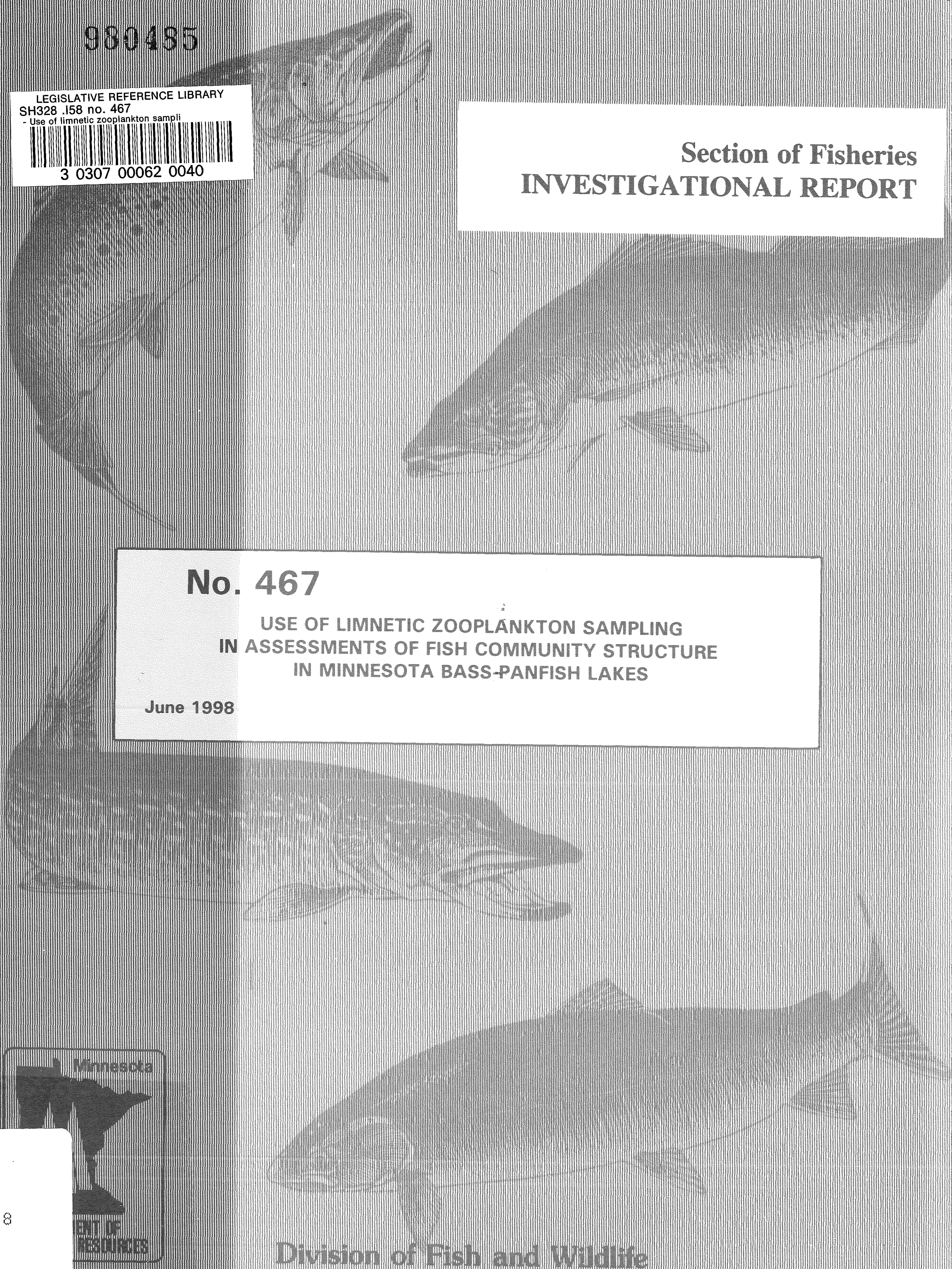

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USE OF LIMNETIC ZOOPLANKTON SAMPLING IN ASSESSMENTS OF FISH COMMUNITY STRUCTURE IN MINNESOTA BASS-PANFISH LAKES[1]

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Abstract.--Zooplankton and fish were sampled in 42 bass-panfish lakes over a two year period to determine if zooplankton sampling coupled with standard fish population assessments could be a useful fisheries management tool. Correlation analysis was used to identify relationships between zooplankton and fish community variables (density and mean size). We found no evidence to support several hypothesized relationships between fish (bluegill and northern pike) and zooplankton populations. Our findings generally were not consistent with theories of trophic dynamics in aquatic ecosystems. Lake-to-lake variability in fish abundance and size were not correlated with characteristics of the zooplankton community in predictable ways. In these lakes, system complexity and variability may have obscured direct trophic interactions involving individual fish species and zooplankton. In addition, the sampling strategies we used may not have been appropriate to detect such diffuse interactions. Zooplankton samples taken once or twice in a summer, combined with standard fish population assessments, were not useful in gaining insight about fish community structure or trophic dynamics in Minnesota's bass-panfish lakes.

Introduction

Linkages between predator and prey species in aquatic systems have been extensively studied, and the effects of organisms on one another at adjacent trophic levels are well documented. Zooplankton and planktivore abundance are known to be directly related to predator growth rates (Noble 1975; Galbraith 1975). Many studies have documented the effects of fish stocks on zooplankton community structure through size-selective and species-selective predation (Hrbacek et al. 1961; Brooks and Dodson 1965; Galbraith 1967; Hutchinson 1971; Mittlebach 1981; Post and McQueen 1987). These interactions cascade up and down through aquatic ecosystems, from top predators (piscivores) down to primary producers.

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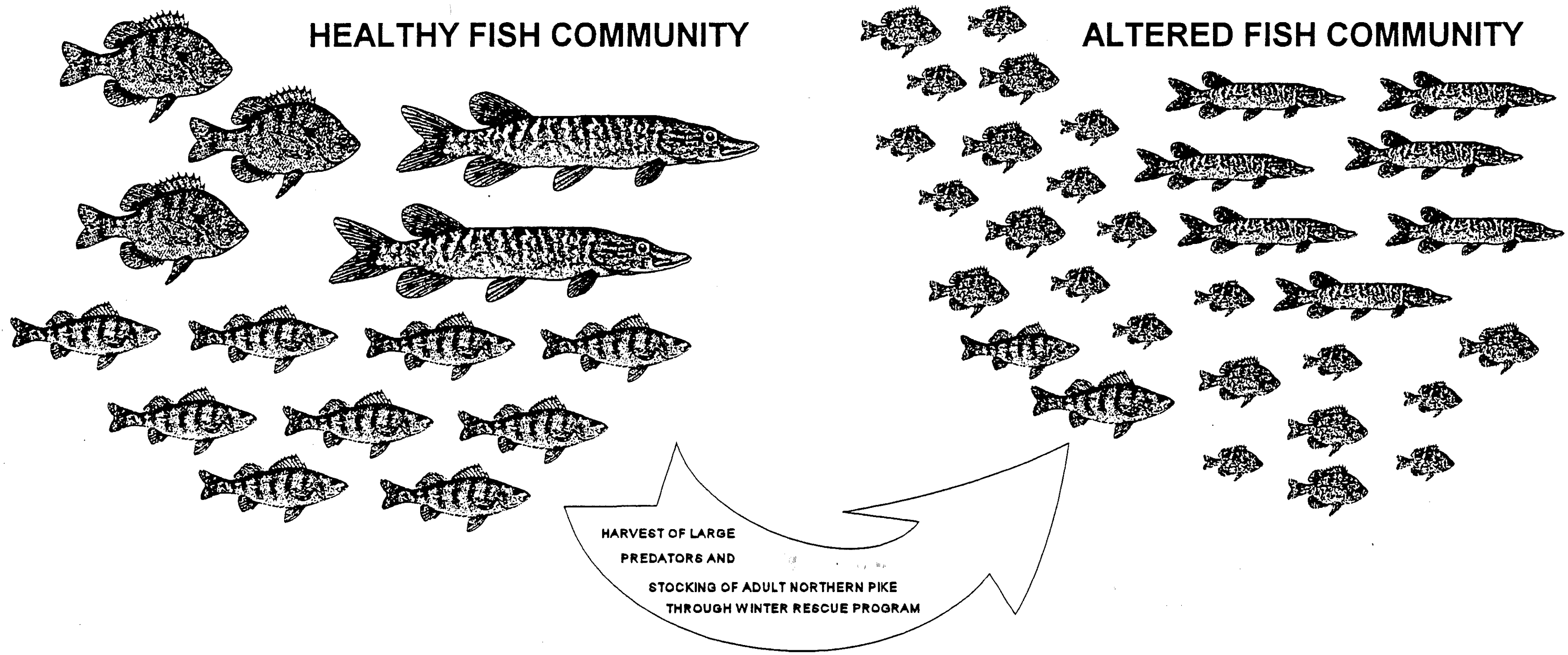
Relationships between fish and zooplankton assemblages may be of particular interest to fishery managers. Readily sampled zooplankton population variables (e.g. mean length) have been proven to be directly associated with fish community variables (e.g. predator:prey ratio, mean yellow perch length, bluegill growth; Mills and Schiavone 1982; Mills et al. 1987; Theiling 1990). Zooplankton assessments have been included as a standard part of lake assessments conducted by the New York Department of Environmental Conservation, and zooplankton data has influenced fisheries management decisions there (Ed Mills, Cornell University, personal communication 1993).

In Minnesota, there is a growing trend towards fisheries management on an individual waters basis. This magnifies the need for additional information about fish community status, especially with regards to trophic level and species interactions. Investigating trophic level interactions, such as with zooplankton, could aid in understanding the variability of fish communities in lakes with similar physical characteristics and fish species assemblages. For example, zooplankton data may aid in interpreting existing fish data such as abundance, year class strength, and growth rates. It could also be used as an additional criterion for comparing and classifying fish communities among lakes. Knowledge of changes in the zooplankton community is potentially valuable in interpreting changes in the fish community over time, or in evaluating changes in management practices such as experimental regulations, introductions of new species, stocking, or improvements to water quality or other fish habitat.

Previous studies (Mills and Schiavone 1982; Mills et al. 1987; Rodriguez et al. 1993) used a correlative approach to establish relationships between fish and zooplankton in a wide variety of lakes. For example, Mills et al. (1987) sampled fish and zooplankton in 35 lakes ranging from small ponds to two-story trout lakes. Because physiochemical, geographical, and morphometric characteristics of lakes affect species assemblages, size structures, and abundance of zooplankton and fish populations (Johnson et al. 1977; Pinel-Alloul et al. 1990), the fish-zooplankton associations observed in Mills' study may be direct relationships, or they could be an indirect result of the abiotic variability among study lakes.

The objective of our study was to identify associations between limnetic zooplankton community variables and fish community variables (as sampled by standard fish population assessment methods) in Minnesota bass-panfish lakes. The study was designed to test more directly for trophic level interactions between fish and zooplankton by limiting the study sites to lakes with similar limnological characteristics. This approach was intended to minimize the potential of observing indirect fish and zooplankton relationships that may be manifestations of abiotic differences in study lakes.

A long-term study of Horseshoe Lake, Minnesota (Anderson and Schupp 1986) and data from Minnesota Department of Natural Resources (DNR) lake surveys suggests that two types of fish communities exist in small bass-panfish lakes. A "healthy," or balanced fish community contains low densities of northern pike with large, abundant adult yellow perch, and low densities of fast growing bluegill. Ecological disturbance, such as stocking adult northern pike or removal of large northern pike by anglers, are associated with changing a "healthy" community to the altered state. In the altered community structure, small northern pike become abundant (large northern pike may control recruitment through cannibalism; Grimm 1983), yellow perch populations decline, and small bluegill increase in abundance (Figure 1). Although zooplankton were not sampled in Horseshoe Lake, other studies (Mills et al. 1987; Carpenter et al. 1985) suggest that zooplankton in a balanced fish community, where densities of planktivores are low, tend to be dominated by large individuals, especially cladocerans. In the altered community, we would expect zooplankton, especially cladoceran, size to be smaller due to the abundance of planktivores which have size selective feeding habits (O'Brien et al. 1976; Werner 1974). We hypothesized that correlation analysis would show differentiation of the two



THE HEALTHY FISH COMMUNITY:
- large northern pike
- abundant yellow perch
- low density, large, fast growing bluegill
- low planktivore density

ZOOPLANKTON:
- not impacted by heavy planktivory
- abundant large zooplankton, especially cladocerans

THE ALTERED FISH COMMUNITY:
- abundant small northern pike; large pike absent
- few yellow perch
- high density, slow growing bluegill
- high planktivore density

ZOOPLANKTON
- heavily impacted by planktivory
- large zooplankton uncommon

Figure 1. Simplified structures of the healthy and altered fish community states described by Anderson and Schupp (1986) from Horseshoe Lake, Minnesota, with hypothesized structures of zooplankton communities.

fish community types and their zooplankton communities. We expected the following relationships:

- Bluegill and northern pike density are negatively correlated with zooplankton size and density of large cladocerans (>1.0 mm).
- Bluegill and northern pike size are positively correlated with zooplankton size and density of large cladocerans (>1.0 mm).
- Bluegill growth is positively correlated with zooplankton size and density of large cladocerans (>1.0 mm)

Methods

Minnesota's lake classification system (Schupp 1992), which groups lakes based on physical and chemical characteristics, was used to select the study lakes. Study lakes were chosen from Lake Classes 28, 29, and 31. These are Minnesota's typical bass-panfish lakes, ranging in size from 20 to 350 hectares. Fish species assemblages are dominated by northern pike *Esox lucius*, yellow bullhead *Ameiurus natalis*, and bluegill *Lepomis macrochirus*, or by northern pike, bluegill, and black crappie *Poxomis nigromaculatus*. Largemouth bass *Micopterus salmoides* and yellow perch *Perca flavescens* are also present. Net catches of bluegill and northern pike in these lakes can vary greatly. Lakes were selected that most widely represented the range of fish community characteristics within the designated lake classes. Specific study lakes were selected from a list of lakes to be surveyed by fisheries management personnel in 1994 and 1995, with the criteria that they were not subject to winterkill and that the surveys used at least six trap nets and nine gill nets. After the study lakes were chosen, one lake was reclassified to Lake Class 27, and two were reclassified to Lake Class 24 (Table 1).

Standard fish sampling was conducted by Minnesota DNR fisheries management personnel according to the methods described in the Minnesota DNR lake survey manual. Fish were sampled with 76 m by 1.8 m experimental gill nets (mesh sizes 19, 25, 38, 60, 64 mm bar measure) and double frame (frame size 1.8 m by 0.9 m) trap nets (mesh size 19 mm bar measure) fished overnight. Length and weight data were collected from all species. Scale samples were taken from some species for age and growth analysis. Data from 42 population assessments conducted by Minnesota DNR fisheries management staff were used in this study.

Zooplankton samples were collected from 34 lakes in 1994 and 20 lakes in 1995. Sampling was conducted in June, August, or both (Table 1). Three or six replicate samples were collected during each sampling event, 20 to 50 meters apart, in the deepest portion of the lake. A 12 cm diameter Wisconsin style plankton net with 153 μm mesh was towed vertically from approximately 30 cm above the lake bottom to the surface at a speed of 0.5 meters per second. Samples were temporarily stored in 95% ethanol in Whirl-pak® bags, then transferred to 60 ml bottles and preserved with 85% ethanol for permanent storage. Temperature and dissolved oxygen profiles, and water chemistry data for most lakes were taken coincident with zooplankton sampling. A total of 471 zooplankton tows were made over 82 sampling events in 1994 and 1995. From these samples, over 18,000 individual zooplankton were identified and measured.

Zooplankton samples were processed using the following protocol. Sample volumes were adjusted to a known volume by filtering through 80 μm mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that would provide approximately 100 or more organisms per 5 ml aliquot. After thorough mixing, one 5 ml aliquot was withdrawn from each sample using a bulb pipet and transferred to a counting wheel. Specimens were counted and measured at 25 x magnification with the use of a dissecting microscope, a computerized image analysis system, and a zooplankton counting software package (Charpentier and Jamnik 1994). Individuals were identified with a compound microscope and grouped at various taxonomic levels (Table 2). Zooplankton lengths were measured in millimeters and densities were calculated as number per liter. Individual

Table 1. Lakes names, DOW numbers, and sampling dates utilized in the study.

Lake Name	Lake Class	DOW number	Lake survey date	Zooplankton sampling date			
				Early 94	Late 94	Early 95	Late 95
2nd Crow Wing	31	290085	7/18/94	June 07	Aug 19		
5th Crow Wing	31	290092	8/22/94		Aug 29		
Beaver	31	730023	7/05/94	June 06	Aug 02		
Big	24	710082	8/08/94	June 06			
Bowen	31	110350	6/15/94	June 07	Aug 17		
Carnelian	31	730038	8/01/94	June 06	Aug 02		
Cowdry	31	210103	7/25/94	June 07	Aug 10		
Donalds	31	560200	7/05/94	June 14			
East Leaf	31	560116	8/01/94	June 14	Aug 11		
Fladmark	28	560727	8/24/94	June 08	Aug 23		
George	27	290216	7/07/94	June 06	Aug 30		
Green Prairie	29	490035	7/18/94	June 07	Aug 16		
Hanging Kettle	31	010170	7/18/94	June 15	Aug 16		
Irene	31	210076	8/08/94	June 07	Aug 10		
Kings	31	730233	7/18/94	June 06			
Maud	31	030500	8/01/94	June 14	Aug 04		
May	31	110482	7/27/94	June 06	Aug 18		
Middle Leaf	31	560116	7/25/94		Aug 11		
Monson	31	030357	8/01/94	June 20	Aug 04		
Moses	31	210245	6/13/94		Aug 10		
Ox Yoke	31	110355	5/25/94	June 07	Aug 17		
Sieverson	28	030108	7/25/94	June 20	Aug 02		
10th Crow Wing	29	290045	6/19/95		Aug 19		Aug 16
Bass	24	860234	7/10/95			June 05	Aug 08
Beauty	31	770035	7/04/95			June 06	Aug 08
Big Bass	28	290032	6/05/95			June 15	Aug 16
Duck	31	290142	8/21/95			June 15	Aug 15
Gun	31	010099	8/21/95	June 15	Aug 17	June 20	Aug 09
Hungry	29	030166	6/12/95	June 14	Aug 11	June 07	Aug 21
Latimer	31	770105	8/21/95			June 06	Aug 08
Mill	29	770050	7/24/95			June 06	Aug 08
Murphy	31	560229	7/31/95	June 14	Aug 15	June 13	Aug 21
Nord	29	010117	6/27/95	June 15	Aug 16	June 20	Aug 09
North Browns	31	730147	6/26/95	June 06	Aug 03	June 06	Aug 08
Pleasant	31	730051	8/07/95	June 06	Aug 02	June 06	Aug 08
Portage	31	560140	8/14/95	June 15	Aug 24	June 13	Aug 22
Sauer	31	030355	6/19/95	June 14	Aug 04	June 12	Aug 23
Turtle	28	770088	8/07/95	June 07	Aug 16	June 06	Aug 08
Twenty One	28	560728	6/26/95	June 08	Aug 22		
Union	31	210041	7/17/95			June 05	Aug 08
Waukenabo	31	010136	8/07/95	June 15	Aug 17	June 20	Aug 09
Welsh	31	110493	8/28/95				Aug 15

Table 2. Combined groups of zooplankton taxa used in analysis.

	All	Adult	Daphnids	Cladocerans	Adult Copepods
Bosmina spp.	X	X		X	
Calanoids	X	X			X
Ceriodaphnia spp.	X	X		X	
Chydorus spp.	X	X		X	
Copepodites	X				
Cyclopoids	X	X			X
Daphnia ambigua	X	X	X	X	
Daphnia galeata mendotae	X	X	X	X	
Daphnia laevis	X	X	X	X	
Daphnia parvula	X	X	X	X	
Daphnia pulex	X	X	X	X	
Daphnia retrocurva	X	X	X	X	
Diaphanosoma spp	X	X		X	
Ergasilus spp.	X	X			
Holopedium gibberum.	X	X		X	
Leptodora kindti	X	X		X	
Nauplii	X				
Sida spp.	X	X		X	

zooplankton data from multiple samples taken on the same lake and day were pooled for the analysis. Initially, data were pooled after processing. However, later in the study, samples were pooled before processing.

Values for six water chemistry variables (pH, total alkalinity, total phosphorus, orthophosphate, chlorophyll a, and Secchi disk transparency) for each lake were computed by averaging all available data (0 to 6 values) from 1994 and 1995 (some lakes were not sampled for all water chemistry variables). Data sources included this study, Minnesota DNR fisheries lake surveys, and Minnesota Pollution Control Agency reports. Lake physical parameters (area, littoral area, maximum depth, and shoreline length) were taken from Minnesota DNR fisheries lake surveys. Water temperature at the depth where the oxygen concentration reached 3 parts per million was used as a measure of the amount of cool, oxygenated water available.

Correlation analysis (Wilkinson 1996) was used to evaluate relationships of 22 zooplankton variables with 29 fish variables and 12 lake physical and chemical variables. Statistical significance was accepted at $P<0.10$. To determine the appropriate level of significance for the number of comparisons, correlation matrices reported in Tables 4-7 were adjusted using the Bonferroni technique (Miller 1981). Fish catch per unit effort and zooplankton densities were log transformed to normalize the data. Zooplankton groupings were chosen based on known characteristics of certain groups (e.g. *Bosmina* spp. are commonly associated with eutrophic systems) and from observations of trends during processing (e.g. samples dominated by *Daphnia galeata mendotae* and *Daphnia retrocurva* had few or no *Daphnia pulex*, and vice versa).

Zooplankton variables were narrowed from an initial suite of 22 variables (Table 3) to 4 (adult zooplankton mean length, cladoceran

Table 3. Minimum, maximum, mean, standard deviation and sample size for all fish, zooplankton, and lake variables used in this study.

	EARLY (June 5-June 20)					LATE (August 2-August 30)				
	Minimum	Maximum	Mean	Standard deviation	Sample size	Minimum	Maximum	Mean	Standard deviation	Sample size
Bluegill per trap net lift	2.80	402.70	43.46	68.17	36	2.80	402.70	42.68	65.77	38
Northern pike per gill net lift	0.50	22.80	7.59	5.82	36	0.50	22.80	7.56	5.77	38
Yellow perch per gill net lift	0.00	185.70	24.02	34.36	36	0.00	185.70	23.91	34.29	38
Black crappie per trap net lift	0.00	14.00	2.41	3.63	36	0.00	14.00	1.74	2.94	38
Hybrid sunfish per trap net lift	0.00	17.00	2.65	4.30	36	0.00	17.00	2.54	4.28	38
Pumpkinseed per trap net lift	0.00	18.90	2.92	4.05	36	0.00	22.30	3.70	4.98	38
Largemouth bass per trap net lift	0.00	3.70	0.59	0.84	36	0.00	3.70	0.69	0.94	38
Walleye per gill net lift	0.00	16.00	4.04	4.25	36	0.00	16.00	4.21	4.22	38
White sucker per gill net lift	0.00	9.70	1.48	2.11	36	0.00	9.70	1.74	2.17	38
Black bullhead per gill net lift	0.00	84.00	5.58	17.45	36	0.00	84.00	4.64	16.76	38
Brown bullhead per gill net lift	0.00	7.70	1.12	1.87	36	0.00	7.70	1.03	1.84	38
Yellow bullhead per gill net lift	0.00	51.70	7.80	10.72	36	0.00	51.70	6.99	10.58	38
Bluegill mean weight (pounds)	0.01	0.26	0.15	0.07	36	0.01	0.26	0.15	0.06	38
Northern pike mean weight (pounds)	1.00	4.90	2.30	0.93	35	1.00	4.90	2.27	0.88	37
Yellow perch mean weight (pounds)	0.02	0.27	0.13	0.05	32	0.02	0.27	0.13	0.05	34
Black crappie mean weight (pounds)	0.10	0.90	0.32	0.19	33	0.10	0.90	0.34	0.20	32
Hybrid sunfish mean weight (pounds)	0.10	0.40	0.21	0.09	21	0.10	0.30	0.20	0.08	20
Pumpkinseed mean weight (pounds)	0.10	0.40	0.20	0.08	33	0.10	0.40	0.19	0.08	35
Largemouth bass mean weight (pounds)	0.10	1.80	0.54	0.49	29	0.10	1.80	0.57	0.48	32
Walleye mean weight (pounds)	0.30	5.30	2.24	1.19	34	0.30	5.30	2.12	1.18	36
White sucker mean weight (pounds)	0.30	3.50	1.95	0.88	29	0.30	3.50	1.92	0.78	30
Black bullhead mean weight (pounds)	0.40	1.90	1.01	0.47	19	0.10	1.90	0.93	0.49	19
Brown bullhead mean weight (pounds)	0.50	1.60	1.01	0.35	23	0.50	1.60	1.02	0.36	24
Yellow bullhead mean weight (pounds)	0.10	1.30	0.70	0.29	29	0.10	3.80	0.83	0.62	31
Bluegill RSD-7	0.40	56.50	18.68	16.67	36	0.40	56.50	18.60	16.27	38
Bluegill RSD-8	0.00	30.30	2.71	5.37	36	0.00	30.30	2.79	5.26	38
Bluegill length at age 6	115	199	161	21	33	115	199	159	20	36
Yellow perch length at age 4	140	190	158	14	13	140	190	157	14	14
Black crappie length at age 4	182	230	204	14	11	182	252	211	20	12
Lake area (ha)	55	798	273	183	36	55	822	294	201	38
Littoral area (ha)	34	453	133	93	36	34	453	145	100	38

Table 3. Continued.

	EARLY (June 5-June 20)					LATE (August 2-August 30)				
	Minimum	Maximum	Mean	Standard deviation	Sample size	Minimum	Maximum	Mean	Standard deviation	Sample size
Maximum depth (feet)	18	60	38	11	36	18	60	38	11	38
Shoreline length (miles)	1.10	7.18	3.08	1.33	29	1.10	7.18	3.14	1.29	32
Temperature at 3 ppm of oxygen (^{0}F)	48.20	74.40	65.97	13.71	31	48.20	74.40	63.83	17.80	32
Average pH	7.21	8.90	8.42	0.33	31	7.21	8.90	8.39	0.31	32
Average total alkalinity (mg/l)	19.20	219.25	143.89	48.60	32	19.20	232.00	146.21	48.76	34
Average total suspended solids (mg/l)	0.90	5.52	3.35	1.17	26	0.90	5.52	3.30	1.14	28
Average total phosphorus (µg/l)	6.00	143.00	29.39	24.03	31	6.00	143.00	28.89	23.55	33
Average orthophosphate (µg/l)	9.00	67.50	24.19	15.14	18	9.00	67.50	23.57	14.46	20
Average chlorophyll a (µg/l)	0.50	20.10	9.33	4.99	31	0.50	20.10	9.53	4.94	33
Average Secchi transparency (feet)	3.50	27.02	9.74	5.10	36	3.50	27.02	9.75	5.00	38
All zooplankton mean length (mm)	0.51	1.24	0.84	0.18	36	0.35	1.27	0.69	0.19	38
Adult zooplankton mean length (mm)	0.54	1.25	0.88	0.19	36	0.35	1.29	0.73	0.21	38
Cladoceran mean length (mm)	0.44	1.46	0.97	0.25	35	0.31	1.46	0.71	0.28	38
Bosmina spp. mean length (mm)	0.27	0.44	0.35	0.04	28	0.23	0.52	0.32	0.06	28
Daphnia spp. mean length (mm)	0.57	1.52	1.04	0.21	35	0.58	1.98	0.95	0.27	34
D. galeata and *D. retrocurva* mean length (mm)	0.57	1.43	0.98	0.17	32	0.58	1.90	0.94	0.24	34
D. pulex mean length (mm)	0.53	2.33	1.32	0.38	21	0.49	1.98	1.24	0.55	9
Copepod mean length (mm)	0.60	0.93	0.72	0.09	36	0.44	1.00	0.74	0.14	38
Cyclopoid mean length (mm)	0.47	0.88	0.64	0.08	36	0.44	0.96	0.65	0.12	38
Calanoid mean length (mm)	0.64	1.20	0.92	0.15	34	0.69	1.16	0.95	0.13	38
All zooplankton density (number/liter)	4.17	265.09	57.56	51.97	36	5.04	196.89	30.59	35.96	38
Adult zooplankton density (number/liter)	3.00	247.54	53.29	49.18	36	4.65	185.74	27.99	34.67	38
Cladoceran density (number/liter)	0.00	102.18	27.65	22.02	36	1.63	120.73	15.52	24.97	38
Bosmina spp. density (number/liter)	0.00	71.14	3.77	12.02	36	0.00	81.11	2.87	13.09	38
Daphnia spp. density (number/liter)	0.00	100.86	23.02	18.46	36	0.00	39.31	6.04	8.19	38
D. galeata and *D. retrocurva* density (num-	0.00	100.86	17.94	18.99	36	0.00	39.31	5.59	8.12	38
D. pulex density (number/liter)	0.00	33.92	4.44	8.20	36	0.00	2.92	0.25	0.69	38
Copepod density (number/liter)	2.11	154.96	25.64	31.60	36	1.69	65.01	12.47	11.61	38
Calanoid density (number/liter)	0.00	69.63	7.67	13.41	36	0.24	16.78	3.32	3.43	38
Cyclopoid density (number/liter)	1.62	146.19	17.97	26.56	36	0.92	64.39	9.12	11.32	38
Large zooplankton (>1mm) density (number/liter)	0.00	60.65	13.35	11.59	36	0.00	18.91	4.08	4.40	38
Large cladoceran (>1mm) density (number/liter)	0.00	54.71	11.29	10.76	36	0.00	16.12	2.49	3.87	38

Table 4. Pearson correlation coefficients (r) between fish net catch rate and zooplankton variables, for early (June 5-June 20) and late (August 2-August 30) summer samples taken in 1994 and 1995. Zooplankton density values and fish catch rates were log (ln+1) transformed. The number of lakes included in each correlation is shown in parentheses. Initial significant correlations are shown in bold (alpha=0.10). There were no significant correlations after Bonferroni adjustment for 96 comparisons (*P*<0.001).

	Adult zooplankton mean length		Cladoceran mean length		Adult zooplankton density		Large cladoceran density	
	Early (36)	Late (38)	Early (35)	Late (38)	Early (36)	Late (38)	Early (36)	Late (38)
Bluegill per trap net lift	0.053	**0.304**	0.073	**0.311**	-0.022	-0.061	0.102	0.127
Northern pike per gill net lift	**0.282**	-0.014	**0.301**	-0.072	-0.188	-0.201	0.275	-0.198
Yellow perch per gill net lift	-0.069	-0.013	-0.076	-0.005	0.183	0.100	0.062	0.151
Black crappie per trap net lift	0.049	-0.183	0.084	-0.185	0.117	0.246	0.135	-0.139
Hybrid sunfish per trap net lift	**0.279**	0.217	**0.317**	0.269	-0.070	**-0.345**	0.209	-0.113
Pumpkinseed per trap net lift	-0.257	0.085	**-0.357**	0.047	0.141	0.059	-0.060	0.127
Largemouth bass per trap net lift	0.021	0.213	0.110	0.228	0.013	-0.266	0.048	0.142
Walleye per gill net lift	-0.180	-0.170	-0.190	-0.108	0.205	-0.042	-0.109	0.057
White sucker per gill net lift	**-0.280**	-0.076	**-0.312**	-0.036	**0.373**	-0.053	-0.172	0.091
Black bullhead per gill net lift	0.203	-0.155	0.165	-0.118	0.069	**0.443**	**0.288**	0.001
Brown bullhead per gill net lift	-0.049	**-0.337**	-0.175	**-0.382**	**0.327**	0.230	0.239	**-0.340**
Yellow bullhead per gill net lift	0.165	**0.298**	0.162	0.242	**-0.328**	0.020	-0.050	0.223

Table 5. Pearson correlation coefficients (r) between fish weight and zooplankton variables, for early (June 5-June 20) and late (August 2-August 30) summer samples taken in 1994 and 1995. Zooplankton density values were log (ln+1) transformed. The number of lakes included in each correlation is shown in parentheses. Initial significant correlations are shown in bold (alpha=0.10). There were no significant correlations after Bonferroni adjustment for 96 comparisons (P<0.001).

	Adult zooplankton mean length		Cladoceran mean length		Adult zooplankton density		Large cladoceran density	
	Early	Late	Early	Late	Early	Late	Early	Late
Bluegill mean weight	0.106 (36)	-0.152 (38)	0.196 (35)	-0.052 (38)	0.199 (36)	-0.005 (38)	0.251 (36)	-0.048 (38)
Northern pike mean weight	**-0.338** (35)	0.112 (37)	**-0.296** (34)	0.212 (37)	0.085 (35)	-0.019 (37)	**-0.395** (35)	0.085 (37)
Yellow perch mean weight	-0.107 (32)	-0.236 (34)	-0.199 (32)	-0.127 (34)	**0.424** (32)	**0.343** (34)	0.148 (32)	-0.111 (34)
Black crappie mean weight	-0.254 (33)	-0.001 (32)	-0.229 (33)	0.033 (32)	0.259 (33)	-0.100 (32)	-0.080 (33)	0.033 (32)
Hybrid sunfish mean weight	0.107 (21)	-0.217 (20)	0.194 (21)	-0.210 (20)	0.352 (21)	-0.249 (20)	0.483 (21)	-0.317 (20)
Pumpkinseed mean weight	-0.053 (33)	-0.009 (35)	0.038 (32)	0.082 (35)	0.287 (33)	-0.067 (35)	0.252 (33)	0.010 (35)
Largemouth bass mean weight	-0.067 (29)	-0.080 (32)	-0.147 (29)	-0.100 (32)	**-0.366** (29)	0.031 (32)	-0.464 (29)	-0.026 (32)
Walleye mean weight	-0.110 (34)	0.230 (36)	-0.078 (33)	0.105 (36)	-0.147 (34)	-0.177 (36)	-0.094 (34)	0.092 (36)
White sucker mean weight	0.128 (29)	0.116 (30)	0.136 (29)	0.099 (30)	-0.160 (29)	0.068 (30)	0.056 (29)	0.165 (30)
Black bullhead mean weight	0.080 (19)	**0.453** (19)	0.355 (18)	**0.533** (19)	**-0.429** (19)	-0.222 (19)	-0.159 (19)	0.298 (19)
Brown bullhead mean weight	0.019 (23)	0.224 (24)	-0.054 (22)	0.231 (24)	-0.269 (23)	-0.230 (24)	**-0.364** (23)	0.051 (24)
Yellow bullhead mean weight	**-0.374** (29)	-0.242 (31)	-0.300 (28)	-0.186 (31)	**0.353** (29)	-0.064 (31)	0.054 (29)	-0.186 (31)

Table 6. Pearson correlation coefficients (r) between bluegill size structure and fish age and zooplankton variables, for early (June 5-June 20) and late (August 2-August 30) summer samples taken in 1994 and 1995. Zooplankton density values were (ln+1) transformed. The number of lakes included in each correlation is shown in parentheses. Initial significant correlations are shown in bold (alpha=0.10). There were no significant correlations after Bonferroni adjustment for 40 comparisons (*P*<0.0025).

	Adult zooplankton mean length		Cladoceran mean length		Adult zooplankton density		Large cladoceran density	
	Early	Late	Early	Late	Early	Late	Early	Late
Bluegill RSD-7	0.174 (36)	-0.255 (38)	0.217 (35)	-0.201 (38)	0.163 (36)	0.051 (38)	0.256 (36)	-0.198 (38)
Bluegill RSD-8	0.270 (36)	-0.239 (38)	**0.323** (35)	-0.211 (38)	-0.230 (36)	-0.137 (38)	-0.001 (36)	-0.201 (38)
Northern pike:yellow perch gillnet catch rate	0.282 (33)	-0.068 (35)	0.193 (33)	-0.176 (35)	-0.136 (33)	-0.103 (35)	0.178 (33)	-0.121 (35)
Bluegill length at age 6	-0.002 (33)	-0.193 (36)	0.032 (32)	-0.176 (36)	0.004 (33)	0.120 (36)	-0.035 (33)	-0.091 (36)
Yellow perch length at age 4	0.243 (13)	0.374 (14)	0.358 (13)	0.356 (14)	-0.297 (13)	-0.259 (14)	0.028 (13)	0.318 (14)
Black crappie length at age 4	0.411 (11)	-0.220 (12)	0.254 (11)	-0.117 (12)	-0.135 (11)	-0.071 (12)	0.098 (11)	-0.185 (12)

Table 7. Pearson correlation coefficients (r) between lake physiochemical and zooplankton variables, for early (June 5-June 20) and late (August 2-August 30) summer samples taken in 1994 and 1995. Water chemistry averages for individual lakes were computed from 0 to 6 values collected over two summers (1994-1995). Zooplankton density values were log (ln+1) transformed. The number of lakes included in each correlation is shown in parentheses. Initial significant correlations are shown in bold (alpha=0.10). Significant correlations after Bonferroni adjustment for 96 comparisons (P<0.001) are shown with an asterisk.

	Adult zooplankton mean length		Cladoceran mean length		Adult zooplankton density		Large cladoceran density	
	Early	Late	Early	Late	Early	Late	Early	Late
Lake area	0.097 (36)	**-0.300** (38)	-0.010 (35)	**-0.306** (38)	0.012 (36)	0.129 (38)	-0.019 (36)	-0.024 (38)
Littoral area	0.069 (36)	-0.258 (38)	-0.036 (35)	-0.248 (38)	0.105 (36)	0.190 (38)	0.072 (36)	0.049 (38)
Maximum depth	0.142 (36)	0.129 (38)	**0.311** (35)	0.071 (38)	-0.193 (36)	***-0.533** (38)	0.112 (36)	-0.138 (38)
Shoreline length	0.248 (29)	**-0.301** (32)	0.172 (28)	**-0.333** (32)	-0.116 (29)	-0.069 (32)	0.107 (29)	-0.151 (32)
Temperature at 3 ppm of oxygen	**-0.358** (31)	-0.184 (32)	-0.411 (30)	-0.272 (32)	0.165 (31)	**0.467** (32)	-0.119 (31)	0.032 (32)
Average pH	0.035 (31)	-0.066 (32)	0.102 (30)	-0.040 (32)	0.179 (31)	0.232 (32)	0.249 (31)	0.070 (32)
Average total alkalinity	0.165 (32)	-0.022 (34)	0.222 (31)	0.017 (34)	-0.069 (32)	-0.070 (34)	0.168 (32)	0.054 (34)
Average total suspended solids	0.013 (26)	**-0.432** (28)	-0.102 (25)	**-0.379** (28)	**0.356** (26)	**0.483** (28)	0.171 (26)	-0.092 (28)
Average total phosphorus	0.125 (31)	0.013 (33)	0.179 (30)	-0.018 (33)	0.062 (31)	0.061 (33)	0.221 (31)	-0.061 (33)
Average orthophosphate	0.222 (18)	-0.031 (20)	0.236 (17)	-0.136 (20)	-0.076 (18)	-0.003 (20)	0.116 (18)	-0.069 (20)
Average chlorophyll a	-0.035 (31)	**-0.438** (33)	-0.169 (30)	**-0.451** (33)	0.276 (31)	0.273 (33)	0.108 (31)	-0.107 (33)
Average Secchi transparency	0.201 (36)	**0.377** (38)	**0.353** (35)	**0.371** (38)	-0.249 (36)	**-0.383** (38)	0.071 (36)	0.016 (38)

mean length, adult zooplankton density, and large cladoceran density) for presentation of results. These four were the simplest and most directly related to previous studies which focused on the interactions between fish and cladocerans. Furthermore, analysis of zooplankton groups at greater resolution did not show any new or different trends. Correlation coefficients for all zooplankton groups with fish and lake characteristics are presented in the Appendix.

Results

We found no statistical evidence to support our hypothesized relationships between fish and zooplankton in bass-panfish lakes. Numbers of bluegill per trap net and northern pike per gill net were positively correlated with zooplankton mean length, which was opposite of what we expected (Table 4). Neither were correlated with adult zooplankton density or large cladoceran density. Mean weight of bluegill also was not correlated with zooplankton variables (Table 5). Northern pike mean weight was negatively correlated with zooplankton mean length and large cladoceran density, which was again opposite of our hypothesis. There were no correlations between indices of fish growth (length at age for bluegill, yellow perch, or black crappie) and zooplankton variables (Table 6).

Of the correlations that were significant, we did not find them useful in defining plausible, broad based fish-zooplankton relationships. Only two correlations were significant in both the early and the late sampling periods: yellow perch mean weight and adult zooplankton density (early: $r=0.424$; late: $r=0.343$; Table 5); and average Secchi disk transparency and cladoceran mean length (early: $r=0.353$; late: $r=0.371$; Table 7). The strongest significant correlation between a fish variable and a zooplankton variable was between black bullhead mean weight and cladoceran mean length (late: $r=0.533$; Table 5). After Bonferroni adjustment of correlation matrices, only one correlation was significant (adult zooplankton density and lake maximum depth, late: $r=-0.533$, $P<0.001$; Table 7).

Other types of analyses yielded few significant relationships, and showed no meaningful patterns in the data. Based on the work of Mills et al. (1987), who reported that the predator to panfish ratio was positively correlated with zooplankton size, we correlated the ratio of northern pike:yellow perch gillnet catch rates and biomass with zooplankton mean length and found no significant relationships with the four major zooplankton variables (Table 6). Ranges of fish lengths and relative stock densities appropriate for each fish species were used to determine if a fish population's size structure was related to zooplankton density or mean length. No meaningful patterns were detected from this analysis (correlation coefficients for bluegill are in Table 6). Measures of species richness were also analyzed, and showed no relationships between the number of zooplankton taxa present and the number of fish species (limited to the 12 species we used) present (early: $r=0.164$, $P=0.340$, $N=36$; late: $r=0.092$, $P=0.583$, $N=38$). Changes in zooplankton mean length and density from early to late samples were correlated with very few of the fish variables.

Cisco *Coregonus artedii* are important planktivores and are known to be present in 14 of the study lakes. Because standard lake surveys are ineffective at sampling this pelagic species, they were not included in our correlation analysis. T-tests were used to determine if zooplankton populations differed in the two categories (presence or absence of cisco) of lakes. No significant differences between mean values of zooplankton mean length and mean density for cisco lakes vs. non-cisco lakes were detected ($P>0.05$ for all tests).

There were several significant and potentially meaningful relationships between zooplankton and lake physiochemical variables (Table 7). Although we did not hypothesize about zooplankton-lake relationships, we did this analysis for its potential of defining mechanistic forces in fish-zooplankton relationships, and observing trophic cascades down to the primary producer level. However, the absence of fish-zooplankton relationships obscures the usefulness of this data in terms of our project objectives.

Discussion

Very few of the expected relationships were observed in this data set, and some relatively strong relationships emerged which were unexpected and difficult to explain, such as the strong correlations between black bullhead mean weight and zooplankton density and mean length (Table 5). The pattern of statistically significant correlations appeared to be random. Significant values occurred for both early and late comparisons only twice. There are essentially two explanations for our results: 1) no direct relationships exist between zooplankton variables and individual fish species in our study lakes; and 2) direct relationships exist, but we failed to measure them. Several factors make either, or a combination of both explanations viable. The lakes included in our study are complex, speciose aquatic systems, with 41 fish species in all lakes combined. Habitat complexity is also high, with diverse aquatic plant communities present in these lakes. In these types of lakes, direct trophic relationships are less likely to be present (Strong 1992). If they are indeed present, different sample sizes, gear types, sample times, and analyses may be necessary to detect them.

The notion that species assemblages affect those at adjacent trophic levels is a long standing ecological concept. Theories of trophic cascades, top-down, and bottom-up forces argue that effects extend beyond adjacent trophic levels, and that changes in production at a given level will result in fluctuations throughout the system (Carpenter et al. 1985; McQueen et al. 1986). However, in speciose systems, trophic interactions are buffered by system complexity and true trophic cascades are not possible (Strong 1992). Direct effects from one trophic level to another (e.g. reduction in densities of large cladocerans due to high densities of bluegill) are less likely to occur when the food chain is more like a web (complex, speciose systems) than a ladder (few species and well defined trophic levels). In complex systems, species are more apt to exhibit omnivory, resource generalization, ontogenetic shifts in food habits, and facultative (as opposed to obligate) feeding. These feeding "behaviors" decrease a predator's direct effect on a single prey type. Spatial and temporal heterogeneity add to the complexity of these systems. Discrete habitats lessen the effects of predation through predator avoidance, and time lags mask the influence of predation over the long term. Strong (1992) suggests that "trophic trickles" are a more appropriate metaphor for more diverse aquatic systems.

Much of the evidence for trophic interactions in freshwater lakes is from work in very simple systems. Empirical evidence is largely gathered from northern oligotrophic lakes containing one to four fish species, usually salmonids (Hutchinson 1971; Nilsson and Pejler 1973; Northcote and Clarotto 1973; Rodriquez et al. 1993). Observable trophic interactions occur in these systems because they are swayed by a single or few "keystone" predator (piscivore) species and a simple assemblage of zooplankton (herbivores), often dominated by one or two species. Furthermore, evidence for top-down control of production at lower trophic levels is stronger for oligotrophic lakes (McQueen et al. 1986).

Manipulations of freshwater aquatic systems have also provided evidence of fish affecting zooplankton assemblages. Pond or enclosure experiments, in which only a few fish species were present (Hambright 1994; Post and McQueen 1987), or whole lake studies, in which plankton communities and water chemistry were compared before and after an episodic fish kill (Hrbacek et al. 1961; Shapiro and Wright 1984; Hanson and Butler 1994; Vanni et al. 1990), show significant trophic interactions between two or more levels. However, these experiments were not representative of typical aquatic systems, they did not account for the variability between individual bodies of water, and they controlled for all other factors by using a small number of fish species or a single body of water. While these studies made valuable contributions to knowledge of trophic cascades under various circumstances, they had little predictive power in large numbers of complex aquatic systems.

The detailed study of Horseshoe Lake by Anderson and Schupp (1986) documented changes in the fish community over time and provided explanations for those changes based primarily on predator-prey interactions. In the current study, we hoped to identify Anderson and Schupp's healthy and altered community types, and assumed that the expected fish-zooplankton relationships would follow. However, we failed to identify discrete community types through correlations of bluegill, northern pike, and yellow perch abundance and size. Furthermore, the two fish community types may have similar impacts on zooplankton communities. If adult yellow perch are size selective planktivores in these systems, the result could be small zooplankton, contrary to our hypothesis that zooplankton in the "healthy" fish community are large. Reductions in zooplankton size may result from yellow perch in a balanced community, or from high densities of small bluegill in an unbalanced community. However, results of this study did not clearly identify the role of either fish species in shaping zooplankton communities.

Our ability to identify discrete fish community types may have been limited by sample sizes. Our study included only one year of fish sampling data for 42 lakes, whereas Anderson and Schupp sampled fish in one lake 12 times in 14 years. They caution against the use of a single sample for fish management decisions: "A single survey of a fish community is a reflection of the community structure at the present time. Trend through time data developed from periodic surveys is needed to infer cause and effect relationships." The number of lakes in the study or the sampling frequency of zooplankton or fish may have been inadequate to detect overall trends in fish and zooplankton communities.

Regardless of sample size, standard gill and trap net assessments alone may not be adequate for this type of study. These gears do not effectively sample some important zooplankton consumers such as young yellow perch, young bluegill, large bluegill, black crappie, and cisco. For example, young of the year yellow perch can have profound effects on abundance and seasonal variation in zooplankton communities (Mills and Forney 1983; Mills et al. 1987). The absence of these important planktivores in our sampling may have played a substantial role in our inability to describe fish-zooplankton relationships.

Other factors, such as zooplankton distributions and invertebrate predation, may have affected our findings. Zooplankton populations generally do not display a random or homogenous distribution throughout a lake, but rather have a heterogenous or "patchy" distribution both vertically and horizontally (Tessier 1993). Zooplankton communities may also differ substantially between a lake's littoral and limnetic zones, and young fish that we did not sample could have been the most important consumers of zooplankton in the limnetic zone. Invertebrate predation can also have an impact on the overall zooplankton community structure. This predation may be opposite of that imposed by planktivorous fish because invertebrates generally select for smaller bodied zooplankton (Vanni 1988; Hall et al. 1976). The phantom midge larvae (*Chaoborus* spp.) may be an important invertebrate predator in these study lakes. *Chaoborus* were present in some of the zooplankton samples, but were not enumerated because sampling methods did not allow for representative samples of *Chaoborus*. Zooplankton tows were conducted during daylight hours, and the species of *Chaoborus* present in the study lakes tend to be benthic during the day and vertically migrate into the water column only at night.

Our work was largely based upon previous studies by Mills and Schiavone (1982) and Mills et al. (1987), which showed that measures of zooplankton populations could be useful tools for fish managers. By collecting the same type of data, we aimed to define similar relationships between zooplankton and fish in centrarchid lakes, and to add zooplankton sampling as a management tool in Minnesota. However, we failed to do so. The major difference in these studies was that we attempted to minimize variation in lake type, while Mills and his associates studied a range of lakes. The wide range of lake types studied by Mills may have been the driving force behind the fish-zooplankton relationships he described. In other words, differences in zooplankton and fish community characteristics could be due to physical, chemical, morphometric, or geographic differences among lakes rather than trophic interactions between communities.

Our failure to find supporting evidence for our hypotheses may be a result of some combination of the factors listed above. In the future, more complex analysis and increased sampling may better describe the relationships that link planktivorous fishes as a group to zooplankton, and these relationships may occur in a dynamic and changing fashion. The "snapshot" approach of a single zooplankton sample paired with a standard fish assessment did not provide the level of detail required to understand and make predictions about these complex aquatic communities. Increased sampling would have to consist of measuring zooplankton and fish communities through time (at least several years). However, the objective of this study was to provide fish managers with a basis for a simple tool that could give them more information about the trophic dynamics in a given lake. This study does not indicate that a "snapshot" approach to zooplankton sampling can serve as a management tool for Minnesota's bass-panfish lakes.

Summary and Management Recommendations

Sampling zooplankton with a single sample as part of the current standard lake survey protocol in Minnesota's bass-panfish lakes would not be an effective fisheries management tool. These fish communities may be too complex, or our standard survey methods insufficient for single zooplankton measurements to provide meaningful insights into fish-zooplankton trophic interactions. It is possible that zooplankton sampling may be useful in other lake types, such as trout lakes or in long-term monitoring studies.

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Appendix Table 1. Pearson correlation coefficients (r) between fish and lake variables and additional zooplankton variables, for early (June 5-June 20) and late (August 2-August 23) summer samples taken in 1994 and 1995. Fish catch rates and zooplankton density values were log (ln+1) transformed. Water chemistry averages for individual lakes were computed from values collected over two summers (1994-1995). The number of lakes included in each correlation is shown in parentheses. Significant correlations are shown in bold (Bonferroni adjustments were not made).

	All zooplankton mean length		Adult zooplankton mean length		Cladoceran mean length		*Bosmina* spp. mean length		*Daphnia* spp. mean length		*D. galeata* and *D. retrocurva* mean length		*D. pulex* mean length	
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
Bluegill per trap net lift	0.094 (36)	**0.309** (38)	0.053 (36)	**0.304** (38)	0.073 (35)	**0.311** (38)	0.049 (28)	0.300 (28)	-0.028 (35)	0.152 (34)	0.209 (32)	0.171 (34)	-0.174 (21)	**-0.949** (9)
Northern pike per gill net lift	0.222 (36)	0.006 (38)	**0.282** (36)	-0.014 (38)	**0.301** (35)	0.072 (38)	0.146 (28)	0.006 (28)	**0.354** (35)	0.212 (34)	**0.458** (32)	0.155 (34)	0.173 (21)	**0.680** (9)
Yellow perch per gill net lift	-0.123 (36)	-0.069 (38)	-0.069 (36)	-0.013 (38)	-0.076 (35)	-0.005 (38)	0.068 (28)	0.220 (28)	-0.052 (35)	0.156 (34)	-0.033 (32)	0.249 (34)	-0.101 (21)	-0.005 (9)
Black crappie per trap net lift	0.011 (36)	-0.151 (38)	0.049 (36)	-0.183 (38)	0.084 (35)	-0.185 (38)	0.175 (28)	-0.272 (28)	0.173 (35)	.0148 (34)	-0.023 (32)	0.167 (34)	0.355 (21)	0.559 (9)
Hybrid sunfish per trap net lift	0.277 (36)	0.213 (38)	**0.279** (36)	0.217 (38)	0.317 (35)	0.269 (38)	-0.116 (28)	0.011 (28)	0.229 (35)	.0272 (34)	**0.424** (32)	**0.300** (34)	-0.100 (21)	-0.492 (9)
Pumpkinseed per trap net lift	-0.242 (36)	0.086 (38)	-0.257 (36)	0.085 (38)	**-0.357** (35)	0.047 (38)	0.210 (28)	0.124 (28)	-0.245 (35)	-0.110 (34)	-0.035 (32)	-0.120 (34)	0.137 (21)	0.275 (9)
Largemouth bass per trap net lift	0.058 (36)	0.198 (38)	0.021 (36)	0.213 (38)	0.110 (35)	0.228 (38)	**-0.488** (28)	**0.453** (28)	0.020 (35)	0.003 (34)	0.193 (32)	0.049 (34)	-0.290 (21)	-0.381 (9)
Walleye per gill net lift	-0.181 (36)	-0.191 (38)	-0.180 (36)	-0.170 (38)	-0.190 (35)	-0.108 (38)	-0.284 (28)	0.284 (28)	**-0.311** (35)	-0.255 (34)	-0.106 (32)	-0.212 (34)	-0.236 (21)	-0.571 (9)
White sucker per gill net lift	-0.226 (36)	-0.096 (38)	**-0.280** (36)	-0.076 (38)	**-0.312** (35)	-0.036 (38)	-0.243 (28)	0.225 (28)	**-0.360** (35)	0.022 (34)	**-0.435** (32)	0.055 (34)	-0.294 (21)	-0.074 (9)
Black bullhead per gill net lift	0.145 (36)	-0.150 (38)	0.203 (36)	-0.155 (38)	0.165 (35)	-0.118 (38)	0.099 (28)	-0.080 (28)	0.134 (35)	-0.017 (34)	0.172 (32)	-0.012 (34)	-0.154 (21)	0.535 (9)
Brown bullhead per gill net lift	-0.038 (36)	**-0.309** (38)	-0.049 (36)	**-0.337** (38)	-0.175 (35)	**-0.382** (38)	0.275 (28)	-0.132 (28)	0.130 (35)	**-0.287** (34)	0.000 (32)	**-0.288** (34)	0.229 (21)	-0.134 (9)
Yellow bullhead per gill net lift	0.217 (36)	**0.316** (38)	0.165 (36)	**0.298** (38)	0.162 (35)	0.242 (38)	-0.029 (28)	0.143 (28)	0.136 (35)	0.025 (34)	0.257 (32)	-0.009 (34)	0.064 (21)	0.000 (9)
Bluegill mean weight	0.120 (36)	-0.172 (38)	0.106 (36)	-0.152 (38)	0.196 (35)	-0.052 (38)	-0.113 (28)	0.032 (28)	**0.316** (35)	0.020 (34)	**0.337** (32)	0.037 (34)	0.326 (21)	-0.007 (9)
Northern pike mean weight	**-0.324** (35)	0.110 (37)	**-0.338** (35)	0.112 (37)	**-0.296** (34)	0.212 (37)	-0.241 (27)	0.201 (28)	**-0.378** (34)	0.065 (33)	**-0.331** (31)	0.116 (33)	-0.312 (20)	**-0.672** (9)
Yellow perch mean weight	-0.193 (32)	-0.257 (34)	-0.107 (32)	-0.236 (34)	-0.199 (32)	-0.127 (34)	0.141 (25)	0.063 (27)	-0.095 (32)	**-0.435** (30)	0.127 (30)	**-0.415** (30)	0.342 (19)	-0.664 (7)
Black crappie mean weight	-0.189 (33)	-0.004 (32)	-0.254 (33)	-0.001 (32)	-0.229 (33)	0.033 (32)	**-0.343** (27)	0.019 (24)	-0.263 (33)	-0.105 (29)	-0.203 (30)	-0.088 (29)	-0.215 (21)	-0.275 (8)
Hybrid sunfish mean weight	0.104 (21)	-0.175 (20)	0.107 (21)	-0.217 (20)	0.194 (21)	-0.120 (20)	0.159 (16)	-0.292 (13)	0.166 (21)	0.102 (17)	**0.397** (19)	0.132 (17)	0.121 (12)	-0.175 (7)
Pumpkinseed mean weight	-0.023 (33)	0.059 (35)	-0.053 (33)	-0.009 (35)	0.038 (32)	0.082 (35)	0.008 (25)	-0.048 (26)	-0.004 (32)	0.036 (32)	0.113 (31)	0.034 (32)	-0.075 (19)	-0.351 (8)
Largemouth bass mean weight	-0.147 (29)	-0.183 (32)	-0.067 (29)	-0.080 (32)	-0.147 (29)	-0.100 (32)	**-0.414** (23)	-0.298 (25)	-0.137 (29)	-0.251 (29)	-0.180 (27)	-0.228 (29)	0.216 (16)	0.014 (8)
Walleye mean weight	0.007 (34)	0.228 (36)	-0.110 (34)	0.230 (36)	-0.078 (33)	0.105 (36)	-0.094 (26)	0.118 (28)	-0.165 (33)	0.165 (32)	-0.118 (31)	0.178 (32)	-0.226 (19)	0.418 (8)
White sucker mean weight	0.075 (29)	0.090 (30)	0.128 (29)	0.116 (30)	0.136 (29)	0.099 (30)	0.015 (23)	0.029 (22)	0.075 (29)	0.007 (28)	0.307 (27)	0.054 (28)	0.154 (16)	0.071 (8)
Black bullhead mean weight	0.095 (19)	**0.506** (19)	0.080 (19)	**0.453** (19)	0.355 (18)	**0.533** (19)	0.185 (14)	.0272 (15)	0.345 (18)	**0.667** (15)	0.241 (16)	**0.547** (15)	0.434 (12)	0.193 (3)
Brown bullhead mean weight	0.023 (23)	0.188 (24)	0.019 (23)	0.224 (24)	-0.054 (22)	0.231 (24)	0.065 (18)	0.183 (20)	-0.049 (22)	0.041 (20)	0.021 (21)	0.031 (20)	0.278 (12)	-0.089 (4)
Yellow bullhead mean weight	**-0.358** (29)	-0.236 (31)	**-0.374** (29)	-0.242 (31)	-0.300 (28)	-0.186 (31)	0.037 (22)	-0.054 (23)	-0.313 (28)	-0.174 (28)	-0.123 (27)	-0.167 (28)	-0.089 (17)	-0.467 (8)
Bluegill RSD-7	0.185 (36)	-0.250 (38)	0.174 (36)	-0.255 (38)	0.217 (35)	-0.201 (38)	-0.177 (28)	-0.153 (28)	**0.323** (35)	-0.031 (34)	0.253 (32)	-0.004 (34)	**0.409** (21)	0.040 (9)
Bluegill RSD-8	0.231 (36)	-0.236 (38)	0.270 (36)	-0.239 (38)	**0.323** (35)	-0.211 (38)	**-0.372** (28)	**-0.333** (28)	**0.321** (35)	-0.090 (34)	0.091 (32)	-0.082 (34)	0.143 (21)	0.020 (9)
Bluegill length at age 6	-0.062 (33)	-0.226 (36)	-0.002 (33)	-0.193 (36)	0.032 (32)	-0.176 (36)	-0.215 (26)	-0.241 (26)	0.054 (32)	-0.198 (32)	-0.008 (30)	-0.180 (32)	0.116 (19)	-0.037 (8)
Yellow perch length at age 4	0.281 (13)	0.329 (14)	0.243 (13)	0.374 (14)	0.358 (13)	0.356 (14)	0.200 (11)	0.033 (11)	0.415 (13)	0.402 (13)	0.288 (12)	0.370 (13)	-0.100 (7)	0.701 (5)
Black crappie length at age 4	0.379 (11)	-0.202 (12)	0.411 (11)	-0.220 (12)	0.254 (11)	-0.117 (12)	0.196 (9)	-0.300 (8)	0.356 (11)	-0.220 (12)	0.081 (10)	-0.303 (12)	0.090 (8)	-0.296 (5)
Lake area	0.121 (36)	**-0.320** (38)	0.097 (36)	**-0.300** (38)	-0.010 (35)	**-0.306** (38)	-0.278 (28)	-0.057 (28)	-0.068 (35)	-0.248 (34)	-0.104 (32)	-0.227 (34)	0.170 (21)	0.041 (9)
Littoral area	0.116 (36)	-0.253 (38)	0.069 (36)	-0.258 (38)	-0.036 (35)	-0.248 (38)	-0.110 (28)	0.062 (28)	-0.086 (35)	-0.213 (34)	-0.100 (32)	-0.201 (34)	0.267 (21)	0.012 (9)
Maximum depth	0.191 (36)	0.135 (38)	0.142 (36)	0.129 (38)	**0.311** (35)	0.071 (38)	-0.113 (28)	-0.216 (28)	**0.286** (35)	0.095 (34)	0.292 (32)	0.070 (34)	-0.211 (21)	-0.182 (9)
Shoreline length	0.259 (29)	**-0.308** (32)	0.248 (29)	**-0.301** (32)	0.172 (28)	**-0.333** (32)	-0.164 (22)	0.013 (24)	0.061 (28)	-0.245 (29)	0.132 (25)	-0.202 (29)	-0.097 (16)	-0.347 (9)
Temperature at 3 ppm of oxygen	**-0.307** (31)	-0.193 (32)	**-0.358** (31)	-0.184 (32)	**-0.411** (30)	0.272 (32)	0.209 (25)	-0.033 (23)	**-0.430** (30)	-0.197 (28)	**-0.480** (28)	-0.147 (28)	-0.135 (18)	-0.318 (6)
Average pH	0.002 (31)	-0.053 (32)	0.035 (31)	-0.066 (32)	0.102 (30)	-0.040 (32)	-0.222 (23)	-0.137 (23)	0.116 (30)	0.083 (28)	0.164 (27)	0.077 (28)	-0.007 (18)	-0.042 (8)
Average total alkalinity	0.120 (32)	0.072 (34)	0.165 (32)	-0.022 (34)	0.222 (31)	0.017 (34)	-0.278 (24)	0.083 (25)	0.164 (31)	0.040 (30)	0.269 (28)	0.037 (30)	0.026 (19)	0.270 (8)
Average total suspended solids	-0.071 (26)	**-0.421** (28)	0.013 (26)	**-0.432** (28)	-0.102 (25)	**-0.379** (28)	-0.164 (18)	-0.017 (20)	-0.089 (25)	-0.082 (24)	-0.078 (22)	-0.080 (24)	0.429 (15)	0.498 (8)
Average total phosphorus	0.087 (31)	0.050 (33)	0.125 (31)	0.013 (33)	0.179 (30)	-0.018 (33)	0.123 (23)	-0.231 (24)	0.211 (30)	**0.529** (29)	0.052 (27)	**0.525** (29)	0.114 (18)	0.611 (8)
Average orthophosphate	0.353 (18)	-0.008. (20)	0.222 (18)	-0.031 (20)	0.236 (17)	-0.136 (20)	0.016 (12)	-0.193 (15)	0.228 (17)	**0.488** (17)	-0.228 (15)	**0.509** (17)	-0.007 (10)	**0.735** (6)
Average chlorophyll a	-0.087 (31)	**-0.433** (33)	-0.035 (31)	**-0.438** (33)	-0.169 (30)	**-0.451** (33)	0.136 (23)	-0.095 (24)	-0.132 (30)	**-0.334** (29)	-0.141 (27)	**-0.342** (29)	**0.456** (18)	0.437 (8)
Average Secchi transparency	0.259 (36)	**0.399** (38)	0.201 (36)	**0.377** (38)	**0.353** (35)	**-0.371** (38)	-0.185 (28)	0.098 (28)	**0.337** (35)	0.238 (34)	**0.419** (32)	0.199 (34)	-0.072 (21)	-0.299 (9)

Appendix Table 1. Continued

	Copepod mean length		Cyclopoid mean length		Calanoid mean length		All zooplankton density		Adult zooplankton density		Cladoceran density		*Bosmina* spp. density	
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
Bluegill per trap net lift	0.144 (36)	0.146 (38)	-0.008 (36)	**0.278** (38)	-0.103 (34)	0.211 (38)	-0.041 (36)	-0.074 (38)	-0.022 (36)	-0.061 (38)	0.024 (36)	-0.206 (38)	-0.230 (36)	**-0.344** (38)
Northern pike per gill net lift	0.083 (36)	-0.010 (38)	0.009 (36)	-0.093 (38)	0.196 (34)	0.010 (38)	-0.172 (36)	-0.213 (38)	-0.188 (36)	-0.201 (38)	0.002 (36)	-0.199 (38)	-0.059 (36)	-0.127 (38)
Yellow perch per gill net lift	-0.029 (36)	0.070 (38)	0.048 (36)	0.182 (38)	-0.100 (34)	-0.008 (38)	0.205 (36)	0.125 (38)	0.183 (36)	0.100 (38)	0.142 (36)	0.156 (38)	0.099 (36)	-0.087 (38)
Black crappie per trap net lift	-0.272 (36)	0.051 (38)	-0.025 (36)	-0.022 (38)	0.056 (34)	0.019 (38)	0.132 (36)	0.227 (38)	0.117 (36)	0.246 (38)	0.189 (36)	**0.313** (38)	0.180 (36)	0.215 (38)
Hybrid sunfish per trap net lift	0.171 (36)	0.051 (38)	0.022 (36)	0.169 (38)	-0.177 (34)	0.154 (38)	-0.072 (36)	**-0.357** (38)	-0.070 (36)	**-0.345** (38)	-0.009 (36)	**-0.436** (38)	**-0.362** (36)	**-0.330** (38)
Pumpkinseed per trap net lift	0.121 (36)	0.078 (38)	-0.057 (36)	0.129 (38)	0.136 (34)	0.155 (38)	0.140 (36)	0.050 (38)	0.141 (36)	0.059 (38)	0.161 (36)	0.124 (38)	**0.351** (36)	-0.245 (38)
Largemouth bass per trap net lift	-0.060 (36)	0.034 (38)	-0.172 (36)	0.147 (38)	-0.102 (34)	0.252 (38)	-0.011 (36)	**-0.277** (38)	0.013 (36)	-0.266 (38)	-0.052 (36)	-0.211 (38)	-0.230 (36)	-0.265 (38)
Walleye per gill net lift	0.049 (36)	**-0.312** (38)	-0.215 (36)	**-0.295** (38)	0.095 (34)	-0.114 (38)	0.207 (36)	-0.022 (38)	0.205 (36)	-0.042 (38)	0.060 (36)	-0.116 (38)	-0.036 (36)	0.040 (38)
White sucker per gill net lift	-0.087 (36)	-0.074 (38)	0.016 (36)	-0.020 (38)	**-0.344** (34)	0.079 (38)	**0.363** (36)	-0.032 (38)	**0.373** (36)	-0.053 (38)	0.182 (36)	-0.024 (38)	0.255 (36)	0.055 (38)
Black bullhead per gill net lift	0.134 (36)	-0.226 (38)	0.187 (36)	-0.137 (38)	0.017 (34)	-0.146 (38)	0.085 (36)	**0.437** (38)	0.069 (36)	**0.443** (38)	0.156 (36)	**0.382** (38)	-0.127 (36)	**0.570** (38)
Brown bullhead per gill net lift	0.033 (36)	-0.265 (38)	-0.015 (36)	-0.227 (38)	0.068 (34)	-0.249 (38)	**0.338** (36)	0.209 (38)	**0.327** (36)	0.230 (38)	**0.417** (36)	0.042 (38)	0.174 (36)	0.143 (38)
Yellow bullhead per gill net lift	**0.309** (36)	0.202 (38)	0.189 (36)	0.135 (38)	**0.326** (34)	0.078 (38)	**-0.356** (36)	0.015 (38)	**-0.328** (36)	0.020 (38)	**-0.331** (36)	-0.020 (38)	-0.255 (36)	-0.192 (38)
Bluegill mean weight	-0.161 (36)	-0.185 (38)	-0.159 (36)	-0.226 (36)	0.091 (34)	-0.162 (36)	0.185 (36)	-0.006 (38)	0.199 (36)	-0.005 (38)	0.164 (36)	0.036 (38)	0.094 (36)	-0.016 (38)
Northern pike mean weight	-0.055 (35)	0.028 (37)	-0.014 (35)	0.062 (35)	-0.276 (33)	0.120 (35)	0.087 (35)	-0.017 (37)	0.085 (35)	-0.019 (37)	-0.130 (35)	-0.070 (37)	0.082 (35)	-0.084 (37)
Yellow perch mean weight	0.197 (32)	**-0.354** (34)	-0.278 (32)	**-0.309** (32)	0.096 (31)	-0.144 (32)	**0.449** (32)	**0.340** (34)	**0.424** (32)	**0.343** (34)	**0.360** (32)	0.224 (34)	0.229 (32)	0.133 (34)
Black crappie mean weight	-0.016 (33)	-0.084 (32)	-0.246 (33)	-0.109 (33)	-0.223 (32)	-0.063 (33)	0.220 (33)	-0.101 (32)	0.259 (33)	-0.100 (32)	0.038 (33)	-0.189 (32)	0.084 (33)	-0.019 (32)
Hybrid sunfish mean weight	-0.036 (21)	-0.048 (20)	-0.309 (21)	-0.255 (21)	0.165 (21)	-0.048 (21)	0.343 (21)	-0.266 (20)	0.352 (21)	-0.249 (20)	**0.400** (21)	**-0.410** (20)	-0.111 (21)	-0.026 (20)
Pumpkinseed mean weight	-0.081 (33)	-0.045 (35)	-0.192 (33)	-0.091 (33)	0.023 (31)	0.001 (33)	0.278 (33)	-0.115 (35)	0.287 (33)	-0.067 (35)	0.255 (33)	-0.138 (35)	-0.061 (33)	-0.273 (35)
Largemouth bass mean weight	0.040 (29)	-0.061 (32)	**-0.345** (29)	-0.079 (29)	0.039 (28)	0.082 (29)	**-0.337** (29)	0.096 (32)	**-0.366** (29)	0.031 (32)	**-0.417** (29)	0.081 (32)	-0.030 (29)	0.256 (32)
Walleye mean weight	-0.108 (34)	0.238 (36)	0.101 (34)	**0.326** (34)	-0.166 (32)	0.248 (34)	-0.188 (34)	-0.180 (36)	-0.147 (34)	-0.177 (36)	-0.127 (34)	-0.243 (36)	-0.055 (34)	**-0.340** (36)
White sucker mean weight	**0.377** (29)	0.099 (30)	0.260 (29)	0.140 (29)	**0.320** (28)	0.169 (29)	-0.146 (29)	0.086 (30)	-0.160 (29)	0.068 (30)	-0.175 (29)	0.091 (30)	**-0.330** (29)	**-0.316** (30)
Black bullhead mean weight	-0.224 (19)	0.264 (19)	-0.194 (19)	0.087 (19)	0.191 (18)	**0.391** (19)	**-0.422** (19)	-0.245 (19)	**-0.429** (19)	-0.222 (19)	-0.285 (19)	-0.169 (19)	-0.161 (19)	-0.356 (19)
Brown bullhead mean weight	**0.386** (23)	0.221 (24)	**0.354** (23)	0.155 (23)	0.079 (21)	0.263 (23)	-0.262 (23)	-0.207 (24)	-0.269 (23)	-0.230 (24)	-0.302 (23)	-0.208 (24)	-0.065 (23)	**-0.349** (24)
Yellow bullhead mean weight	-0.304 (29)	-0.142 (31)	-0.144 (29)	-0.191 (29)	-0.161 (27)	-0.271 (29)	**0.365** (29)	-0.060 (31)	**0.353** (29)	-0.064 (31)	0.254 (29)	-0.166 (31)	0.195 (29)	-0.020 (31)
Bluegill RSD-7	-0.207 (36)	-0.186 (38)	-0.104 (36)	-0.217 (36)	0.011 (34)	-0.188 (36)	0.160 (36)	0.036 (38)	0.163 (36)	0.051 (38)	0.223 (36)	0.079 (38)	0.030 (36)	0.054 (38)
Bluegill RSD-8	-0.199 (36)	-0.200 (38)	-0.108 (36)	**-0.285** (36)	0.154 (34)	-0.192 (36)	-0.225 (36)	-0.137 (38)	-0.230 (36)	-0.137 (38)	-0.160 (36)	-0.72 (38)	-0.208 (36)	0.217 (38)
Bluegill length at age 6	-0.149 (33)	-0.184 (36)	0.024 (33)	-0.154 (33)	0.103 (31)	-0.182 (33)	0.025 (33)	0.141 (36)	0.004 (33)	0.120 (36)	-0.094 (33)	0.139 (36)	-0.054 (33)	**0.419** (36)
Yellow perch length at age 4	-0.156 (13)	**0.471** (14)	-0.324 (13)	0.394 (13)	0.255 (12)	0.149 (13)	-0.356 (13)	-0.199 (14)	-0.297 (13)	-0.259 (14)	-0.320 (13)	0.077 (14)	-0.197 (13)	-0.237 (14)
Black crappie length at age 4	**0.721** (11)	-0.296 (12)	0.333 (11)	-0.301 (11)	-0.321 (11)	-0.447 (11)	-0.122 (11)	-0.087 (12)	-0.135 (11)	-0.071 (12)	0.071 (11)	-0.097 (12)	0.038 (11)	0.416 (12)
Lake area	0.096 (36)	-0.268 (38)	-0.125 (36)	-0.252 (36)	0.219 (34)	-0.148 (36)	0.005 (36)	0.159 (38)	0.012 (36)	0.129 (38)	0.081 (36)	0.097 (38)	-0.083 (36)	0.160 (38)
Littoral area	0.150 (36)	**-0.282** (38)	-0.164 (36)	-0.257 (36)	0.262 (34)	-0.100 (36)	0.090 (36)	0.199 (38)	0.105 (36)	0.190 (38)	0.188 (36)	0.144 (38)	-0.024 (36)	0.071 (38)
Maximum depth	-0.170 (36)	0.180 (38)	0.044 (36)	0.064 (36)	0.150 (34)	-0.166 (36)	-0.223 (36)	**-0.534** (38)	-0.193 (36)	**-0.533** (38)	-0.217 (36)	**-0.490** (38)	-0.178 (36)	-0.151 (38)
Shoreline length	0.073 (29)	-0.235 (32)	-0.259 (29)	-0.228 (29)	0.235 (27)	-0.014 (29)	-0.127 (29)	-0.055 (32)	-0.116 (29)	-0.069 (32)	0.061 (29)	-0.101 (32)	-0.237 (29)	0.133 (32)
Temperature at 3 ppm of oxygen	-0.136 (31)	0.004 (32)	-0.068 (31)	-0.024 (31)	-0.112 (29)	-0.115 (31)	0.157 (31)	**0.484** (32)	0.165 (31)	**0.467** (32)	0.104 (31)	**0.359** (32)	0.138 (31)	0.253 (32)
Average pH	-0.276 (31)	-0.058 (32)	-0.072 (31)	-0.121 (31)	0.021 (29)	-0.191 (31)	0.192 (31)	0.233 (32)	0.179 (31)	0.232 (32)	0.147 (31)	0.149 (32)	0.016 (31)	0.189 (32)
Average total alkalinity	0.042 (32)	-0.150 (34)	0.028 (32)	-0.201 (32)	0.117 (30)	-0.249 (32)	-0.055 (32)	-0.034 (34)	-0.069 (32)	-0.070 (34)	-0.077 (32)	-0.145 (34)	-0.261 (32)	-0.005 (34)
Average total suspended solids	-0.015 (26)	**-0.456** (28)	-0.252 (26)	**-0.452** (26)	0.013 (25)	-0.078 (26)	**0.386** (26)	**0.485** (28)	**0.356** (26)	**0.483** (28)	**0.430** (26)	**0.415** (28)	0.181 (26)	**0.460** (28)
Average total phosphorus	-0.139 (31)	0.124 (33)	-0.063 (31)	-0.015 (31)	-0.167 (30)	0.125 (31)	0.074 (31)	0.042 (33)	0.062 (31)	0.061 (33)	0.132 (31)	0.096 (33)	-0.041 (31)	0.066 (33)
Average orthophosphate	-0.152 (18)	0.161 (20)	0.026 (18)	0.140 (18)	-0.136 (17)	0.209 (18)	-0.119 (18)	-0.012 (20)	-0.076 (18)	-0.033 (20)	0.031 (18)	0.112 (20)	-0.127 (18)	0.071 (20)
Average chlorophyll a	-0.060 (31)	**-0.319** (33)	-0.283 (31)	**-0.321** (31)	0.234 (30)	-0.152 (31)	0.295 (31)	0.284 (33)	0.276 (31)	0.273 (33)	**0.395** (31)	0.273 (33)	0.208 (31)	**0.346** (33)
Average Secchi transparency	-0.090 (36)	0.243 (38)	-0.017 (36)	0.227 (36)	-0.073 (34)	0.119 (36)	**-0.284** (36)	**-0.405** (38)	-0.249 (36)	**-0.383** (38)	-0.245 (36)	**-0.403** (38)	-0.262 (36)	**-0.364** (38)

Appendix Table 1. Continued

	Daphnia spp. density		*D. galeata* and *D. retrocurva* density		*D. pulex* density		Copepod density		Cyclopoid density		Calanoid density		Large zooplankton (> 1mm) density		Large cladoceran (> 1mm) density	
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
Bluegill per trapnet	0.103 (36)	0.069 (38)	0.055 (36)	0.056 (38)	0.105 (36)	0.025 (38)	-0.099 (36)	0.018 (38)	-0.193 (36)	0.177 (38)	0.148 (36)	-0.046 (38)	0.085 (36)	0.193 (38)	0.102 (36)	0.127 (38)
Northern pike per gillnet	0.039 (36)	-0.253 (38)	-0.078 (36)	**-0.298** (38)	-0.009 (36)	0.071 (38)	**-0.338** (36)	-0.124 (38)	-0.208 (36)	-0.060 (38)	**-0.400** (36)	-0.188 (38)	0.223 (36)	-0.074 (38)	0.275 (36)	-0.198 (38)
Yellow perch per gillnet	0.099 (36)	0.151 (38)	-0.014 (36)	0.138 (38)	0.016 (36)	-0.074 (38)	0.234 (36)	-0.052 (38)	0.145 (36)	-0.025 (38)	0.217 (36)	-0.055 (38)	0.107 (36)	0.096 (38)	0.062 (36)	0.151 (38)
Black crappie per trapnet	0.119 (36)	-0.069 (38)	-0.130 (36)	-0.106 (38)	0.132 (36)	0.027 (38)	0.081 (36)	0.094 (38)	0.173 (36)	0.051 (38)	-0.127 (36)	0.072 (38)	0.080 (36)	-0.058 (38)	0.135 (36)	-0.139 (38)
Hybrid sunfish per trapnet	0.097 (36)	-0.218 (38)	-0.003 (36)	-0.269 (38)	0.160 (36)	0.172 (38)	-0.153 (36)	-0.180 (38)	-0.268 (36)	-0.070 (38)	0.080 (36)	-0.261 (38)	0.205 (36)	-0.082 (38)	0.209 (36)	-0.113 (38)
Pumpkinseed per trapnet	0.002 (36)	0.232 (38)	0.230 (36)	**0.277** (38)	**-0.331** (36)	-0.211 (38)	0.071 (36)	-0.052 (38)	0.006 (36)	-0.030 (38)	0.139 (36)	0.023 (38)	-0.041 (36)	0.185 (38)	-0.060 (36)	0.127 (38)
Largemouth bass per trap net lift	0.011 (36)	0.076 (38)	0.079 (36)	0.073 (38)	0.007 (36)	0.023 (38)	0.051 (36)	**-0.326** (38)	-0.035 (36)	-0.201 (38)	0.043 (36)	**-0.329** (38)	0.007 (36)	0.087 (38)	0.048 (36)	0.142 (38)
Walleye per gillnet	0.110 (36)	0.059 (38)	**0.329** (36)	0.127 (38)	-0.156 (36)	-0.242 (38)	0.269 (36)	0.039 (38)	0.162 (36)	0.052 (38)	**0.312** (36)	-0.025 (38)	-0.071 (36)	-0.094 (38)	-0.109 (36)	0.057 (38)
White sucker per gillnet	0.167 (36)	.0136 (38)	0.178 (36)	0.103 (38)	-0.043 (36)	-0.061 (38)	**0.502** (36)	-0.072 (38)	**0.408** (36)	-0.078 (38)	**0.452** (36)	-0.010 (38)	-0.118 (36)	-0.035 (38)	-0.172 (36)	0.091 (38)
Black bullhead per gillnet	0.212 (36)	-0.043 (38)	-0.023 (36)	-0.030 (38)	**0.317** (36)	-0.074 (38)	-0.060 (36)	**0.458** (38)	-0.041 (36)	**0.489** (38)	0.004 (36)	-0.085 (38)	**0.302** (36)	-0.097 (38)	**0.288** (36)	0.001 (38)
Brown bullhead per gillnet	**0.349** (36)	-0.230 (38)	**0.351** (36)	-0.167 (38)	-0.030 (36)	-0.247 (38)	0.114 (36)	**0.383** (38)	0.150 (36)	**0.365** (38)	0.073 (36)	0.213 (38)	0.262 (36)	-0.158 (38)	0.239 (36)	**-0.340** (38)
Yellow bullhead per gillnet	**-0.282** (36)	0.169 (38)	-0.069 (36)	0.166 (38)	-0.088 (36)	0.203 (38)	**-0.322** (36)	0.053 (38)	**-0.296** (36)	-0.024 (38)	-0.197 (36)	0.225 (38)	-0.007 (36)	**0.319** (38)	-0.050 (36)	0.233 (38)
Bluegill mean weight	0.102 (36)	0.050 (38)	0.090 (36)	0.031 (38)	0.138 (36)	0.077 (38)	0.214 (36)	-0.093 (38)	0.200 (36)	-0.100 (38)	0.069 (36)	-0.009 (38)	0.214 (36)	-0.138 (38)	0.251 (36)	-0.048 (38)
Northern pike mean weight	-0.157 (35)	0.079 (37)	-0.034 (35)	0.079 (37)	-0.028 (35)	0.021 (37)	**0.284** (35)	0.025 (37)	0.112 (35)	-0.012 (37)	**0.440** (35)	0.053 (37)	**-0.346** (35)	-0.049 (37)	**-0.395** (35)	0.085 (37)
Yellow perch mean weight	0.214 (32)	.0130 (34)	**0.358** (32)	0.216 (34)	-0.125 (32)	-0.240 (34)	**0.322** (32)	**0.410** (34)	0.175 (32)	**0.414** (34)	**0.422** (32)	0.138 (34)	0.174 (32)	-0.082 (34)	0.148 (32)	-0.111 (34)
Black crappie mean weight	0.056 (33)	0.020 (32)	0.095 (33)	0.006 (32)	0.070 (33)	0.101 (32)	**0.319** (33)	0.032 (32)	0.173 (33)	-0.058 (32)	**0.482** (33)	0.107 (32)	-0.045 (33)	-0.116 (32)	-0.080 (33)	0.033 (32)
Hybrid sunfish mean weight	**0.425** (21)	**-0.396** (20)	0.215 (21)	-0.374 (20)	0.161 (21)	-0.166 (20)	0.188 (21)	0.007 (20)	0.201 (21)	-0.194 (20)	0.070 (21)	0.219 (20)	**0.448** (21)	-0.282 (20)	**0.483** (21)	-0.317 (20)
Pumpkinseed mean weight	0.289 (33)	-0.019 (35)	0.170 (33)	-0.026 (35)	0.279 (33)	-0.045 (35)	0.260 (33)	0.026 (35)	0.255 (33)	0.001 (35)	0.159 (33)	0.010 (35)	0.202 (33)	-0.078 (35)	0.252 (33)	0.010 (35)
Largemouth bass mean weight	**-0.466** (29)	0.005 (32)	-0.116 (29)	0.079 (32)	-0.297 (29)	-0.463 (32)	-0.255 (29)	-0.026 (32)	**-0.345** (29)	-0.003 (32)	0.067 (29)	-0.065 (32)	**-0.444** (29)	-0.020 (32)	**-0.464** (29)	-0.026 (32)
Walleye mean weight	-0.065 (34)	-0.044 (36)	0.033 (34)	-0.087 (36)	-0.215 (34)	0.117 (36)	-0.153 (34)	-0.105 (36)	-0.137 (34)	-0.017 (36)	-0.154 (34)	-0.148 (36)	-0.114 (34)	0.210 (36)	-0.094 (34)	0.092 (36)
White sucker mean weight	-0.115 (29)	0.187 (30)	0.050 (29)	0.212 (30)	-0.151 (29)	-0.262 (30)	-0.107 (29)	0.079 (30)	-0.147 (29)	0.148 (30)	-0.014 (29)	-0.035 (30)	0.131 (29)	0.206 (30)	0.056 (29)	0.165 (30)
Black bullhead mean weight	-0.253 (19)	0.205 (19)	-0.143 (19)	0.125 (19)	-0.271 (19)	**0.461** (19)	**-0.410** (19)	-0.240 (19)	-0.220 (19)	-0.219 (19)	**-0.546** (19)	-0.071 (19)	-0.281 (19)	0.342 (19)	-0.159 (19)	0.298 (19)
Brown bullhead mean weight	-0.345 (23)	0.088 (24)	-0.074 (23)	0.101 (24)	-0.225 (23)	0.110 (24)	-0.217 (23)	-0.250 (24)	-0.253 (23)	-0.265 (24)	-0.132 (23)	0.057 (24)	-0.331 (23)	0.143 (24)	**-0.364** (23)	0.051 (24)
Yellow bullhead mean weight	0.219 (29)	-0.144 (31)	0.291 (29)	-0.105 (31)	0.014 (29)	-0.207 (31)	**0.342** (29)	0.037 (31)	**0.371** (29)	-0.052 (31)	0.089 (29)	0.143 (31)	0.023 (29)	-0.246 (31)	0.054 (29)	-0.186 (31)
Bluegill RSD-7	0.153 (36)	-0.113 (38)	-0.027 (36)	-0.116 (38)	**0.315** (36)	-0.025 (38)	0.088 (36)	-0.045 (38)	0.141 (36)	-0.050 (38)	-0.109 (36)	-0.004 (38)	0.185 (36)	-0.189 (38)	0.256 (36)	-0.198 (38)
Bluegill RSD-8	-0.118 (36)	-0.239 (38)	**-0.304** (36)	-0.235 (38)	0.288 (36)	-0.027 (38)	-0.217 (36)	-0.165 (38)	-0.148 (36)	**-0.144** (38)	-0.197 (36)	-0.140 (38)	-0.042 (36)	**-0.276** (38)	-0.001 (36)	-0.201 (38)
Bluegill length at age 6	-0.103 (33)	-0.081 (36)	-0.203 (33)	-0.065 (36)	**0.236** (33)	-0.058 (36)	0.121 (33)	0.074 (36)	0.201 (33)	0.098 (36)	-0.008 (33)	-0.136 (36)	-0.004 (33)	-0.192 (36)	-0.035 (33)	-0.091 (36)
Yellow perch length at age 4	-0.334 (13)	0.168 (14)	-0.407 (13)	0.108 (14)	0.248 (13)	0.369 (14)	-0.139 (13)	**-0.461** (14)	-0.066 (13)	**-0.585** (14)	-0.098 (13)	-0.028 (14)	-0.026 (13)	0.299 (14)	0.028 (13)	0.318 (14)
Black crappie length at age 4	0.046 (11)	-0.053 (12)	-0.167 (11)	-0.044 (12)	0.495 (11)	0.046 (12)	-0.246 (11)	0.079 (12)	-0.264 (11)	-0.020 (12)	0.110 (11)	0.227 (12)	0.125 (11)	-0.227 (12)	0.098 (11)	-0.185 (12)
Lake area	0.112 (36)	0.005 (38)	0.131 (36)	0.058 (38)	-0.113 (36)	**-0.286** (38)	-0.095 (36)	0.158 (38)	-0.095 (36)	0.165 (38)	0.009 (36)	0.066 (38)	-0.005 (36)	-0.022 (38)	-0.019 (36)	-0.204 (38)
Littoral area	0.208 (36)	0.085 (38)	0.233 (36)	0.138 (38)	-0.181 (36)	**-0.274** (38)	-0.035 (36)	0.208 (38)	-0.063 (36)	0.230 (38)	0.056 (36)	0.071 (38)	0.067 (36)	-0.049 (38)	0.072 (36)	0.049 (38)
Maximum depth	-0.106 (36)	-0.269 (38)	-0.176 (36)	**-0.297** (38)	0.242 (36)	0.162 (38)	-0.125 (36)	**-0.427** (38)	0.025 (36)	**-0.507** (38)	**-0.326** (36)	0.027 (38)	0.070 (36)	-0.174 (38)	0.112 (36)	-0.138 (38)
Shoreline length	0.161 (29)	-0.206 (32)	0.160 (29)	-0.133 (32)	-0.088 (29)	**-0.379** (32)	-0.286 (29)	-0.007 (32)	-0.286 (29)	0.058 (32)	-0.106 (29)	-0.111 (32)	0.071 (29)	-0.125 (32)	0.107 (29)	-0.151 (32)
Temperature at 3 ppm of oxygen	0.053 (31)	0.061 (32)	0.084 (31)	0.111 (32)	-0.118 (31)	-0.058 (32)	0.160 (31)	**0.440** (32)	0.131 (31)	**0.342** (32)	0.135 (31)	**0.330** (32)	-0.086 (31)	0.133 (32)	-0.119 (31)	0.032 (32)
Average pH	0.173 (31)	0.051 (32)	-0.010 (31)	0.004 (32)	0.240 (31)	0.068 (32)	0.141 (31)	0.262 (32)	0.240 (31)	0.166 (32)	-0.000 (31)	0.223 (32)	0.225 (31)	0.053 (32)	0.249 (31)	0.070 (32)
Average total alkalinity	0.026 (32)	0.019 (34)	0.070 (32)	-0.002 (34)	-0.003 (32)	0.078 (34)	-0.115 (32)	0.044 (34)	-0.145 (32)	0.016 (34)	0.035 (32)	0.069 (34)	0.203 (32)	-0.030 (34)	0.168 (32)	0.054 (34)
Average total suspended solids	**0.395** (26)	0.012 (28)	0.284 (26)	0.020 (28)	-0.108 (26)	-0.236 (28)	0.215 (26)	**0.527** (28)	0.135 (26)	**0.560** (28)	**0.336** (26)	-0.020 (28)	0.161 (26)	-0.136 (28)	0.171 (26)	-0.092 (28)
Average total phosphorus	0.133 (31)	-0.123 (33)	**-0.310** (31)	-0.262 (33)	0.290 (31)	**0.300** (33)	0.004 (31)	0.036 (33)	0.024 (31)	-0.018 (33)	0.060 (31)	0.014 (33)	0.205 (31)	-0.010 (33)	0.221 (31)	-0.061 (33)
Average orthophosphate	0.061 (18)	-0.255 (20)	-0.389 (18)	**-0.448** (20)	0.266 (18)	**0.419** (20)	-0.155 (18)	-0.127 (20)	-0.145 (18)	-0.126 (20)	-0.096 (18)	-0.140 (20)	0.081 (18)	-0.022 (20)	0.116 (18)	-0.069 (20)
Average chlorophyll a	**0.344** (31)	0.003 (33)	**0.311** (31)	0.071 (33)	-0.174 (31)	**-0.406** (33)	0.134 (31)	0.276 (33)	0.190 (31)	0.277 (33)	0.103 (31)	0.058 (33)	0.093 (31)	-0.103 (33)	0.108 (31)	-0.107 (33)
Average Secchi transparency	-0.175 (36)	-0.085 (38)	-0.244 (36)	-0.135 (38)	**0.278** (36)	**0.320** (38)	-0.222 (36)	-0.266 (38)	-0.140 (36)	-0.257 (38)	-0.262 (36)	-0.069 (38)	-0.004 (36)	0.082 (38)	0.071 (36)	0.016 (38)

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