Morphological and Ecological Characteristics of 25 Fishes Occurring in Great Lakes' Areas of Concern

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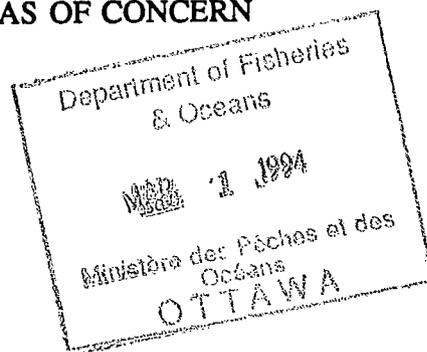# MORPHOLOGICAL AND ECOLOGICAL CHARACTERISTICS OF
25 FISHES OCCURRING IN GREAT LAKES' AREAS OF CONCERN

by

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ABSTRACT

Minns, C.K., S.W. King, and C.B. Portt. 1993. Morphological and ecological characteristics of 25 fishes occurring in Great Lakes' Areas of Concern. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2209.

Morphological, life history, feeding, and thermal characteristics were compiled for 25 freshwater fish species occurring in the Great Lakes, using the methods and criteria of Portt *et al.* (1988). Principal components and cluster analyses reveal associations within sets of characteristics and among groups of species. These eco-morphometric data, when combined with that collected earlier on 52 species common in Ontario's inland lakes, will provide the basis for guilding fish assemblages and analyzing relationships with species distributions and abundance.

SOMMAIRE

Minns, C.K., S.W. King, and C.B. Portt. 1993. Caractéristiques morphologiques et écologiques de 25 espèces de poissons présentes dans les secteurs préoccupants des Grands Lacs. Rapport manuscrit canadien des sciences halieutiques et aquatiques 0000.

On a compilé des données sur les caractéristiques concernant la morphologie, le cycle biologique, l'alimentation et la chaleur de 25 espèces de poissons d'eau douce que l'on trouve dans les Grands Lacs. À cette fin, les methodes et las critères de Portt *et al.* (1988) ont été utilisés. Les principaux éléments et les analyses typologiques révèlent des associations à l'intérieur de groupes de caractéristiques et au sein de groupes d'espèces. Ces données écomorphométriques, combinées à celles recueillies précédemment sur 52 espèces courantes dans les lacs intérieurs de l'Ontario, constitueront une base qui permettra d'établir des guildes au sein des communautés de poissons et d'analyser les liens avec la distribution et l'abondance des espèces.

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INTRODUCTION

The ecomorphological characteristics of 52 fish species commonly found in Ontario lakes were documented in Portt *et al.* (1988). This study provides the same information for an additional 25 fish species, which are found in three Great Lakes' Areas of Concern: Hamilton Harbour and the Bay of Quinte on Lake Ontario, and Severn Sound on Georgian Bay. The primary purpose of this and the previous data compilation is to allow testing a broad hypothesis that using quantitative indices based on ecomorphometric, life history, and trophic characteristics can predict the abundance and composition of fish assemblages in observed in Ontario's freshwaters after consideration of abiotic factors. In this report, the analysis focuses on the consistency of species grouping, or guilding, tendencies based on objective analysis the various data attributes with groupings observed with the previous compilation for 52 species.

METHODOLOGY

We determined the morphometric characteristics of 25 species from preserved specimens following the methodology of Mahon (1981, 1984) as closely as possible. Descriptions of the functional significance of morphological characters and the measurement methodology are given by Mahon (1984), Watson and Balon (1984), and Gatz (1979a), and summarized in Portt *et al.* (1988). The characteristics are defined as follows:

1) Lateral compression index (CI): maximum body depth divided by maximum body width.

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, defined exteriorly as the base of the caudal fin rays.

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.

4) Index of caudal peduncle compression (IPC): caudal peduncle depth divided by caudal peduncle width, measured at the midpoint of the peduncle.

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.

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.

7) Pectoral fin shape or pectoral aspect ratio (PAR): The length of the pectoral fin divided by its maximum width.

8) Relative caudal area (RCA): The area of the caudal fin divided by body area, which is estimated as for RPA.

9) Caudal fin aspect ratio (CAR): the square of the maximum height of the caudal fin divided by its area.

10) Eye position (EP): the proportion of head depth which occurs below the centre of the eye.

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.

Ten individuals of each species were measured. Measurements of lengths less than 180 mm were made to the nearest .05 mm using Vernier callipers. Measurements greater than 180 mm were made to the nearest mm. Fins areas were determined to the nearest mm^2 from tracings of fully extended fins using a planimeter.

The ecological characteristics were taken largely from secondary sources following the criteria laid out by Mahon (1984). 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. Recognizing that these characteristics

may bw stock-dependent, the approach was to look for 'typical' or medial values for each species. For many species, values for particular parameters were only available from a single source and those values were used. 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 possible total length and fork length were converted to standard length by dividing by 1.2 and 1.1 respectively after Mahon (1984). In many cases the type of length measurement was not documented and given values were assumed to represent standard lengths; Given the objective is to identify major and not minor differences between species, the effect of length errors will be minimal.

The feeding guild of adults of each species was described by three parameters, feeding location (benthic, pelagic, surface), feeding method (filtering, grazing/picking, sorting/suck and spit, stalking, pursuing, ambush), and preferred food (phytoplankton, macrophytes, annelids, 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. Temperature requirements were characterized by spawning and preferred temperatures.

The analysis of the data for 25 fish species was similar to that used by Portt *et al.* (1988). We used principle components analysis (PCA) to examine relationships among the morphometric and life history groups of characters. As the life history data values had large ranges and because allometric relationships are usually logarithmic, we used $\log_e$ transforms for all 6 characters. The

PCA were computed using correlation matrices, were varimax rotated, and factor scores computed for all factors with eigenvalues greater than 1.

Since the feeding characters were ordinal and we wanted each character to weight equally in any clustering of species, we used three binary variables to represent each character, i.e., a 1 was 111, a 2 was 011, a 3 was 001, and absence was coded 000. The Jaccard index of similarity was used to measure the agreement between species regarding feeding.

The PCA and Jaccard index results for morphometrics, life history, and feeding were then used to cluster the species using Euclidean distance and Ward's minimum variance criterion pairing. All statistics were computed using SYSTAT (Wilkinson, 1990).

RESULTS

The mean values of the ecomorphological characteristics for each species, and the overall mean, standard deviation, minimum and maximum are provided in Table 1. The summary statistics for each species are contained in Appendix B. The life history and reproductive guild data are presented in Table 2. Feeding information is contained in Table 3. Spawning and preferred temperatures are given in Table 4.

The PCA for morphometric characters in 25 species produced results similar to that obtained earlier by Portt *et al.* (1988) for 52 species; 4 factors explained 77.9 percent of the variance (Table 5). All but 3 of the characters grouped into rotated factors in a similar manner. The PCA for life history characters also produced results similar to that obtained previously; 2 factors accounted for 84.1 percent of variance (Table 6). Factor L1 was a measure of size and age while factor L2 showed the contrast between fecundity and egg diameter, which both had relatively high loadings on L1.

The clusterings by morphometry, life history, and feeding produced well-defined groupings (Figure 1). The salmonids tended to produce a tight grouping in all three dendrograms. Other species did not appear to group consistently across the three groups of characters. The cluster diagrams were divided into groupings with the aim of producing 4 groups for each set of characters. For morphometrics, 6 groups were assigned as 4 larger species (S161 quillback, S371 freshwater drum, S051 bowfin, and S251 American eel) appeared to be outliers. Cross-tabulation showed some agreement groupings dominated by 4 salmons (S071 pink salmon, S073 coho salmon, S075 chinook salmon, and S077 Atlantic) being together. The low agreement of groupings may be a consequence of the limited number of species involved in the analysis compared to the number of combinations possible.

The groupings obtained here do not agree with the groupings obtained in the previous study (Portt *et al.* 1988). The 25 species examined here represent disparate life-style groups, e.g. large pelagic/oceanic fast swimmers versus small and large littoral warmwater species, all drawn from the Great Lakes. These sub-groups may be viewed as outliers to the groups examined previously which were selected on the basis of common occurrence in Ontario inland lakes.

DISCUSSION

The data assembled here and the preliminary analyses suggest that the patterns of relationships among groups of ecomorphometric characters are similar in these 25 fish species present in the Great Lakes to the patterns found earlier by Portt et al. (1988) for 52 fish species common in Ontario's inland lakes. Further analysis should be undertaken by combining the results of this and the earlier study, especially to explain clustering differences. Combined analyses of the three groups of characters (morphometric, life history, and feeding) should be

examined as the basis for developing an objective classification and guilding of fish species by 'life style', useful for assessing the condition of fish assemblages and their habitat requirements. In Great Lakes' Areas of Concern, fish abundance datasets exist (Randall *et al.* 1993 *in press*) which will be used to assess the relationships between life style and abundance under differing degrees of habitat and water quality impairment and of exploitation, and of invasion by exotic species.

ACKNOWLEDGEMENTS

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*   Quoted in Becker (1983).
**   Quoted in Scott and Crossman (1973).
***   Quoted in Wismer and Christie (1987).
****   Quoted in Mahon (1984).

Table 1   Means of morphological characters for each of 25 species, plus summary statistics [Sample size per species = 10]: 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). RPL and IPC for bowfin and American eel are not included in summary statistics.

Species	CI	RD	RPL	IPC	IVF	RPA	PAR	RCA	CAR	EP	MP
longnose gar	1.16	0.09	0.08	1.67	0.59	0.04	2.03	0.13	0.78	0.53	2
bowfin	1.32	0.22	0.00	0.00	0.54	0.05	1.42	0.17	0.95	0.67	2
alewife	2.87	0.29	0.07	3.12	0.58	0.05	2.08	0.14	2.89	0.65	1
gizzard shad	3.17	0.36	0.09	2.54	0.53	0.04	2.14	0.12	3.26	0.55	3
pink salmon	2.43	0.28	0.14	1.56	0.49	0.04	1.63	0.12	2.92	0.55	2
coho salmon	2.13	0.28	0.15	1.95	0.52	0.04	1.67	0.11	2.43	0.59	2
chinook salmon	1.97	0.26	0.14	1.75	0.53	0.03	1.90	0.10	2.62	0.50	2
Atlantic salmon	1.90	0.21	0.16	1.70	0.54	0.06	1.85	0.13	2.40	0.60	2
brown trout	1.90	0.25	0.13	2.19	0.48	0.06	1.76	0.14	1.92	0.64	2
round whitefish	1.45	0.23	0.14	1.46	0.49	0.04	2.31	0.09	2.73	0.59	3
quillback	2.29	0.37	0.09	3.64	0.35	0.05	1.95	0.16	2.03	0.63	4
silver redhorse	1.82	0.30	0.11	2.96	0.53	0.06	2.08	0.17	1.81	0.64	4
shorthead redhorse	1.61	0.26	0.12	2.27	0.51	0.06	2.06	0.16	2.00	0.59	4
goldfish	2.10	0.42	0.12	2.85	0.42	0.05	1.73	0.17	2.11	0.56	3
hornyhead chub	1.61	0.26	0.19	1.97	0.55	0.05	1.89	0.18	1.79	0.64	3
channel catfish	1.40	0.22	0.11	2.32	0.57	0.08	2.02	0.20	1.68	0.61	2
American eel	1.25	0.06	0.00	0.00	0.58	0.02	1.39	0.01	0.61	0.59	1
fourspine stickleback	2.01	0.22	0.17	1.32	0.52	0.05	1.60	0.11	0.56	0.65	1
white perch	2.22	0.36	0.18	2.14	0.40	0.06	2.05	0.13	2.01	0.59	1
white bass	2.36	0.33	0.13	2.87	0.47	0.05	1.92	0.18	1.52	0.74	2
green sunfish	1.95	0.45	0.16	2.21	0.47	0.07	1.42	0.14	1.61	0.73	2
tessellated darter	1.28	0.18	0.20	1.46	0.46	0.15	1.73	0.20	1.08	0.72	3
brook silverside	1.40	0.14	0.14	1.56	0.68	0.08	1.58	0.19	1.46	0.59	1
freshwater drum	2.69	0.34	0.07	3.09	0.32	0.07	2.19	0.17	0.98	0.56	3
slimy sculpin	1.09	0.18	0.08	1.61	0.66	0.32	1.53	0.24	1.16	0.84	2
mean	1.90	0.26	0.13	2.18	0.51	0.07	1.84	0.15	1.81	0.62	
s.d.	0.54	0.09	0.05	0.85	0.08	0.06	0.25	0.05	0.74	0.07	
minimum	1.09	0.06	0.07	1.32	0.32	0.02	1.39	0.01	0.56	0.50	
maximum	3.17	0.45	0.20	3.64	0.68	0.32	2.31	0.24	3.26	0.84	

Table 2   Life history characteristics for 25 species. Length (mm) and Age (years) at maturity (Mat) and maximum length (Max) in mm. Fecundity as number of eggs per female. Egg diameter (E.D.) in mm. Reproductive guild (R.G.) from Balon, 1975. Spawning locations (SL) 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) may be found in Appendix C.

| Species | Length | | Age | | Fecundity | E.D. | R.G. | SL | References | | | | | |
	Mat	Max	Mat	Max					A	B	C	D	E	F
longnose gar	500	1830[1]	6	32	31848	2.7	A.1.5	3	1	1	1	21	29	21
bowfin	610	870	4	25	43800	2.8[2]	B.2.5	3	2	1	2	1	24	38
alewife	138[1]	205[1]	3	6	16000	0.9[3]	A.1.4	1	3	3	19	22	3	39
gizzard shad	279[1]	521	2	6	377645	0.8[3]	A.1.2	3	4b	17b	4b	4a	4a	4a
pink salmon	411	508	2	2	1700	6.0	A.2.3	1	5	5	2	2	2	2
coho salmon	635	900[1]	3	3	3807	6.9[4]	A.2.3	1	6	1	2	1	40	2
chinook salmon	750	968	3	9	2500	6.5	A.2.3	1	6	2	2	23	2	2
Atlantic salmon	800	1550	3	5	8500	6.0	A.2.3	2	7	7	2	24	30	30
brown trout	258[1]	874	3	18	3950	4.5	A.2.3	1	1	1	1	1	11	2
round whitefish	183	468[1]	3	14	6460	2.7[3]	A.1.3	3	1	2	1	25	31	2
quillback	472[1]	660	6	12	39507	1.7	A.1.6	3	8	17b	8	1	32	1
silver redhorse	391	635	5	14	25625	1.2[3]	A.1.3	2	9	17a	9	1	9	2
shorthead redhorse	195	620	3	14	20325	1.9[3]	A.1.3	2	2	17a	1	2	9	2
goldfish	175	457	4	30	270000	1.4	A.1.5	3	10	17b	10	26	10	2
hornyhead chub	93[1]	188[1]	3	4	593	1.7	A.2.3	2	1	1	1	27	33	1
channel catfish	337	1004	7	24	19250	3.8[3]	B.2.7	3	2	17a	2	2	2	2
American eel	457	1520	9	27	12500000	1.0	A.1.1	4	12	1	44	45	1	7
fourspine stickleback	41[1]	52[1]	2	2	36	1.5	B.2.4	2	13	28	13	28	13	2
white perch	254	482	2	12	160000	0.9[5]	A.1.4	1	14	14	14	2	2	1
white bass	115[1]	322[1]	3	8	587500	0.8	A.1.4	1	15	18	18	18	34	1
green sunfish	76	169[1]	2	9	32500	1.2	B.2.3	3	1	2	20	2	12	43
tessellated darter	43[1]	77	1	4	385	1.5	B.2.7	3	1	1	1	2	35	2
brook silverside	74	81[1]	1	1.5	618	0.8[3]	A.1.4	1	1	1	2	2	1	2
freshwater drum	292	940	5	17	275500	1.4	A.1.1	3	16	1	16	1	36	36
slimy sculpin	63	120	3	7	1400	2.5[5]	B.2.7	3	41	42	41	1	37	37

[1] standard length; E.D. - [2] length of an oval shape, [3] unfertilized, [4] formalin-preserved, [5] water-hardened

Table 3 Feeding location, method, and principal foods of 25 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 filtering (F), grazing/picking (G), sorting (S), stalking (St), pursuit (P), or ambush (A). Diet may include one or more of seven categories: phytoplankton (P), macrophytes (M), annelids (A), 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							
Species	B	P	S	F	G	S	St	P	A	P	M	C	A	M	I	F	O
longnose gar	-	1	-	-	-	-	-	-	1	-	-	3	-	-	-	1	3
bowfin	1	-	-	-	1	-	1	-	-	-	-	1	-	-	2	1	1
alewife	1	1	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-
gizzard shad	1	-	-	-	1	1	-	-	-	1	1	-	-	-	-	-	-
pink salmon	-	1	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-
coho salmon	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-
chinook salmon	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-
Atlantic salmon	-	1	-	-	-	-	-	1	-	-	-	1	-	-	-	1	-
brown trout	-	1	1	-	-	-	-	1	1	-	-	1	-	2	1	1	2
round whitefish	1	-	-	-	1	1	-	-	-	-	1	2	-	-	1	3	-
goldfish	1	-	-	-	-	1	-	-	-	-	1	1	2	1	1	-	-
hornyhead chub	1	2	1	-	1	-	-	1	-	1	1	1	3	-	1	3	-
quillback	1	-	-	-	-	1	-	-	-	-	1	-	-	-	1	-	-
silver redhorse	1	-	-	-	-	1	-	-	-	3	-	1	-	2	1	-	-
shorthead redhorse	1	-	-	-	-	1	-	-	-	3	-	1	-	2	1	-	-
channel catfish	1	-	2	-	1	-	-	2	-	-	1	1	-	1	1	1	-
American eel	1	-	-	-	-	-	-	1	-	-	-	1	1	1	1	1	-
fourspine stickleback	1	2	-	-	1	-	-	2	-	1	-	1	-	-	-	-	-
white perch	1	1	-	-	1	-	-	1	-	-	-	1	3	3	1	1	-
white bass	-	1	-	-	-	-	-	1	-	-	-	1	-	-	1	1	-
green sunfish	1	1	-	-	-	-	-	-	1	-	1	-	-	-	1	2	-
tessellated darter	1	-	-	-	-	-	-	-	1	-	-	1	-	-	1	-	-
brook silverside	-	1	1	-	-	-	-	1	-	-	-	1	-	-	1	-	-
freshwater drum	1	-	-	-	1	1	-	-	-	-	-	1	-	2	1	2	-
slimy sculpin	1	-	-	-	1	-	-	-	-	-	-	1	-	1	1	1	-

Table 4.   Spawning and preferred temperatures (°C) of species for which data were available.

Species	Spawning	Reference	Preferred	Reference
longnose gar	20.3	Haase, 1969.	30.9	Coutant, 1977.
bowfin	17.5	Reighard, 1904.	30.5	Reynolds *et al.*, 1978.
alewife	14.5	Becker, 1983.	18.8	Coutant, 1977.
gizzard shad	20.0	Bodola, 1966.	23.0	Coutant, 1977.
pink salmon	10.0	Scott and Crossman, 1973.	11.7	Coutant, 1977.
coho salmon	6.1	Brown, 1974.	15.5	Wismer and Christie, 1987.
chinook salmon	-	-	17.3	Coutant, 1977.
Atlantic salmon	6.0	Peterson *et al.*, 1977.	16.0	Coutant, 1977.
brown trout	7.8	Mansell, 1966.	21.1	Brynildson *et al.*, 1963.
round whitefish	4.5	Scott and Crossman, 1973.	17.5	Coutant, 1977.
quillback	23.5	Woodward and Wissing, 1976.	30.0	Coutant, 1977.
silver redhorse	13.3	Meyer, 1962.	24.0	Coutant, 1977.
shorthead redhorse	11.1	Meyer, 1962.	24.0	Coutant, 1977.
goldfish	15.6	Becker, 1983.	27.0	Coutant, 1977.
hornyhead chub	23.9	Carter, 1940.	-	-
channel catfish	26.7	Scott and Crossman, 1973.	25.2	Coutant, 1977.
American eel	-	-	19.0	Haro, 1991.
fourspine stickleback	-	-	-	-
white perch	13.0	Sheri and Power, 1968.	32.0	Coutant, 1977.
white bass	17.8	Scott and Crossman, 1973.	29.0	Coutant, 1977.
green sunfish	21.5	Scott and Crossman, 1973.	30.6	Coutant, 1977.
tessellated darter	16.4	Becker, 1983.	22.9	Ingersoll and Claussen, 1984.
brook silverside	21.4	Cahn, 1927.	24.5	Coutant, 1977.
freshwater drum	22.2	Butler, 1965.	20.6	Coutant, 1977.
slimy sculpin	7.5	Koster, 1936.	5.0	Wells, 1966.

Table 5   Character loadings, eigenvalues, and percentages of variance explained by 4 factors derived from a principle components analysis of 11 morphological characters in 25 fish species.

Character	Factor			
	M1	M2	M3	M4
RD	0.897	0.071	0.128	0.272
IVF	-0.817	0.118	-0.259	0.173
CI	0.749	-0.315	0.040	0.368
IPC	0.623	0.148	0.534	0.337
RPA	-0.238	0.860	-0.030	0.011
EP	0.042	0.857	-0.270	-0.097
RCA	0.035	0.841	0.313	0.103
MP	0.247	0.145	0.817	-0.122
PAR	0.127	-0.253	0.796	0.295
CAR	0.224	-0.343	0.233	0.732
RPL	0.089	0.190	-0.017	0.688
Eigenvalue	2.616	2.560	1.897	1.483
% Variance	23.8	23.3	17.3	13.5
% Cumulative	23.8	47.1	64.4	77.9

- Underlined coefficient is the largest for each character

Table 6   Character loadings, eigenvalues, and percentage of variance explained by 2 factors derived from a principle components analysis of 6 life history characters in 24 fish species (Data incomplete for American eel). [Log_e-transformation of each character used.]

Character	Factor	
	L1	L2
Length, maturity	0.856	0.347
Length, maximum	0.954	0.181
Age, maturity	0.836	-0.095
Age, maximum	0.773	-0.418
Fecundity	0.639	-0.661
Egg diameter	0.406	0.874
Eigenvalue	3.512	1.537
% Variance	58.5	25.6
% Cumulative	58.5	84.1

Table 7   Frequency cross-tabulation of clustering group memberships assigned for morphometric, life history, and feeding character sets (numbers on trees in Figure 1).

Group	Group	Life history				Feeding			
		1	2	3	4	1	2	3	4
Morphometrics:									
1		3	0	4	0	1	1	1	4
2		3	1	0	1	1	0	2	2
3		0	1	0	4	1	2	1	1
4		1	3	0	0	2	0	2	0
5		1	1	0	0	1	1	0	0
6		0	2	0	0	0	2	0	0
Feeding:									
1		2	3	0	1				
2		2	3	0	1				
3		3	1	0	2				
4		1	1	4	1				

Figure 1
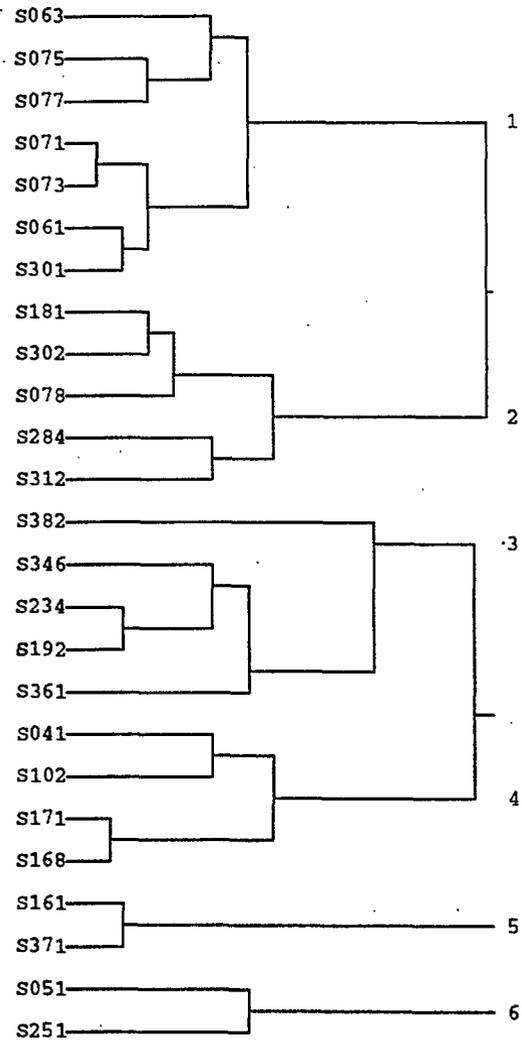
A) Morphometrics   B) Life history   C) Feeding
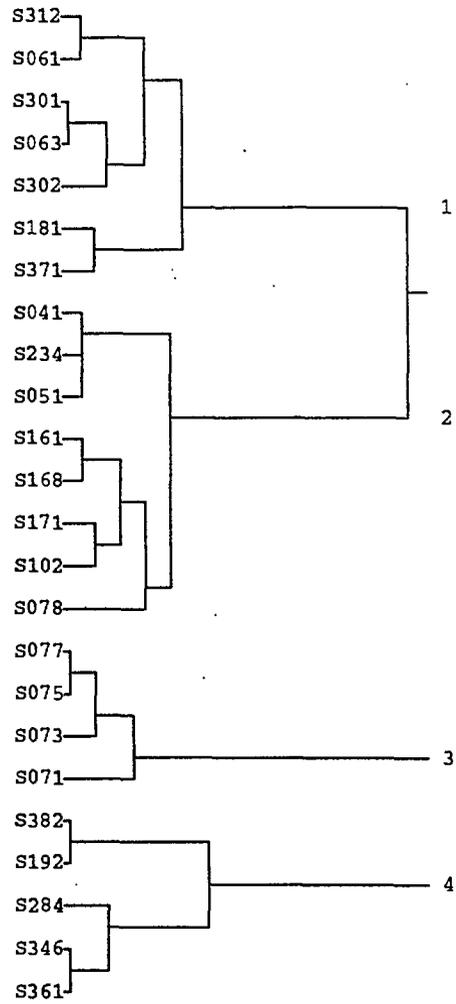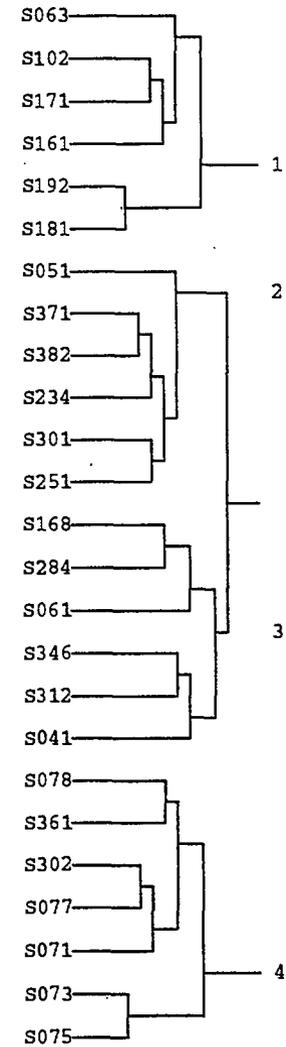
APPENDIX A

Table A   OMNR codes, common and scientific names of the 25 species examined in this study.

OMNR Code	Common name	Scientific name
S041	longnose gar	*Lepisosteus osseus*
S051	bowfin	*Amia calva*
S061	alewife	*Alosa pseudoharengus*
S063	gizzard shad	*Dorosoma cepedianum*
S071	pink salmon	*Oncorhynchus gorbuscha*
S073	coho salmon	*Oncorhynchus kisutch*
S075	chinook salmon	*Oncorhynchus tshawytscha*
S077	Atlantic salmon	*Salmo salar*
S078	brown trout	*Salmo trutta*
S102	round whitefish	*Prosopium cylindraceum*
S161	quillback	*Carpiodes cyprinus*
S168	silver redhorse	*Moxostoma anisurum*
S171	shorthead redhorse	*Moxostoma macrolepidotum*
S181	goldfish	*Carassius auratus*
S192	hornyhead chub	*Nocomis biguttatus*
S234	channel catfish	*Ictalurus punctatus*
S251	American eel	*Anguilla rostrata*
S284	fourspine stickleback	*Apeltes quadracus*
S301	white perch	*Morone americana*
S302	white bass	*Morone chrysops*
S312	green sunfish	*Lepomis cyanellus*
S346	tessellated darter	*Etheostoma olmstedi*
S361	brook silverside	*Labidesthes sicculus*
S371	freshwater drum	*Aplodinotus grunniens*
S382	slimy sculpin	*Cottus cognatus*

APPENDIX B

Table B   Mean, standard deviation (s.d.), minimum (min) and maximum (max) for each of 10 morphological characters for the 25 species examined on this study. [Abbreviations of characters are given in Table 1.]

Species	Var.	CI	RD	RPL	IPC	IVF	RPA	PAR	RCA	CAR	EP
longnose gar	mean	1.16	0.09	0.08	1.67	0.59	0.04	2.03	0.13	0.78	0.53
	s.d.	0.11	0.01	0.01	0.18	0.06	0.01	0.37	0.01	0.15	0.06
	min	0.95	0.08	0.07	1.40	0.48	0.03	1.45	0.11	0.58	0.41
	max	1.35	0.11	0.11	1.96	0.65	0.05	2.63	0.14	1.14	0.61
bowfin	mean	1.32	0.22	0.00	0.00	0.54	0.05	1.42	0.17	0.95	0.67
	s.d.	0.16	0.03	-	-	0.08	0.01	0.16	0.05	0.13	0.05
	min	1.10	0.18	-	-	0.41	0.04	1.13	0.10	0.81	0.57
	max	1.60	0.28	-	-	0.68	0.08	1.64	0.29	1.30	0.74
alewife	mean	2.87	0.29	0.07	3.12	0.58	0.05	2.08	0.14	2.89	0.65
	s.d.	0.31	0.01	0.01	0.20	0.03	0.00	0.23	0.01	0.33	0.03
	min	2.41	0.28	0.06	2.89	0.54	0.04	1.77	0.12	2.51	0.61
	max	3.39	0.31	0.08	3.46	0.61	0.06	2.49	0.15	3.53	0.69
gizzard shad	mean	3.17	0.36	0.09	2.54	0.53	0.04	2.14	0.12	3.26	0.55
	s.d.	0.14	0.02	0.01	0.41	0.01	0.01	0.18	0.01	0.47	0.03
	min	3.01	0.33	0.08	1.63	0.52	0.03	1.93	0.10	2.81	0.50
	max	3.47	0.38	0.10	3.38	0.56	0.05	2.54	0.13	4.09	0.59
pink salmon	mean	2.43	0.28	0.14	1.56	0.49	0.04	1.63	0.12	2.92	0.55
	s.d.	0.16	0.02	0.01	0.15	0.03	0.01	0.12	0.01	0.32	0.03
	min	2.23	0.25	0.12	1.25	0.43	0.04	1.46	0.11	2.54	0.51
	max	2.71	0.30	0.15	1.85	0.55	0.05	1.80	0.13	3.56	0.60
coho salmon	mean	2.13	0.28	0.15	1.95	0.52	0.04	1.67	0.11	2.43	0.59
	s.d.	0.32	0.03	0.01	0.15	0.07	0.01	0.10	0.02	0.14	0.04
	min	1.76	0.25	0.13	1.68	0.40	0.03	1.54	0.08	2.29	0.51
	max	2.91	0.36	0.16	2.13	0.62	0.05	1.89	0.14	2.82	0.68
chinook salmon	mean	1.97	0.26	0.14	1.75	0.53	0.03	1.90	0.10	2.62	0.50
	s.d.	0.14	0.03	0.02	0.21	0.05	0.01	0.23	0.02	0.52	0.19
	min	1.70	0.22	0.11	1.42	0.48	0.03	1.51	0.09	2.03	0.01
	max	2.17	0.32	0.16	2.02	0.66	0.04	2.22	0.13	3.47	0.66
Atlantic salmon	mean	1.90	0.21	0.16	1.70	0.54	0.06	1.85	0.13	2.40	0.60
	s.d.	0.17	0.01	0.01	0.23	0.05	0.01	0.15	0.01	0.32	0.05
	min	1.65	0.20	0.14	1.15	0.47	0.05	1.63	0.12	2.07	0.53
	max	2.14	0.25	0.18	1.98	0.63	0.07	2.07	0.15	3.08	0.72

Table B (Continued)

Species	Var.	CI	RD	RPL	IPC	IVF	RPA	PAR	RCA	CAR	EP
brown trout	mean	1.90	0.25	0.13	2.19	0.48	0.06	1.76	0.14	1.92	0.64
	s.d.	0.17	0.01	0.01	0.30	0.06	0.01	0.20	0.02	0.25	0.13
	min	1.64	0.24	0.12	1.44	0.39	0.04	1.42	0.11	1.49	0.55
	max	2.18	0.28	0.15	2.46	0.57	0.08	2.20	0.17	2.46	1.01
round whitefish	mean	1.45	0.23	0.14	1.46	0.49	0.04	2.31	0.09	2.73	0.59
	s.d.	0.12	0.02	0.01	0.10	0.08	0.01	0.22	0.02	0.52	0.04
	min	1.32	0.20	0.13	1.25	0.37	0.03	1.91	0.06	1.98	0.51
	max	1.71	0.25	0.15	1.62	0.62	0.05	2.58	0.13	3.81	0.65
quillback	mean	2.29	0.37	0.09	3.64	0.35	0.05	1.95	0.16	2.03	0.63
	s.d.	0.14	0.02	0.01	0.42	0.03	0.01	0.17	0.02	0.33	0.04
	min	2.08	0.35	0.05	3.00	0.29	0.04	1.61	0.12	1.56	0.58
	max	2.51	0.41	0.11	4.30	0.39	0.06	2.30	0.19	2.66	0.67
silver redhorse	mean	1.82	0.30	0.11	2.96	0.53	0.06	2.08	0.17	1.81	0.64
	s.d.	0.09	0.02	0.01	0.43	0.03	0.00	0.19	0.02	0.23	0.02
	min	1.61	0.26	0.10	2.18	0.48	0.05	1.90	0.14	1.22	0.59
	max	1.92	0.33	0.12	3.53	0.60	0.07	2.51	0.20	2.05	0.68
shorthead redhorse	mean	1.61	0.26	0.12	2.27	0.51	0.06	2.06	0.16	2.00	0.59
	s.d.	0.10	0.01	0.01	0.45	0.04	0.01	0.20	0.03	0.52	0.04
	min	1.48	0.25	0.11	1.24	0.44	0.05	1.84	0.14	1.24	0.53
	max	1.82	0.28	0.13	2.85	0.56	0.08	2.48	0.20	2.89	0.65
goldfish	mean	2.10	0.42	0.12	2.85	0.42	0.05	1.73	0.17	2.11	0.56
	s.d.	0.17	0.02	0.03	0.15	0.04	0.01	0.10	0.02	0.23	0.01
	min	1.72	0.40	0.10	2.63	0.37	0.03	1.56	0.14	1.86	0.54
	max	2.32	0.45	0.19	3.10	0.48	0.06	1.86	0.20	2.55	0.58
hornyhead chub	mean	1.61	0.26	0.19	1.97	0.55	0.05	1.89	0.18	1.79	0.64
	s.d.	0.18	0.02	0.03	0.20	0.05	0.01	0.13	0.02	0.26	0.09
	min	1.45	0.24	0.16	1.65	0.45	0.04	1.58	0.14	1.24	0.59
	max	1.99	0.30	0.27	2.34	0.63	0.07	2.12	0.22	2.34	0.90
channel catfish	mean	1.40	0.22	0.11	2.32	0.57	0.08	2.02	0.20	1.68	0.61
	s.d.	0.07	0.01	0.01	0.12	0.04	0.01	0.15	0.02	0.24	0.03
	min	1.32	0.21	0.10	2.09	0.50	0.05	1.83	0.16	1.33	0.56
	max	1.55	0.24	0.13	2.48	0.66	0.10	2.23	0.23	2.05	0.67

Table B   (Continued)

Species	Var.	CI	RD	RPL	IPC	IVF	RPA	PAR	RCA	CAR	EP
American eel	mean	1.25	0.06	0.00	0.00	0.58	0.02	1.39	0.01	0.61	0.59
	s.d.	0.04	0.01	-	-	0.08	0.00	0.13	0.00	0.19	0.07
	min	1.18	0.05	-	-	0.40	0.01	1.22	0.00	0.23	0.47
	max	1.33	0.07	-	-	0.70	0.02	1.61	0.01	0.87	0.67
fourspine stickleback	mean	2.01	0.22	0.17	1.32	0.52	0.05	1.60	0.11	0.56	0.65
	s.d.	0.18	0.01	0.03	0.20	0.05	0.01	0.19	0.03	0.14	0.08
	min	1.75	0.20	0.12	1.06	0.46	0.03	1.29	0.07	0.32	0.51
	max	2.33	0.23	0.19	1.64	0.63	0.07	1.92	0.16	0.82	0.78
white perch	mean	2.22	0.36	0.18	2.14	0.40	0.06	2.05	0.13	2.01	0.59
	s.d.	0.20	0.01	0.01	0.34	0.03	0.01	0.11	0.01	0.28	0.06
	min	1.86	0.34	0.16	1.34	0.38	0.04	1.83	0.11	1.57	0.47
	max	2.52	0.38	0.21	2.63	0.45	0.08	2.23	0.15	2.56	0.67
white bass	mean	2.36	0.33	0.13	2.87	0.47	0.05	1.92	0.18	1.52	0.74
	s.d.	0.19	0.01	0.02	0.22	0.04	0.01	0.15	0.02	0.20	0.05
	min	2.05	0.31	0.11	2.47	0.42	0.03	1.71	0.14	1.26	0.67
	max	2.69	0.34	0.16	3.24	0.52	0.07	2.16	0.21	1.90	0.82
green sunfish	mean	1.95	0.45	0.16	2.21	0.47	0.07	1.42	0.14	1.61	0.73
	s.d.	0.12	0.02	0.01	0.12	0.04	0.01	0.10	0.02	0.11	0.03
	min	1.71	0.43	0.15	2.02	0.41	0.06	1.29	0.12	1.44	0.70
	max	2.11	0.48	0.18	2.42	0.55	0.09	1.59	0.17	1.79	0.78
tessellated darter	mean	1.28	0.18	0.20	1.46	0.46	0.15	1.73	0.20	1.08	0.72
	s.d.	0.06	0.01	0.01	0.06	0.06	0.03	0.11	0.04	0.18	0.04
	min	1.18	0.16	0.18	1.36	0.35	0.09	1.60	0.14	0.72	0.62
	max	1.35	0.19	0.23	1.57	0.54	0.20	1.94	0.27	1.40	0.78
brook silverside	mean	1.40	0.14	0.14	1.56	0.68	0.08	1.58	0.19	1.46	0.59
	s.d.	0.13	0.01	0.02	0.28	0.05	0.03	0.57	0.04	0.24	0.05
	min	1.23	0.12	0.11	1.00	0.59	0.03	0.86	0.14	0.88	0.52
	max	1.60	0.15	0.18	2.09	0.75	0.12	2.38	0.29	1.71	0.69
freshwater drum	mean	2.69	0.34	0.07	3.09	0.32	0.07	2.19	0.17	0.98	0.56
	s.d.	0.35	0.03	0.01	0.36	0.03	0.01	0.32	0.02	0.16	0.07
	min	2.08	0.31	0.06	2.57	0.27	0.06	1.68	0.14	0.78	0.46
	max	3.40	0.43	0.08	3.57	0.36	0.08	2.75	0.20	1.26	0.70
slimy sculpin	mean	1.09	0.18	0.08	1.61	0.66	0.32	1.53	0.24	1.16	0.84
	s.d.	0.10	0.01	0.01	0.19	0.06	0.07	0.11	0.02	0.13	0.08
	min	0.86	0.16	0.06	1.27	0.52	0.22	1.36	0.21	0.99	0.72
	max	1.26	0.20	0.10	1.88	0.72	0.43	1.67	0.28	1.41	0.94

APPENDIX C

Table C   References for life history characteristics recorded in Table 2.

#	Reference
1.	Becker, 1983.
2.	Scott and Crossman, 1973
3.	Norden, 1967.
4a.	Bodola, 1966. In Scott and Crossman, 1973.
4b.	Bodola, 1966. In Becker, 1983.
5.	Richey, 1976.
6.	Daly, 1971.
7.	Saila et. al., 1987.
8.	Parker and Franzin, 1991.
9.	Meyer, 1962.
10.	Muus and Dahlstrom, 1971.
11.	Niemuth, 1970.
12.	Carlander, 1969.
13.	Craig and Fitzgerald, 1982.
14.	Robinson and Buchanan, 1984.
15.	Van Oosten, 1942.
16.	Priegel, 1967.
17a.	Trautman, 1957. In Scott and Crossman, 1973.
17b.	Trautman, 1957. In Becker, 1983.
18.	Priegel, 1971.
19.	Graham, 1956.
20.	Hubbs and Cooper, 1935.
21.	Haase, 1969.
22.	Threinen, 1958.
23.	Pritchard, 1940.
24.	MacKay, 1963.
25.	Rawson, 1951.
26.	Brown, 1957.
27.	Carter, 1940.
28.	Schwartz, 1965.
29.	Netch and Witt, 1962.
30.	Mills, 1989.
31.	Normandeau, 1969.
32.	Woodward and Wissing, 1976.
33.	Lachner, 1952.
34.	Riggs, 1955.
35.	Lutterbie, 1976.
36.	Daiber. 1953.
37.	Van Vliet, 1964.
38.	Breder and Rosen, 1966.
39.	Mansueti and Hardy, 1967.
40.	Avery, 1975.
41.	Rottiers, 1965.
42.	McPhail and Lindsey, 1970.
43.	Meyer, 1970.
44.	Naismith and Knights, 1990.
45.	Naismith and Knights, 1993.

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