cm) the midpoint of the range was selected. Where necessary total length and fork length were converted to standard length by dividing by 1.2 and 1.1 respectively after Mahon (1984).

The feeding guild of adults of each species was described by three sets of parameters, feeding location(benthic, pelagic, surface), feeding method (filtering, grazing/picking, sorting/suck and spit, pursuing, ambush), and preferred food (phytoplankton, macrophytes, crustacea, molluscs, insects, fish, amphibians/birds/mammals). Foods were ranked as being of primary, secondary, or minor importance in the overall diet of adult individuals. Assignments were made on the basis of information in Scott and Crossman (1973). In some cases the assignment to location and method categories was based on interpretation of diet and habitat information. There can be little doubt that this characterization of feeding guilds is incomplete and possibly in error. However, an extensive literature review would have produced many contradictory attribute assignments. Therefore, we decided to rely on a single literature source for consistency. Temperature requirements were characterized by spawning and preferred temperatures.

RESULTS

Data collection

The mean values of the ecomorphological characters for 52 species are given in Table 1 together with the overall means, standard deviations, minimums and maximums. The mean, standard deviation, minimum, and maximum values of the morphometric characteristics of the species which we examined are provided in Appendix B. The life history data are presented in Table 2, the feeding characteristics in Table 3, and the temperature data in Table 4.

Ecomorphology

A factor analysis of 11 ecomorphological characters identified 4 factors with eigenvalues greater than 1 which accounted for 73.7 percent of variance (Table 5). All four factors indicate differing aspects of swimming behaviour and performance.

The first factor (M1) distinguishes between active pelagic species with high caudal aspect ratio (CAR), small and narrow pectoral fins (RPA), laterally positioned eyes (EP), and vertical or above vertical mouth orientation (MOUTH) i.e. low scores, and sedentary benthic species with large wide pectorals, small caudal aspect ratios, dorsal eyes, and oblique or horizontal mouth orientation i.e. high scores. Fishes with low scores include golden shiner, banded killifish, and nine-spine stickleback. Fishes with high scores include sculpins, darters, and catfishes.

The second factor (M2) separates deep laterally compressed species with high relative depth (RD), high caudal peduncle compression (IPC), high lateral compression (CI), and a low degree of ventral flattening, from torpedo-shaped species i.e. low scores. Fishes with low scores include nine-spine stickleback, longnose and blacknose dace, and rainbow smelt. Fishes with high scores include <u>Lepomis</u> spp. and carp. High scores are consistent with lower swimming speeds but greater maneuverability.

The third factor (M3) is a 'tail' factor with relative caudal area (RCA) and relative peduncle length (RPL) loading positively. Higher scores reflect greater swimming power and fast acceleration. Fishes with low scores include burbot, lake herring, and rainbow smelt. Fishes with high scores include tadpole madtom, northern redbelly dace, and common shiner.

The fourth factor (M4) is weighted positively with caudal fin aspect ratio (CAR), pectoral aspect ratio (PAR), and mouth orientation (MOUTH). Higher scores are associated with active continuous swimming. Fishes with high scores include lake whitefish, lake herring, longnose sucker, and shorthead redhorse. Fishes with low scores include central mudminnow, nine-spine stickleback, banded killifish, and tadpole madtom.

A hierarchical cluster analysis was performed using the ecomorphological factor scores (Table 6). Species were clustered by Ward's error mean square method using euclidean distances. The analysis suggested 5 groups of species (Figure 1). Groups B and D contain many sedentary benthic species (M1 high) but with B species having more swimming power (M3 high). Group A is dominated by active pelagic forms (M1 low) with higher swimming power (M3 high). Group C contains several piscivores and larger pelagic species associated with continuous swimming (M4 high). Group E is dominated by forms with lower swimming speeds and greater maneuverability (M2 high).

Life-history parameters

A factor analysis of 6 size, age, and fecundity characters identified 2 factors with eigenvalues greater than 1 which accounted for 85.3 percent of variance (Table 7). The first factor (S1) was positively related to the 4 size and age measures. Egg diameter also weighted positively on S1. The second factor (S2) was positively related to fecundity with a lesser negative weight for egg diameter.

A hierarchical cluster analysis was performed using the factor scores (fallfish scores were estimated) (Table 8). Species distances were determined by euclidean distance and species clustered by Ward's error mean square method. This analysis suggested there were 4 groups of species (Figure 2). The groups are ordered by size and age from greatest to least with fecundities being ordered within groups. Group B contains carp and burbot, two species with exceptionally high fecundities.

Feeding

The species by feeding character data were clustered using an information-based procedure after Orloci (1970). Each axis of the data table was clustered separately i.e. species using attributes and vice versa. Then the attribute groupings can be interpreted to explain the species groupings. Attributes which had a categorical scale were modified as follows: 0 became 000, 1 became 111, 2 became 011, and 3 became 001. This allowed the relative weights of food preferences to be included in the analysis. The clustering scale is chi-square and clusters were considered significant at P=0.10.

There were 5 significant groupings of species (Figure 3). Group A is made up largely of piscivores which feed pelagically, sometimes near the surface, using pursuit or ambush to capture their prey. Group B consists largely of benthivores all of whom include molluscs in their diet. Group C contains omnivores both pelagic and benthic. Group D is made up of three species which include vegetation in their diet. Group E is a benthic group some of whom eat algae and/or not molluscs.

Inter-group contrasts

Analyses of contingency among pairs of groupings (morphological, life-history, feeding, and reproductive guild) showed that all but one of the sets of group memberships are not independent (Table 9). Feeding group A includes most of the large piscivores and so are most commonly found in size group A and morphological group C. Feeding group C, mostly omnivores both pelagic and benthic, is drawn largely from morphological groups A, mostly pelagic, and D, sedentary benthic, and is dominated by smaller species from size groups C and D. Feeding group E, benthic algal grazers, are small (size D) and deep laterally compressed (morphological group B). Feeding group B, benthivores which eat molluscs, are drawn evenly from morphological groups C, D, and E, and include both large (size A) and small species (size D). Species in feeding group D include vegetation in their diet, are small (size D) and come from morphological groups B and A. There is no relationship between feeding groups and reproductive guilds.

Cross-tabulations of ecomorphological groups and life-history groups reflect the feeding groupings. the largest species (group A) are concentrated in ecomorphological group C, piscivores and larger pelagic species. The smallest species (group D) are associated with ecomorphological groups A and B, pelagic and benthic species with more swimming power.

Ecomorphological groupings A–C are more strongly associated with reproductive guild A1 while groups D and E are more often in guild B2. With respect to the size-fecundity clusters, reproductive guild A1 is split between the largest and smallest species while guild B2 is more often associated with the two groups of smaller species.

DISCUSSION

Given that the common attributes of all teleost fish are determined by the limitations of an aquatic existence, the ecomorphological differences between the species might be expected to be shaped by the dominant factors influencing the persistence and success of a species i.e. feeding and reproduction. The former is necessary to acquire the energy and nutrients needed to survive and grow. While the latter is necessary for the continued replacement of individuals. The assembly of various characteristics of freshwater fish species has provided us with the opportunity to explore the degree to which each the factors interrelate. These relationships may be examined by comparison of the factor scores and by cross-tabulation of the classifications obtained by cluster analyses.

Ecomorphological factors

The factor analysis of ecomorphology produced results which are partially consistent with elements of similar analyses of Mahon (1984), Gatz (1979a,b), and Watson and Balon (1984). We excluded size from the analysis because in earlier work it weighed heavily on one factor and because we were including it in the related analysis of life-history parameters.

Factor M1 here is similar to the first factor of Mahon (1984) which separates nektonic and benthic fishes. Watson and Balon (1984) had two factors which separated the two fish types. All four factors here are associated with aspects of locomotion much as described by Lindsey (1978) i.e. swimming speed, acceleration, maneuverability, and endurance. The cluster analysis based on the ecomorphological factor scores produced five main types reflecting combinations of the locomotion features. Although the data for 21 of the 52 species examined here came from Mahon's (1984) data tables, the results are not identical. However the four factors used here depend on the same locomotion features as Mahon's (1984) three factors .

Life-history parameters

The results obtained for the factor analysis of size, age and fecundity variables are consistent with the many other allometric relationships found in biota (Peters 1983). This analysis of life-history parameters produced a result very similar to that obtained by Mahon (1984). Size is often correlated with other variables though there are rarely satisfactory explanations. The first factor, S1, is consistent with results compiled by Peters (1983) for fish and other biota. The second factor, S2, shows the extreme range of reproductive strategies which have been selected by different species. Species have a total reproductive effort proportional to body size but vary the allocation of effort along a gradient from many small eggs i.e. by burbot, to few large eggs i.e. tadpole madtom. The factor scores obtained here may not show a strong relationship to ecology as species must pass through several stages with potentially differing ecology as they grow (Keast 1978). Conversely, ultimate size may be a strong indicator given the significance of size in determining ecological rate constants (Peters 1983). Larger species may have a greater tendency to be migratory while less fecund species are more likely to show some form of parental care for their brood (Mahon 1984).

Feeding attributes

The groupings of species by feeding characteristics followed an expected pattern dominated by the types of food selected and to a lesser extent the feeding location. The key food types were fish themselves, molluscs which require the consumer be large and/or possess a mechanism to crush the shells, and plant material either algae or vegetation. Studies like those of Keast (c

1978) show the importance of food specializations and associated habitat preferences.

Interactions

These analyses of various attributes of 52 lake fish species have shown there are identifiable groupings of species for each set of criteria and the patterns of these groupings are not independent. Given the ready explanations of the ecomorphological, life-history, and food habits analyses, the lack of independence of the groupings was to be expected. Noticeably, feeding and reproductive groups were not associated while both are associated with the grouping obtained using other attributes. As with the studies of Gatz (1979b), Mahon (1984), and Watson and Balon (1984) with stream fishes, and Miles et al (1987) with birds, the contingency results provide further support for the use of ecomorphological and life-history measures as surrogates for habitat measures in the assessment of assemblage structures.

These results support the idea of using phenotypically defined niches as a measure of the niche space defined by resource utilization (Gatz 1979b). The results suggest there are stronger links between ecomorphological and life-history characteristics, and food habits than with reproductive guilds although the habitat requirements associated with reproduction are essential to the persistence and success of each species (Balon 1975).

These measures of niche space can now be used to assess their significance in influencing species association patterns both within and between lakes. Ryder and Kerr (1978) have suggested that there are co-evolved assemblages of species in boreal lakes of North America and these measures should provide a basis for objectively testing their hypothesis. Keast(1978) has provided evidence of segregation both spatially and temporally within north temperate lakes. An eventual goal will be to define the rules governing fish species assemblages in lakes.

ACKNOWLEDGMENTS

We wish to acknowledge the assistance and cooperation of staff at Fisheries Branch, Ontario Ministry of Natural Resources in Toronto. The Ichthyology and Herpetology Section of the Royal Ontario Museum, Toronto, and J. Leslie, Great Lakes Fisheries Research Branch, Canada Centre for Inland Waters, provided us with preserved specimens. We thank D.L.G. Noakes, Department of Zoology, University of Guelph, for his assistance.

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Table 1. Means of morphological characters for each of 52 species plus overall means, standard deviations, minimum and maximum for compression index (CI), relative depth (RD), relative peduncle length (RPL), index of peduncle compression (IPC), index of ventral flattening (IVF), relative pectoral fin area (RPA), pectoral fin aspect ratio (PAR), relative caudal fin area (RCA), caudal fin aspect ratio (CAR), eye position (EP), and mouth position (MP). An asterisk (*) indicates species for which data is from Mahon (1984). RPL for burbot is not included in statistics.

Species	CI	RD	RPL	IPC	IVF	RPA	PAR	RCA	CAR	EP	MP
rainbow trout	1.96	0.24	0.17	2.35	0.51	0.05	1.75	0.16	2.29	0.51	2
brook trout *	1.56	0.22	0.16	1.90	0.49	0.06	1.52	0.18	2.35	0.67	2
lake trout	1.69	0.20	0.15	1.73	0.56	0.05	1.89	0.15	2.86	0.60	2
lake whitefish	1.97	0.23	0.12	1.57	0.56	0.04	2.16	0.13	3.15	0.54	2
lake herring	1.95	0.22	0.13	1.62	0.58	0.05	1.79	0.13	3.07	0.55	1
rainbow smelt	1.61	0.17	0.10	1.38	0.56	0.09	1.36	0.15	2.93	0.65	2
northern pike	1.81	0.17	0.12	1.75	0.48	0.04	1.39	0.14	2.18	0.69	2
muskellunge	1.69	0.15	0.14	1.54	0.62	0.04	1.90	0.16	2.52	0.72	2
central mudminnow *	1.38	0.20	0.19	2.65	0.59	0.08	1.13	0.22	1.07	0.66	2
longnose sucker	1.19	0.21	0.16	1.51	0.52	0.06	1.77	0.14	2.23	0.61	4
white sucker *	1.26	0.20	0.14	1.46	0.53	0.08	1.42	0.21	2.13	0.73	4
shorthead redhorse	1.55	0.25	0.15	1.82	0.57	0.06	1.56	0.16	2.66	0.60	4
northern redbelly dace *	1.51	0.23	0.24	1.89	0.49	0.08	1.54	0.23	2.17	0.57	2
finescale dace	1.51	0.24	0.23	1.94	0.45	0.05	1.58	0.15	1.97	0.50	2
lake chub	1.45	0.22	0.22	1.96	0.50	0.09	1.56	0.20	2.05	0.50	2
carp	2.06	0.37	0.16	2.85	0.41	0.06	1.56	0.15	2.54	0.56	2
brassy minnow *	1.49	0.23	0.21	1.79	0.46	0.06	1.71	0.21	2.10	0.59	3
golden shiner *	2.00	0.24	0.18	2.15	0.44	0.05	2.03	0.17	3.42	0.55	1
emerald shiner	1.71	0.18	0.17	1.92	0.42	0.07	1.93	0.19	2.18	0.54	2
common shiner *	1.69	0.20	0.22	1.68	0.47	0.08	1.69	0.24	2.39	0.63	2
blackchin shiner *	1.62	0.21	0.24	1.55	0.47	0.08	1.49	0.21	1.92	0.54	2
blacknose shiner	1.65	0.20	0.26	1.74	0.49	0.06	1.80	0.19	2.04	0.50	2
spottail shiner	1.77	0.25	0.21	1.64	0.54	0.06	1.62	0.20	2.79	0.56	2
mimic shiner	1.55	0.21	0.22	1.76	0.54	0.08	1.71	0.20	2.29	0.55	2
bluntnose minnow *	1.32	0.20	0.23	1.46	0.48	0.07	1.62	0.20	2.57	0.64	3
fathead minnow *	1.47	0.26	0.24	1.88	0.49	0.06	1.76	0.20	2.28	0.64	3

Table 1. (continued)

Species	CI	RD	RPL	IPC	IVF	RPA	PAR	RCA	CAR	EP	MP
blacknose dace *	1.28	0.20	0.24	1.60	0.58	0.11	1.31	0.21	2.30	0.68	3
longnose dace *	1.22	0.20	0.23	1.41	0.58	0.10	1.39	0.20	2.10	0.72	4
creek chub *	1.27	0.22	0.21	1.36	0.49	0.06	1.55	0.19	2.24	0.66	2
fallfish	1.65	0.25	0.19	1.74	0.51	0.05	1.86	0.16	2.61	0.57	2
pearl dace *	1.29	0.21	0.22	1.85	0.50	0.07	1.83	0.20	2.11	0.58	2
brown bullhead *	1.03	0.26	0.16	2.29	0.59	0.07	1.36	0.20	1.51	0.76	2
tadpole madtom	1.18	0.23	0.22	4.01	0.55	0.08	1.49	0.30	0.79	0.59	2
banded killifish	1.31	0.21	0.26	1.83	0.50	0.07	1.41	0.20	1.37	0.53	1
burbot	1.12	0.15	0.00	2.41	0.61	0.07	1.28	0.09	1.17	0.68	2
brook stickleback *	1.73	0.26	0.18	1.05	0.57	0.07	0.98	0.11	1.62	0.62	2
ninespine stickleback	1.79	0.18	0.19	0.50	0.58	0.10	0.93	0.11	1.64	0.54	1
trout-perch	1.44	0.22	0.22	1.60	0.50	0.10	1.95	0.20	2.16	0.65	3
rock bass *	2.14	0.40	0.15	2.42	0.50	0.07	1.54	0.17	1.63	0.63	2
pumpkinseed *	2.36	0.43	0.19	2.08	0.51	0.07	2.08	0.14	1.77	0.66	2
bluegill	2.98	0.52	0.20	2.99	0.46	0.06	2.16	0.13	2.01	0.62	2
smallmouth bass *	1.75	0.26	0.20	1.82	0.51	0.08	1.39	0.20	1.79	0.69	2
largemouth bass	1.94	0.30	0.21	1.98	0.45	0.06	1.49	0.15	1.43	0.64	2
black crappie	3.11	0.42	0.17	2.85	0.49	0.07	1.69	0.23	1.97	0.56	1
yellow perch	1.83	0.26	0.18	1.66	0.42	0.06	1.68	0.15	2.12	0.59	2
sauger	1.38	0.19	0.17	1.26	0.51	0.08	1.78	0.18	2.15	0.64	2
walleye	1.52	0.21	0.16	1.29	0.54	0.06	1.76	0.18	2.53	0.71	2
Iowa darter *	1.38	0.18	0.25	1.39	0.55	0.18	1.37	0.22	1.42	0.73	3
johnny darter *	1.25	0.19	0.23	1.40	0.55	0.17	1.67	0.22	1.54	0.77	3
logperch	1.39	0.18	0.15	1.48	0.59	0.13	1.25	0.14	1.58	0.68	2
mottled sculpin *	0.68	0.22	0.07	1.97	0.56	0.26	1.36	0.19	1.25	0.92	2
slimy sculpin	0.71	0.21	0.09	1.93	0.47	0.24	1.57	0.18	1.12	0.79	2
mean	1.60	0.24	0.18	1.84	0.52	0.08	1.60	0.18	2.08	0.63	
standard deviation	0.44	0.07	0.05	0.54	0.05	0.04	0.27	0.04	0.55	0.08	
minimum	0.68	0.15	0.07	0.50	0.41	0.04	0.93	0.09	0.79	0.50	
maximum	3.11	0.52	0.26	4.01	0.62	0.26	2.16	0.30	3.42	0.92	

Table 2. Life history characteristics for 52 species. Length at maturity (Mat) and maximum length (Max) in mm. Age in years. Fecundity as number of eggs per female. Egg diameter (egg d.) in mm. Reproductive guild (repro guild) from Balon, 1975) Spawning locations coded as 1.-lakes only, 2.-streams only, 3.- either. References for length at maturity (A), maximum length (B), age at maturity (C), maximum age (D), fecundity (E), and egg diameter (F) are as follows: 1. Becker,1983; 2. Carlander,1969; 3. Mahon,1984; 4. Scott and Crossman,1973.

Species	Length		Age		Fecund	Egg	Repro	Spawn	References					
	Mat	Max	Mat	Max		d.	guild		A	B	C	D	E	F
rainbow trout	349	915	4	8	4422	4.0	A.2.3	2	2	4	4	4	2	4
brook trout	156	350	3	9	800	3.5	A.2.3	3	1	3	4	3	3	3
lake trout	510	1310	5	20	18000	5.5	A.2.3	3	1	3	1	1	4	4
lake whitefish	236	526	4	17	48500	3.0	A.1.3	1	2	1	2	4	2	2
lake herring	246	395	3	13	29000	2.0	A.1.2	1	2	2	4	4	4	4
rainbow smelt	125	297	3	6	30705	1.0	A.1.3	3	4	4	4	4	1	4
northern pike	534	1000	3	12	32000	2.8	A.1.5	3	1	3	3	4	3	3
muskellunge	650	1426	4	22	12000	3.0	A.1.5	3	4	4	4	4	4	4
central mudminnow	110	132	1	4	735	1.6	A.1.5	3	4	4	3	3	3	3
longnose sucker	240	583	6	24	38500	2.9	A.1.3	3	4	4	4	4	4	4
white sucker	253	487	4	15	20000	3.0	A.1.3	2	1	3	3	3	3	3
shorthead redhorse	272	620	3	14	33000	1.9	A.1.3	2	1	1	4	4	1	1
northern redbelly dace	46	61	1	8	500	2.0	A.1.5	3	3	3	3	3	3	3
finescale dace	59	80	2	8	420	1.0	A.1.4	3	1	1	1	1	1	1
lake chub	108	189	3	5	5900	1.6	A.1.3	3	1	4	4	4	1	1
carp	353	800	4	20	1120000	1.0	A.1.5	3	2	2	1	1	2	1
brassy minnow	57	158	1	4	375	1.4	A.1.4	3	1	1	3	3	3	3
golden shiner	64	211	2	7	6020	1.3	A.1.5	2	4	3	3	3	3	3
emerald shiner	42	124	1	4	2040	0.9	A.1.1	1	1	1	1	1	1	1
common shiner	74	169	1	5	665	1.5	B.2.3	2	1	3	3	3	3	3
blackchin shiner	37	71	1	4	675	1.0	A.1.5	3	1	1	1	1	1	1
blacknose shiner	24	81	1	3	1135	0.8	A.1.6	3	1	2	1	2	1	1
spottail shiner	55	137	1	4	1950	1.0	A.1.6	3	1	1	4	4	4	4

Table 2. (continued)

Species	Length Mat	Length Max	Age Mat	Age Max	Fecund	Egg d.	Repro guild	Spawn	References A	B	C	D	E	F
mimic shiner	35	63	1	2	367	1.0	A.1.4	3	1	2	1	1	2	1
bluntnose minnow	50	78	1	3	695	1.6	B.2.7	3	1	3	3	3	3	3
fathead minnow	54	73	1	4	755	1.2	B.2.7	3	1	3	3	3	3	3
blacknose dace	49	58	2	3	265	0.8	A.1.3	2	1	3	3	3	3	3
longnose dace	74	118	2	5	5410	1.0	A.1.3	2	1	3	3	3	3	3
creek chub	87	240	2	5	3000	2.2	A.1.3	2	1	3	3	3	3	3
fallfish		420			2300	0.0	B.2.3	2		4			3	3
pearl dace	94	132	2	4	980	0.9	A.1.3	2	1	3	3	3	3	3
brown bullhead	161	297	3	8	7500	3.0	B.2.7	3	1	3	3	3	3	4
tadpole madtom	62	110	1	3	72	3.5	B.2.7	3	4	4	4	4	5	4
banded killifish	53	102	2	3	173	2.0	A.1.5	3	1	4	1	1	1	4
burbot	370	775	3	13	711420	1.3	A.1.2	3	4	4	4	4	4	3
brook stickleback	50	87	1	3	250	1.3	B.2.4	3	1	3	3	3	3	1
ninespine stickleback	35	68	2	3	120	0.8	B.2.4	3	4	1	1	1	1	4
trout-perch	78	123	2	4	349	1.4	A.1.3	3	2	1	2	4	4	3
rock bass	54	222	2	10	5500	1.9	B.2.3	3	1	3	3	3	3	3
pumpkinseed	59	219	2	9	2303	1.0	B.2.3	3	1	3	3	3	3	2
bluegill	93	250	3	9	22690	1.0	B.2.3	3	2	4	4	4	4	3
smallmouth bass	264	423	4	12	5445	2.0	B.2.3	3	1	3	3	3	3	3
largemouth bass	272	453	3	15	5000	1.6	B.2.5	3	4	4	4	4	1	1
black crappie	192	300	3	9	37800	1.0	B.2.5	3	4	4	4	4	4	4
yellow perch	175	334	4	10	72800	3.5	A.1.4	3	1	4	4	4	4	4
sauger	283	593	4	13	114684	1.3	A.1.3	3	4	1	4	4	1	1
walleye	328	641	4	20	135220	1.8	A.1.2	3	4	4	4	4	4	4
Iowa darter	43	58	1	3	1620	1.1	A.1.4	3	1	3	3	3	3	3
johnny darter	37	60	1	4	175	1.5	B.2.7	3	1	1	3	3	3	3
logperch	106	150	2	3	2070	1.3	A.1.6	3	2	2	2	2	4	4
mottled sculpin	60	82	2	4	150	2.2	B.2.7	3	1	1	3	3	3	3
slimy sculpin	50	98	2	7	291	2.5	B.2.7	3	1	1	1	1	1	4

Table 3. Feeding method and location and principal foods of 52 species. Feeding location refers to position in the water column and may be one or more of benthic (B), pelagic (P), or surface (S). Feeding method may be one or more of filter (F), grazing/picking (G), sorting (S), pursuit (P), or ambush (A). Diet may include one or more of seven categories: phytoplankton (P), macrophytes (M), crustaceans (C), molluscs (M), insects (I), fish (F), or amphibians, birds and mammals (O). Categories are rated as primary (1), secondary (2), or minor (3) components of diet. Data compiled from information in Scott and Crossman (1973).

Species	Location			Method					Diet						
	B	P	S	F	G	S	P	A	P	M	C	M	I	F	O
rainbow trout	1	1	1		1		1				2	3	1	3	
brook trout	1	1	1		1		1				1		1	2	
lake trout		1			1		1				2		3	1	3
lake whitefish	1					1					1	1	1	3	
lake herring		1			1						1		1	3	
rainbow smelt		1					1				1		2	3	
northern pike		1	1					1			3			1	2
muskellunge		1	1					1						1	2
central mudminnow	1							1			1	1	1		
longnose sucker	1					1				3	1	1	1		
white sucker	1					1			2		1	1	1		
shorthead redhorse	1					1					1	1	1		
northern redbelly dace	1				1				1	1	2		2		
finescale dace	1					1					2		1		
lake chub	1				1	1				3	3		1	3	
carp	1					1				3	2	2	1		
brassy minnow	1				1				1		1		2		
golden shiner		1	1		1					2	1		1		
emerald shiner		1			1				2		1		2		
blackchin shiner	1		1		1	1				1			1		
common shiner		1			1						1		1		
blacknose shiner		1	1		1						1		1		
spottail shiner	1	1			1					2	1		2	3	

Table 3. (continued)

Species	Location			Method					Diet						
	B	P	S	F	G	S	P	A	P	M	C	M	I	F	O
mimic shiner		1			1					2	1		2		
bluntnose minnow	1					1				1			1		
fathead minnow	1					1				1			1		
blacknose dace	1				2				2				1		
longnose dace	1				1								1		
creek chub	1		1		1		1			3	1		1	3	
fallfish	1		1		1		1				1		1	2	
pearl dace	1				1					3	1	2	1		
brown bullhead	1					1				2	1	1	1	3	
tadpole madtom	1					1					1		1		
banded killifish	1	1	1		1						1		1		
burbot		1					1				2		2	1	
brook stickleback	1	1				1				3	1	3	1		
ninespine stickleback	1	1				1					1		1	3	
trout-perch	1					1					1		1	3	
rock bass	1				1						1		1		
pumpkinseed	1				1						1	1	1		
bluegill	1				1						1	2	1	3	
smallmouth bass	1	1			1		1				1			1	
largemouth bass	1	1			1		1	1			1			1	
black crappie		1	1	1	1						1		1	2	
yellow perch	1	1			1		1				1		1	1	
sauger		1					1				2		2	1	
walleye		1					1				3			1	3
Iowa darter	1				1						1		1		
johnny darter	1				1						1		1		
logperch	1				1						2		1		
mottled sculpin	1				1					3	1		1	3	
slimy sculpin	1				1					3	1		1	3	

Table 4. Spawning and preferred temperatures (■C) of species for which data was available. Spawning temperatures are from Scott and Crossman (1973) except for *Rhinichthys atratulus* which is from Becker (1983). References are for preferred temperatures.

Species	Spawning	Preferred	Reference
rainbow trout	5.0	11.3	McCauley et al, 1977.
brook trout		16.0	Cherry, 1977.
lake trout	9.0	10.8	Peterson et al, 1979.
lake whitefish	7.8	12.7	Ferguson, 1958.
lake herring	4.0	15.5	Spotila et al, 1979.
rainbow smelt	4.4	10.0	Becker, 1983.
northern pike	4.4	20.0	Casselman, 1978.
muskellunge	12.8	25.1	Reynolds and Casterlin, 1979.
central mudminnow	12.8	28.9	Becker, 1983.
longnose sucker	12.8	11.6	Coutant, 1977.
white sucker	7.2	16.2	Becker,1983.
shorthead redhorse	16.0	24.0	Coutant, 1977.
northern redbelly dace			
finescale dace	15.0		
lake chub	14.0		
carp	17.0	29.0	Reynolds and Casterlin, 1977.
brassy minnow	16.0		
golden shiner	20.0	21.0	Becker, 1983.
emerald shiner	24.0	23.0	Coutant, 1977.
blackchin shiner	17.0		
common shiner			
blacknose shiner			
spottail shiner	18.3	14.3	Becker,1983.
mimic shiner			
bluntnose minnow	20.0	28.1	Cherry, 1977.
fathead minnow	15.6	26.6	Cherry, 1977.
blacknose dace	21.0	24.6	Cincotta and Stauffer, 1984.
longnose dace	17.2		

Table 4. (continued)

Species	Spawning	Preferred	Reference
creek chub	12.8		
fallfish	16.6		
pearl dace	17.8	16.2	Becker, 1983.
brown bullhead	23.0	30.0	Crawshaw, 1975.
tadpole madtom			
banded killifish	23.0	24.0	Garside and Morrison, 1977.
burbot	1.2	17.0	Scott and Crossman, 1973.
brook stickleback	17.0		
ninespine stickleback	11.5		
trout-perch	17.8		
rock bass	20.5	29.0	Cherry, 1977.
pumpkinseed	19.4	26.0	Reynolds and Casterlin, 1977.
bluegill	23.0	30.9	Cherry, 1977.
smallmouth bass	17.3	30.3	Cherry, 1977.
largemouth bass	17.5	30.2	Reynolds et al. 1976.
black crappie	19.5		
yellow perch	18.3	21.4	Cherry, 1977.
sauger	8.1	22.0	Smith and Koenst, 1975.
walleye	7.8	23.0	Smith and Koenst, 1975.
Iowa darter	16.4		
johnny darter	13.5	22.9	Ingersoll and Claussen, 1984.
logperch			
mottled sculpin	11.4	16.5	Becker, 1983.
slimy sculpin	5.0	10.0	Becker, 1983.

Table 5 Factor coefficients derived from 11 morphological characters for 52 species with varimax rotation.

Character	Factor			
	M1	M2	M3	M4
CI	-0.568	0.614	-0.187	0.216
RD	-0.129	0.867	-0.066	0.118
RPL	-0.274	-0.049	0.856	0.050
IPC	0.072	0.788	0.137	-0.184
IVF	0.302	-0.458	-0.385	-0.213
RPA	0.763	-0.067	0.061	-0.301
PAR	-0.167	0.381	0.064	0.755
RCA	0.281	0.072	0.850	-0.110
CAR	-0.439	-0.186	-0.152	0.757
EP	0.873	-0.074	-0.212	-0.091
MOUTH	0.515	-0.339	0.114	0.512
Eigenvalue	3.413	1.943	1.641	1.106
% Variance	31.0	17.7	14.9	10.1
% Cumulative	31.0	48.7	63.6	73.7

-underlined coefficient is the largest for each character

Table 6 Morphological factor scores for 52 species ordered by cluster membership.

Sp.	M1	M2	M3	M4
Group A				
76	-0.930	0.489	-0.356	0.084
331	-0.628	0.414	-0.245	0.221
194	-1.349	0.603	-0.076	1.029
196	-0.587	0.192	0.607	0.517
201	-0.820	-0.370	0.332	0.343
213	-0.748	-0.078	-0.160	0.689
182	-0.433	-0.130	1.380	-0.278
185	-0.749	-0.215	0.945	-0.490
199	-0.841	-0.396	1.306	-0.515
200	-1.090	-0.342	1.212	0.023
183	-1.203	-0.086	0.571	-0.383
198	-0.156	-0.124	1.264	0.328
214	-0.290	-0.212	0.873	0.198
206	-0.551	-0.418	0.591	0.017
212	-0.237	-0.605	0.474	0.014
Group B				
163	1.477	-0.751	0.072	1.019
211	1.309	-1.151	0.650	0.795
210	0.655	-1.025	0.779	0.029
338	1.493	-0.686	1.176	-0.435
341	1.887	-0.443	0.973	0.295
189	0.078	-0.067	1.067	0.782
209	0.304	0.049	1.006	1.039
291	0.692	-0.147	0.801	1.288
208	0.143	-0.774	0.977	1.010
Group C				
80	-0.084	-0.010	-0.209	-0.002
332	-0.041	-0.624	-0.123	0.297
334	0.046	-0.573	-0.565	0.626
81	-0.498	-0.426	-0.915	0.870
132	0.036	-0.783	-1.311	0.693
121	-0.252	-1.007	-1.599	-0.003
131	-0.410	-0.266	-1.077	-0.320
91	-0.908	-0.203	-1.513	1.586
93	-0.545	-0.574	-1.350	1.457
162	0.615	-0.792	-0.319	1.575
171	0.518	-0.506	-0.607	1.439
Group D				
141	0.353	0.085	0.433	-2.101
261	-1.286	-0.336	1.153	-1.921
236	0.820	1.470	2.156	-1.905
233	0.986	0.191	-0.267	-1.069
342	0.815	-0.906	-0.923	-0.655
316	0.134	0.263	0.277	-0.639
317	-0.411	0.855	0.071	-0.656
381	3.483	0.473	-1.106	-1.119
382	2.609	0.580	-0.426	-0.850
271	0.517	-0.253	-3.041	-1.741
281	-0.884	-0.900	-1.284	-1.630
283	-1.854	-1.755	-1.215	-2.535
Group E				
186	-0.612	1.846	-0.350	0.223
311	0.099	1.848	-0.634	-0.468
313	0.200	2.101	-0.774	0.773
319	-0.829	2.816	0.100	-0.672
314	-0.045	3.660	-0.801	1.129

Table 7 Factor coefficients derived from 6 life-history measures for 51 species with varimax rotation.

Measure	Factor	
	S1	S2
Lmax	0.939	0.156
Lmat	0.925	0.179
Amax	0.887	0.257
Amat	0.886	0.104
Fecundity	0.239	0.909
Egg diameter	0.740	-0.495
Eigenvalue	3.996	1.121
% Variance	66.6	18.7
% Cumulative	66.6	85.3

-fallfish data was incomplete
-all variables were $\log_e$-transformed
-underlined coefficient is largest for measure

Table 8 Life-history factor scores for 52 species ordered by cluster membership

Sp.	S1	S2
Group A		
76	1.574	-1.175
91	1.177	-0.364
163	1.108	-0.526
131	1.585	-0.271
162	1.820	-0.198
80	0.585	-1.045
233	0.390	-0.787
331	0.807	-0.719
93	0.522	-0.029
316	0.720	-0.143
171	0.738	0.096
317	0.582	0.137
332	0.714	0.722
334	1.197	0.730
81	3.112	-1.518
132	2.680	-0.146
Group B		
186	0.969	5.292
271	0.693	3.278
Group C		
121	-0.250	0.277
314	-0.224	0.293
319	-0.033	0.400
185	-0.236	-0.175
311	-0.221	-0.233
213	0.082	-0.188
182	-0.579	-0.367
261	-0.538	-0.476
381	-0.455	-0.556
212	-0.261	-0.494
382	-0.274	-0.645
236	-0.321	-1.238
Group D		
141	-0.672	-0.218
198	-0.691	-0.154
189	-0.788	-0.134
291	-0.599	-0.134
342	-0.597	-0.084
208	-0.843	-0.269
341	-0.866	-0.205
209	-0.905	-0.041
281	-0.912	-0.116
183	-0.616	0.149
211	-0.674	0.113
214	-0.693	0.133
194	-0.474	0.012
313	-0.478	0.194
196	-0.963	0.119
199	-0.984	0.055
201	-0.907	0.074
210	-0.880	0.133
283	-0.895	0.128
200	-1.084	0.133
206	-1.066	0.007
338	-0.995	-0.014

Table 9 Pairwise contingency analysis of morphological, life-history, and feeding guild, and reproductive guild memberships.

Cluster		Cluster					Chi-square	d.f.	P
		A	B	C	D	E			
				Feeding					
Morphological							45.514	12	0.000
	A	3	1	8	1	2			
	B	0	1	1	2	5			
	C	7	3	1	0	0			
	D	3	2	6	0	1			
	E	1	3	0	0	1			
Life-history							35.346	12	0.000
	A	11	5	1	0	0			
	B	1	1	0	0	0			
	C	2	1	6	0	2			
	D	0	3	9	3	7			
Reproductive							10.907	8	0.207
guild	A1	7	7	10	1	7			
	A2	3	0	0	0	0			
	B2	4	3	6	2	2			
				Morphological					
Life-history							38.935	16	0.001
	A	2	1	11	3	0			
	B	0	0	0	1	1			
	C	4	0	0	4	3			
	D	9	8	0	4	1			
Reproductive							21.993	8	0.005
guild	A1	12	6	9	4	1			
	A2	1	0	2	0	0			
	B2	2	3	0	8	4			
				Life-history					
Reproductive							13.033	6	0.043
guild	A1	11	2	4	15				
	A2	3	0	0	0				
	B2	3	0	7	7				

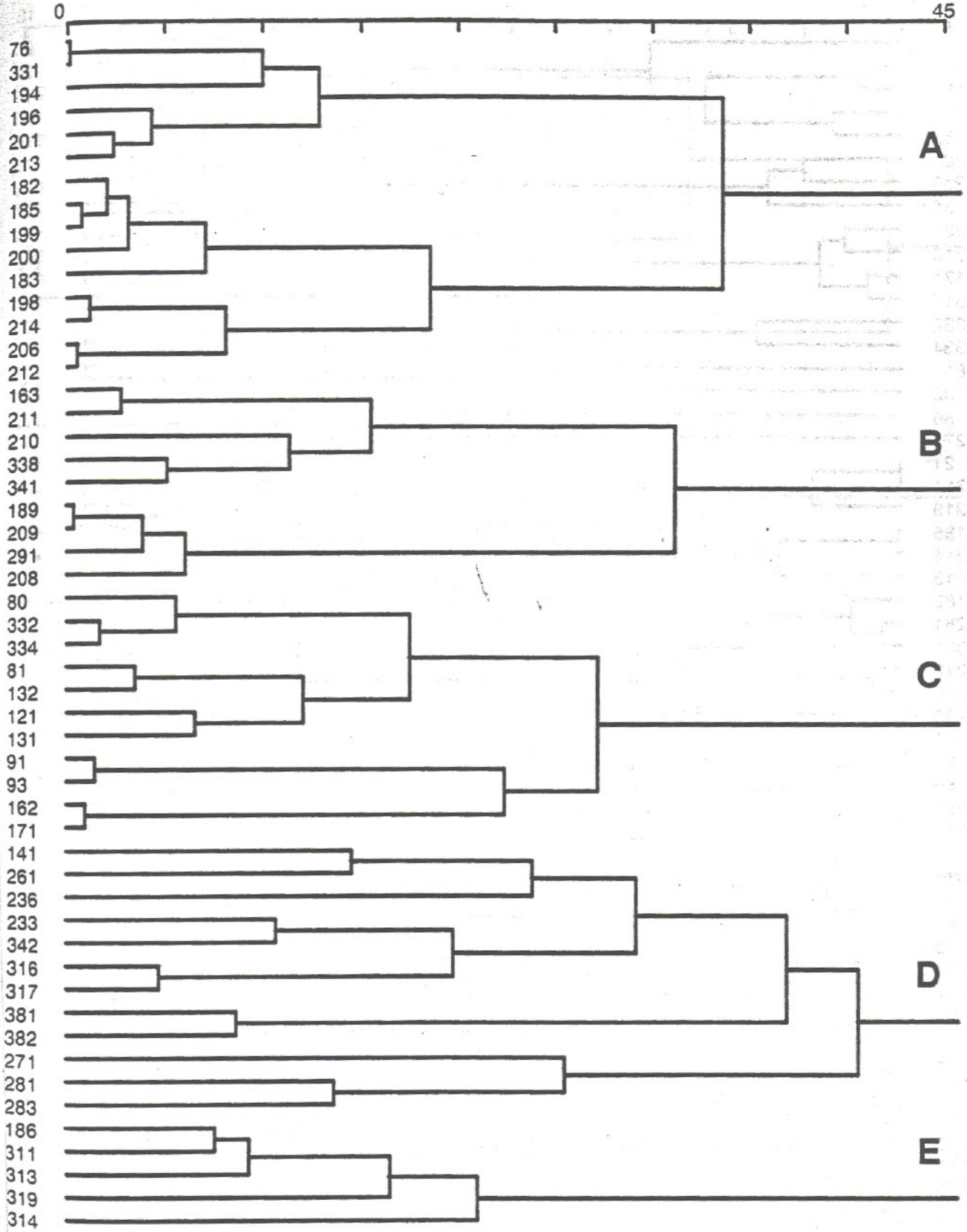

Figure 1. Hierarchical dendrogram for 52 species based on clustering of morphological factor scores using Ward's error mean square method with euclidean distances.

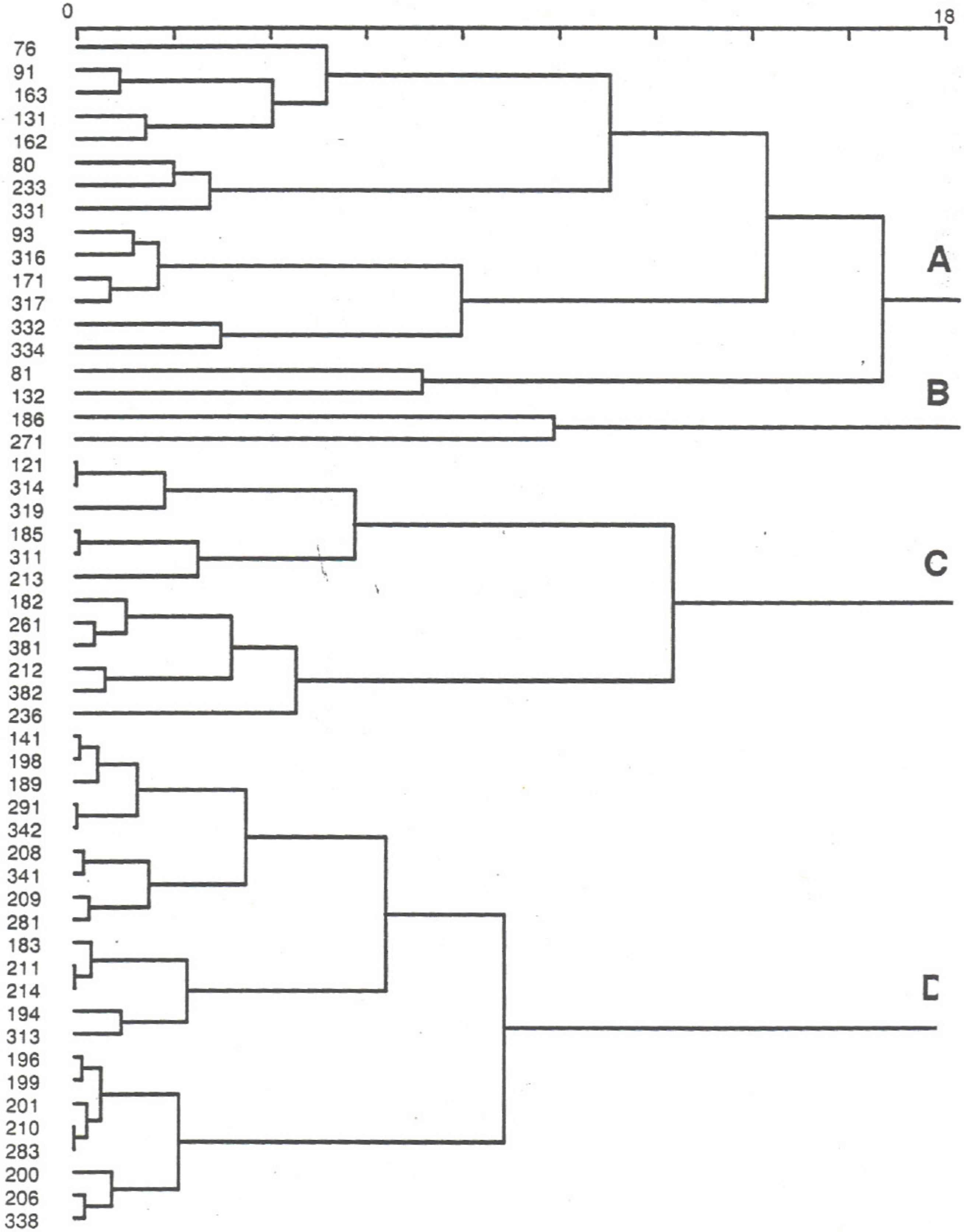

Figure 2. Hierarchical dendrogram for 52 species based on clustering of size-age-fecundity factor scores using Ward's error mean square method euclidean distances.

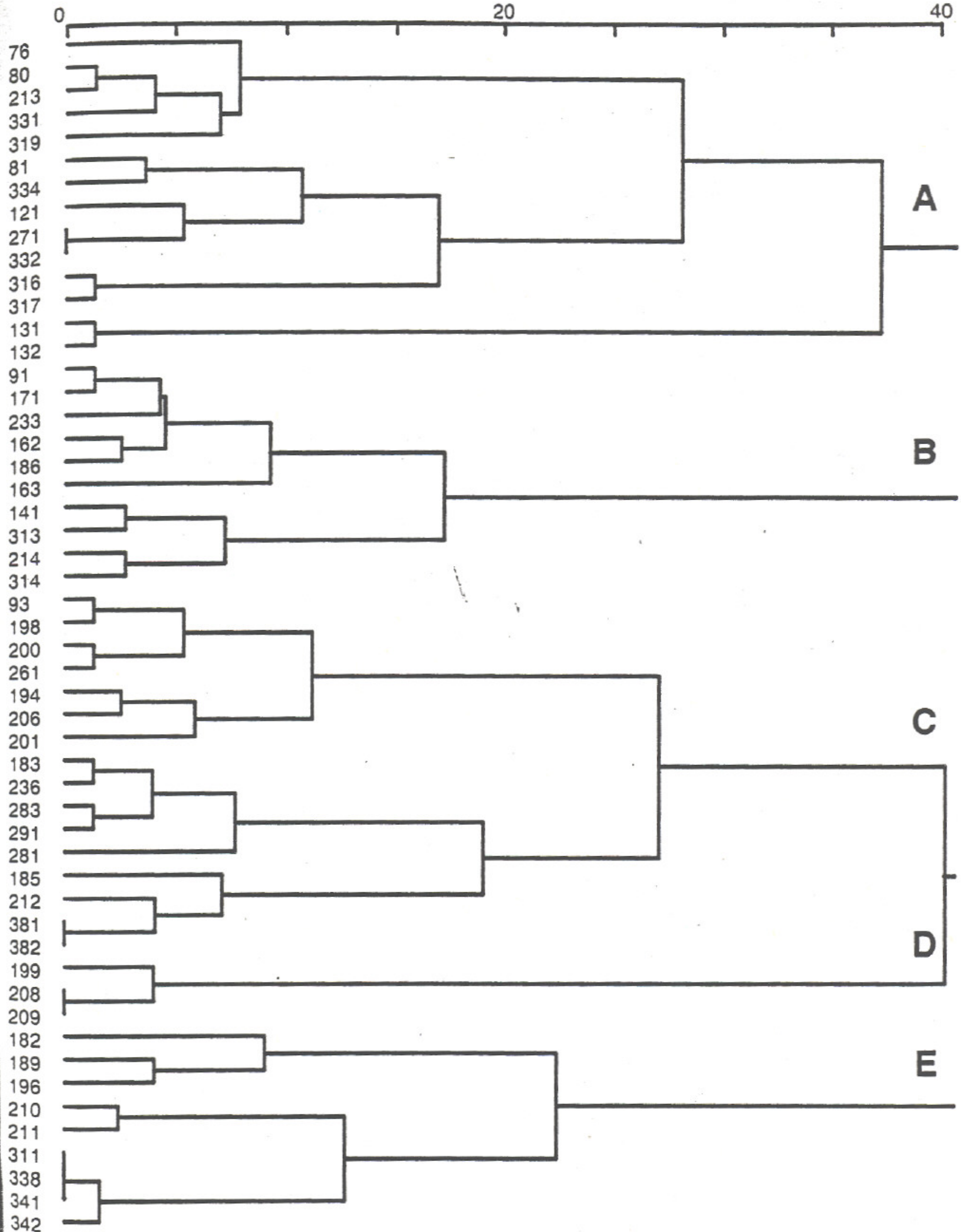

Figure 3. **Hierarchical dendrogram for 52 species based on clustering of feeding atttributes using an information-based clustering of binary data.**

Appendix Table A. Common and scientific names of the 52 species examined in this study.

#	Common name	Scientific name
76	rainbow trout	Salmo gairdneri
80	brook trout	Salvelinus fontinalis
81	lake trout	Salvelinus namaycush
91	lake whitefish	Coregonus clupeaformis
93	lake herring (cisco)	Coregonus artedii
121	rainbow smelt	Osmerus mordax
131	northern pike	Esox lucius
132	muskellunge	Esox masquinongy
141	central mudminnow	Umbra limi
162	longnose sucker	Catostomus catostomus
163	white sucker	Catostomus commersoni
171	shorthead redhorse	Moxostoma macrolepidotum
182	northern redbelly dace	Phoxinus eos
183	finescale dace	Phoxinus neogaeus
185	lake chub	Couesius plumbeus
186	carp	Cyprinus carpio
189	brassy minnow	Hybognathus hankinsoni
194	golden shiner	Notemigonus chrysoleucas
196	emerald shiner	Notropis atherinoides
198	common shiner	Notropis cornutus
199	blackchin shiner	Notropis heterodon
200	blacknose shiner	Notropis heterolepis
201	spottail shiner	Notropis hudsonius
206	mimic shiner	Notropis volucellus
208	bluntnose minnow	Pimephales notatus
209	fathead minnow	Pimephales promelas
210	blacknose dace	Rhinichthys atratulus
211	longnose dace	Rhinichthys cataractae
212	creek chub	Semotilus atromaculatus
213	fallfish	Semotilus corporalis
214	pearl dace	Semotilus margarita
233	brown bullhead	Ictalurus nebulosus
236	tadpole madtom	Noturus gyrinus
261	banded killifish	Fundulus diaphanus
271	burbot	Lota lota
281	brook stickleback	Culaea inconstans
283	ninespine stickleback	Pungitius pungitius
291	trout-perch	Percopsis omiscomaycus
311	rock bass	Ambloplites rupestris
313	pumpkinseed	Lepomis gibbosus
314	bluegill	Lepomis macrochirus
316	smallmouth bass	Micropterus dolomieui
317	largemouth bass	Micropterus salmoides
319	black crappie	Pomoxis nigromaculatus

Appendix Table A. (continued)

#	Common name	Scientific name
331	yellow perch	*Perca flavescens*
332	sauger	*Stizostedion canadense*
334	walleye	*Stizostedion vitreum vitreum*
338	Iowa darter	*Etheostoma exile*
341	johnny darter	*Etheostoma nigrum*
342	logperch	*Percina caprodes*
381	mottled sculpin	*Cottus bairdi*
382	slimy sculpin	*Cottus cognatus*

endix Table B. The mean, standard deviation (s.d.), minimum, and maximum of each of 10 morphological characters the 31 species examined in this study. Abreviations of characters are as in Table 1.

cies		CI	RD	RPL	IPC	IVF	RPA	PAR	RCA	CAR	EP
nbow trout	mean	1.96	0.24	0.17	2.35	0.51	0.05	1.75	0.16	2.29	0.51
	s.d.	0.09	0.01	0.01	0.19	0.04	0.01	0.11	0.02	0.12	0.04
	min.	1.79	0.23	0.16	2.17	0.4	0.04	1.61	0.12	2.03	0.41
	max.	2.12	0.26	0.18	2.7	0.57	0.07	1.96	0.18	2.42	0.54
:e trout	mean	1.69	0.2	0.15	1.73	0.56	0.05	1.89	0.15	2.86	0.6
	s.d.	0.15	0.02	0.01	0.15	0.02	0.01	0.13	0.02	0.23	0.04
	min.	1.4	0.18	0.13	1.42	0.53	0.05	1.75	0.12	2.55	0.53
	max.	2.01	0.25	0.16	1.91	0.62	0.06	2.2	0.17	3.36	0.66
ke whitefish	mean	1.97	0.23	0.12	1.57	0.56	0.04	2.16	0.13	3.15	0.54
	s.d.	0.14	0.01	0.01	0.14	0.04	0	0.12	0.01	0.4	0.04
	min.	1.66	0.22	0.11	1.42	0.48	0.03	1.91	0.11	2.48	0.49
	max.	2.17	0.24	0.14	1.89	0.62	0.05	2.3	0.14	3.75	0.62
ke herring	mean	1.95	0.22	0.13	1.62	0.58	0.05	1.79	0.13	3.07	0.55
	s.d.	0.14	0.01	0.01	0.13	0.02	0.01	0.11	0.01	0.21	0.03
	min.	1.74	0.2	0.12	1.42	0.55	0.04	1.63	0.11	2.81	0.5
	max.	2.22	0.24	0.14	1.84	0.6	0.05	1.95	0.15	3.31	0.59
inbow smelt	mean	1.61	0.17	0.1	1.38	0.56	0.09	1.36	0.13	2.93	0.65
	s.d.	0.04	0.01	0.01	0.07	0.07	0.02	0.15	0.05	0.31	0.04
	min.	1.57	0.16	0.09	1.24	0.44	0.06	1.18	0	2.42	0.62
	max.	1.7	0.18	0.1	1.49	0.67	0.13	1.59	0.17	3.45	0.76
rthern pike	mean	1.81	0.17	0.12	1.75	0.48	0.04	1.39	0.14	2	0.69
	s.d.	0.25	0.02	0.01	0.12	0.05	0.01	0.08	0.01	0.44	0.01
	min.	1.27	0.14	0.11	1.55	0.41	0.03	1.25	0.12	0.85	0.66
	max.	2.15	0.2	0.14	1.93	0.57	0.06	1.5	0.16	2.69	0.7
iskellunge	mean	1.69	0.15	0.14	1.54	0.62	0.04	1.9	0.16	2.38	0.72
	s.d.	0.09	0.01	0.01	0.14	0.04	0	0.09	0.02	0.49	0.04
	min.	1.51	0.13	0.13	1.39	0.54	0.03	1.74	0.13	1.22	0.64
	max.	1.81	0.16	0.15	1.83	0.7	0.04	2.02	0.19	3.22	0.78
ongnose sucker	mean	1.19	0.21	0.16	1.51	0.52	0.06	1.77	0.14	2.23	0.61
	s.d.	0.07	0.01	0.01	0.13	0.03	0.02	0.1	0.01	0.12	0.03
	min.	1.06	0.2	0.15	1.38	0.47	0	1.58	0.13	2.01	0.57
	max.	1.29	0.22	0.19	1.83	0.57	0.07	1.91	0.15	2.41	0.65

Appendix Table B. *(continued)*

Species		CI	RD	RPL	IPC	IVF	RPA	PAR	RCA	CAR	EP
horthead redhorse	mean	1.55	0.25	0.15	1.82	0.57	0.06	1.56	0.16	2.66	0.6
	s.d.	0.16	0.02	0.01	0.19	0.03	0.02	0.12	0.03	0.22	0.02
	min.	1.26	0.21	0.14	1.53	0.53	0	1.33	0.11	2.4	0.56
	max.	1.81	0.28	0.17	2.2	0.62	0.08	1.72	0.2	3.21	0.64
inescale dace	mean	1.51	0.24	0.23	1.94	0.45	0.05	1.58	0.15	1.97	0.5
	s.d.	0.04	0.01	0.01	0.15	0.05	0.02	0.18	0.01	0.21	0.03
	min.	1.45	0.21	0.21	1.7	0.38	0.03	1.33	0.13	1.58	0.46
	max.	1.57	0.25	0.24	2.21	0.52	0.09	1.81	0.18	2.26	0.55
ake chub	mean	1.45	0.22	0.22	1.96	0.5	0.09	1.56	0.2	2.05	0.5
	s.d.	0.08	0.01	0.01	0.08	0.04	0.01	0.09	0.02	0.12	0.03
	min.	1.34	0.2	0.21	1.78	0.45	0.06	1.39	0.17	1.78	0.44
	max.	1.6	0.24	0.24	2.06	0.56	0.1	1.69	0.23	2.17	0.55
arp	mean	2.06	0.37	0.16	2.85	0.41	0.06	1.56	0.15	2.54	0.56
	s.d.	0.14	0.02	0.01	0.25	0.03	0.01	0.1	0.02	0.23	0.03
	min.	1.69	0.34	0.15	2.42	0.34	0.05	1.4	0.13	2.22	0.5
	max.	2.21	0.41	0.17	3.24	0.45	0.07	1.78	0.18	2.96	0.61
erald shiner	mean	1.71	0.18	0.17	1.92	0.42	0.07	1.93	0.19	2.18	0.54
	s.d.	0.09	0.01	0.01	0.15	0.03	0.01	0.13	0.03	0.29	0.04
	min.	1.57	0.16	0.16	1.71	0.37	0.06	1.75	0.15	1.74	0.46
	max.	1.85	0.19	0.18	2.15	0.49	0.08	2.16	0.23	2.77	0.6
ackchin shiner	mean	1.62	0.21	0.24	1.55	0.47	0.08	1.49	0.21	1.92	0.54
	s.d.	0.08	0.01	0.01	0.24	0.02	0.01	0.08	0.02	0.17	0.04
	min.	1.49	0.2	0.23	1.3	0.43	0.06	1.36	0.18	1.66	0.47
	max.	1.74	0.23	0.26	2.06	0.5	0.1	1.58	0.27	2.15	0.6
acknose shiner	mean	1.65	0.2	0.26	1.74	0.49	0.06	1.8	0.19	2.04	0.5
	s.d.	0.14	0.01	0.03	0.09	0.03	0.01	0.09	0.02	0.25	0.05
	min.	1.49	0.18	0.24	1.56	0.44	0.05	1.64	0.16	1.51	0.4
	max.	2	0.22	0.35	1.88	0.54	0.08	1.93	0.22	2.28	0.58
ottail shiner	mean	1.77	0.25	0.21	1.64	0.54	0.06	1.62	0.2	2.79	0.56
	s.d.	0.07	0.01	0.01	0.08	0.02	0.01	0.14	0.02	0.14	0.03
	min.	1.67	0.24	0.21	1.53	0.5	0.05	1.44	0.18	2.6	0.53
	max.	1.85	0.26	0.22	1.76	0.58	0.07	1.86	0.23	3	0.61

endix Table B. (continued)

cies		CI	RD	RPL	IPC	IVF	RPA	PAR	RCA	CAR	EP
ic shiner	mean	1.55	0.21	0.22	1.76	0.54	0.08	1.71	0.2	2.29	0.55
	s.d.	0.1	0.01	0.01	0.08	0.02	0.01	0.07	0.01	0.12	0.03
	min.	1.29	0.19	0.19	1.64	0.5	0.07	1.63	0.18	2.1	0.49
	max.	1.65	0.22	0.23	1.9	0.58	0.1	1.86	0.22	2.47	0.59
.lfish	mean	1.65	0.25	0.19	1.74	0.51	0.05	1.86	0.16	2.61	0.57
	s.d.	0.06	0.01	0.01	0.11	0.04	0.01	0.07	0.01	0.19	0.03
	min.	1.55	0.25	0.19	1.63	0.44	0.04	1.74	0.15	2.2	0.49
	max.	1.73	0.26	0.22	1.94	0.58	0.06	1.97	0.18	2.88	0.61
dpole madtom	mean	1.18	0.23	0.22	4.01	0.55	0.08	1.49	0.3	0.79	0.59
	s.d.	0.16	0.01	0.01	0.66	0.05	0.01	0.11	0.02	0.12	0.06
	min.	0.89	0.2	0.2	2.89	0.49	0.06	1.27	0.26	0.65	0.51
	max.	1.54	0.25	0.25	5.43	0.64	0.1	1.67	0.32	1.05	0.68
nded killifish	mean	1.31	0.21	0.26	1.83	0.5	0.07	1.41	0.2	1.37	0.53
	s.d.	0.09	0.01	0.01	0.14	0.06	0.01	0.08	0.02	0.19	0.07
	min.	1.14	0.2	0.23	1.62	0.42	0.05	1.24	0.17	1.17	0.42
	max.	1.45	0.23	0.28	2.09	0.62	0.08	1.52	0.22	1.76	0.67
rbot	mean	1.12	0.15	0	2.41	0.61	0.07	1.28	0.09	1.17	0.68
	s.d.	0.09	0.01		0.33	0.06	0.01	0.14	0.01	0.16	0.09
	min.	0.99	0.13		1.74	0.51	0.04	1.07	0.07	0.95	0.58
	max.	1.29	0.16		2.93	0.72	0.09	1.55	0.11	1.51	0.88
nespine stickleback	mean	1.79	0.18	0.19	0.5	0.58	0.1	0.93	0.11	1.64	0.54
	s.d.	0.1	0.01	0.02	0.02	0.03	0.01	0.05	0.01	0.16	0.03
	min.	1.59	0.17	0.16	0.47	0.52	0.09	0.87	0.1	1.42	0.5
	max.	1.92	0.21	0.21	0.52	0.62	0.12	1.03	0.13	1.88	0.57
rout-perch	mean	1.44	0.22	0.22	1.6	0.5	0.1	1.95	0.2	2.16	0.65
	s.d.	0.06	0.01	0.03	0.11	0.03	0.01	0.12	0.02	0.08	0.05
	min.	1.32	0.2	0.15	1.49	0.42	0.07	1.77	0.16	2.03	0.56
	max.	1.52	0.24	0.24	1.85	0.55	0.12	2.16	0.21	2.31	0.71
luegill	mean	2.98	0.52	0.2	2.99	0.46	0.06	2.16	0.13	2.01	0.62
	s.d.	0.17	0.04	0.01	0.2	0.03	0.01	0.14	0.02	0.13	0.04
	min.	2.81	0.46	0.17	2.72	0.41	0.05	1.98	0.1	1.78	0.52
	max.	3.38	0.58	0.21	3.43	0.49	0.08	2.44	0.17	2.26	0.65

Appendix Table B. (continued)

pecies		CI	RD	RPL	IPC	IVF	RPA	PAR	RCA	CAR	EP
argemouth bass	mean	1.94	0.3	0.21	1.98	0.45	0.06	1.49	0.15	1.43	0.64
	s.d.	0.2	0.02	0.02	0.22	0.04	0.01	0.12	0.03	0.15	0.04
	min.	1.47	0.28	0.19	1.68	0.39	0.04	1.33	0.12	1.19	0.55
	max.	2.21	0.33	0.23	2.32	0.52	0.07	1.79	0.21	1.66	0.69
lack crappie	mean	3.11	0.42	0.17	2.85	0.49	0.07	1.69	0.23	1.97	0.56
	s.d.	0.25	0.05	0.01	0.44	0.04	0.01	0.22	0.05	0.14	0.04
	min.	2.73	0.35	0.16	2.25	0.4	0.05	1.45	0.14	1.83	0.51
	max.	3.65	0.48	0.19	3.47	0.56	0.09	2.15	0.29	2.31	0.63
ellow perch	mean	1.83	0.26	0.17	1.66	0.42	0.06	1.68	0.15	2.12	0.59
	s.d.	0.11	0.01	0.01	0.15	0.04	0.01	0.12	0.02	0.18	0.04
	min.	1.61	0.25	0.16	1.42	0.37	0.05	1.46	0.1	1.83	0.54
	max.	1.96	0.27	0.18	1.91	0.49	0.08	1.85	0.17	2.44	0.66
auger	mean	1.38	0.19	0.17	1.26	0.51	0.08	1.78	0.18	2.15	0.64
	s.d.	0.09	0.02	0.01	0.1	0.06	0.01	0.09	0.01	0.17	0.03
	min.	1.26	0.16	0.15	1.14	0.39	0.06	1.6	0.16	1.89	0.61
	max.	1.57	0.22	0.18	1.48	0.58	0.09	1.92	0.19	2.37	0.7
alleye	mean	1.52	0.21	0.15	1.29	0.54	0.06	1.76	0.18	2.53	0.71
	s.d.	0.09	0.01	0.01	0.05	0.04	0.01	0.09	0.01	0.25	0.07
	min.	1.37	0.19	0.14	1.21	0.44	0.05	1.65	0.16	2.13	0.61
	max.	1.66	0.22	0.17	1.38	0.59	0.06	1.91	0.2	3.05	0.85
gperch	mean	1.39	0.18	0.15	1.48	0.59	0.13	1.25	0.14	1.58	0.68
	s.d.	0.06	0.01	0.01	0.1	0.03	0.01	0.05	0.01	0.15	0.07
	min.	1.28	0.17	0.14	1.3	0.54	0.11	1.17	0.12	1.39	0.55
	max.	1.47	0.19	0.17	1.61	0.63	0.14	1.33	0.18	1.86	0.76
imy sculpin	mean	0.71	0.21	0.09	1.93	0.47	0.24	1.57	0.18	1.12	0.79
	s.d.	0.04	0.01	0.01	0.14	0.04	0.02	0.09	0.02	0.07	0.05
	min.	0.66	0.19	0.08	1.64	0.41	0.21	1.44	0.16	0.93	0.68
	max.	0.78	0.22	0.12	2.1	0.52	0.28	1.78	0.21	1.2	0.86