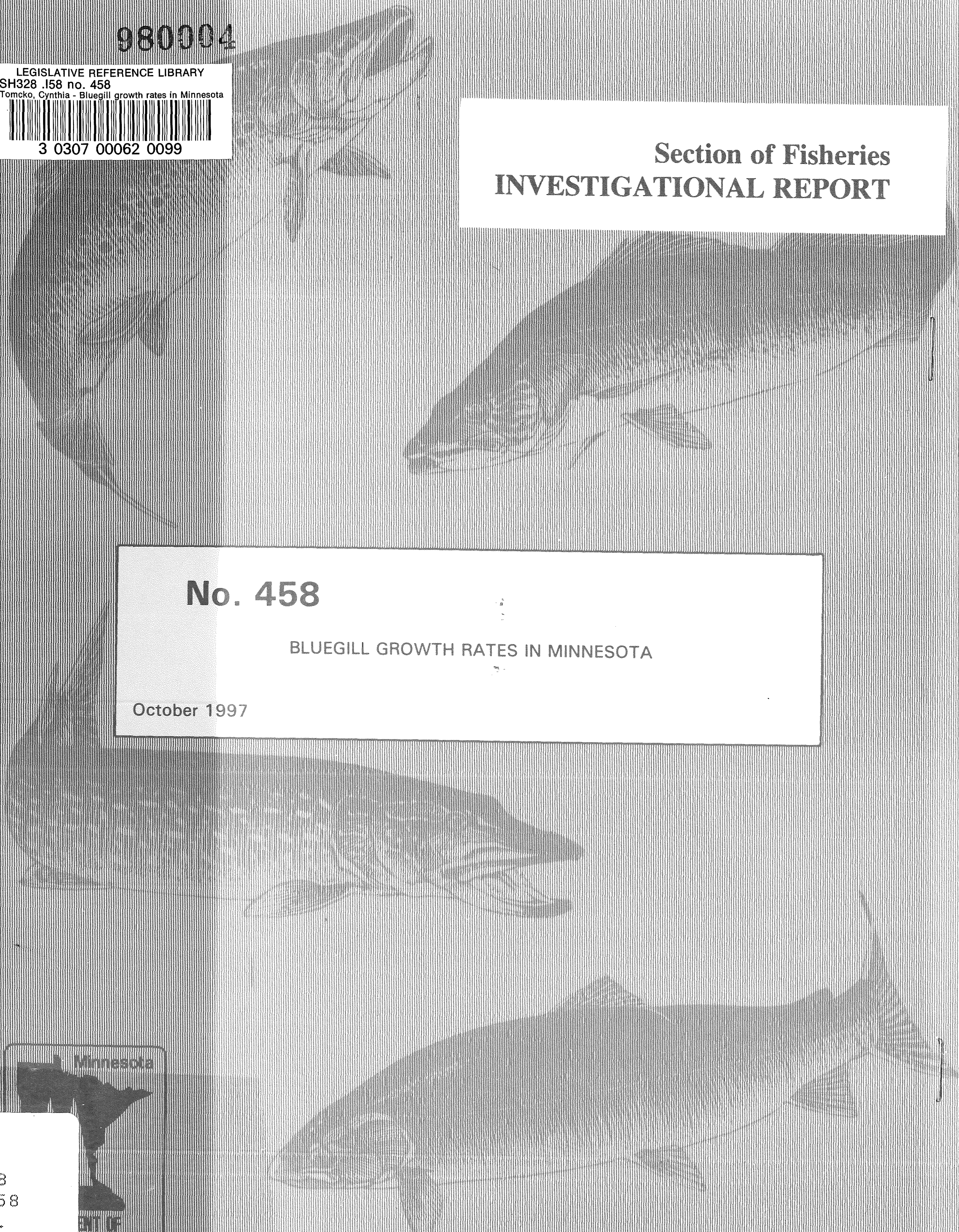

Section of Fisheries
INVESTIGATIONAL REPORT

No. 458

BLUEGILL GROWTH RATES IN MINNESOTA

October 1997

Division of Fish and Wildlife

ERRATA

Minnesota Department of Natural Resources
Investigational Report 458

BLUEGILL GROWTH RATES IN MINNESOTA

by
Cynthia M. Tomcko and Rodney B. Pierce
Fisheries Biologists

Minnesota Department of Natural Resources
Section of Fisheries
500 Lafayette Road
St. Paul, MN 55155-4012

2 Table Errata

Table 1. Median backcalculated total lengths (mm) at age by lake class for bluegill. Samples were taken from Minnesota lakes during 1982-1994. Also listed for purpose of comparison, is an unweighted grand mean based on mean bluegill length per survey (1,947 surveys) and a weighted mean calculated from individual bluegill lengths (77,485 bluegill); a mean for Minnesota lakes from Dobie (1970); and a means of means for Minnesota lakes from Carlander (1977; pages 88-93).

Lake	Number of	Age													
Class	surveys	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	3	42	72	100	129	142	158								
2	10	38	63	94	125	152	177	196	197						
3	7	37	65	96	122	143	163	188	190						
4	1	43	79	115	122	148	162	193							
5	55	37	58	88	121	146	157	173	172	179	173	170	166	170	174
6	2	38	68	97	121	139	186	204							
7	22	38	72	108	145	160	181	199	191	199	206	214	221		
8	2	46	70	103											
10	17	39	66	94	119	143	163	174	176	196	186	181			
11	34	37	66	100	132	154	168	177	188	202	202	228	228		
12	15	38	64	88	119	143	160	182	185	220	196				
13	14	41	70	108	154	160	151	161	174	186	211	228			
14	6	40	66	98	130	154	140								
15	5	40	79	130	178	210	225	243	250	257					
16	14	39	82	122	146	171	176	183	196	208					
17	5	36	77	89	122	126	142	173	185						
19	18	39	75	114	149	172	187	206	209	222	217				
20	37	39	62	89	116	137	162	172	171	179	188	197			
21	29	41	66	92	117	138	158	171	185	197	199	191			
22	133	40	64	89	118	148	162	176	185	194	199	185			
23	106	38	58	80	103	130	151	164	173	181	196	206	236	234	
24	153	42	70	98	124	144	156	165	168	189	190				
25	134	41	68	96	125	146	163	170	180	179	185	189	186		
26	2	49	89	130	154	188	235								
27	137	40	64	90	120	147	161	176	189	198	204	199	211		
28	61	41	64	90	121	144	159	171	183	190	177	181	180		
29	92	39	61	84	106	128	148	162	170	177	182	196	223	235	240
30	77	44	79	112	137	147	157	158	162	170	184				
31	144	41	65	91	117	144	162	173	187	189	185	216			
32	69	38	56	76	95	114	133	148	157	166	167	154	155		
33	27	42	68	100	129	157	175	192	211						
34	108	45	80	112	139	157	175	184	185	175	176	200			
35	29	42	67	94	116	139	155	169	177	193	186	205			
36	34	44	71	99	125	148	163	168	178	184	186	188	197		
37	22	49	81	111	136	155	166	172	179	191	192	221			
38	62	45	76	102	125	144	153	155	155	164	192				
39	62	44	75	108	136	160	177	185	197	208	191	223	208	223	228
40	36	46	83	114	126	146	149	161	178	182					
41	71	48	100	144	162	179	189	197	214	240	247	256			
42	37	49	87	124	150	162	181	192	208	202					
43	54	48	94	132	157	174	182	194	174	188					
unweighted		43	72	102	128	148	163	174	181	187	191	197	198	207	214
weighted		42	68	93	115	135	151	163	172	182	189	194	195	201	214
Dobie (1970)		48	86	124	155	180	198	211	218	231	244				
Carlander (1977)		83	118	133	160	184	200	204	210						

Appendix 1. Median backcalculated total lengths (inches) at age by lake class for bluegill. Samples were taken from Minnesota lakes during 1982-1994.

	Age													
Lake Class	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.6	2.8	3.9	5.0	5.5	6.2								
2	1.5	2.4	3.7	4.9	5.9	6.9	7.7	7.7						
3	1.4	2.5	3.7	4.8	5.6	6.4	7.4	7.4						
4	1.6	3.1	4.5	4.8	5.8	6.3	7.6							
5	1.4	2.2	3.4	4.7	5.7	6.1	6.8	6.7	7.0	6.8	6.6	6.5	6.6	6.8
6	1.5	2.6	3.8	4.7	5.4	7.3	8.0							
7	1.5	2.8	4.2	5.7	6.3	7.1	7.8	7.5	7.8	8.1	8.4	8.7		
8	1.8	2.7	4.0											
10	1.5	2.6	3.7	4.6	5.6	6.4	6.8	6.9	7.7	7.3	7.1			
11	1.4	2.6	3.9	5.2	6.0	6.6	6.9	7.4	7.9	7.9	8.9	8.9		
12	1.5	2.5	3.4	4.6	5.6	6.3	7.1	7.2	8.6	7.7				
13	1.6	2.7	4.2	6.0	6.3	5.9	6.3	6.8	7.3	8.3	8.9			
14	1.5	2.6	3.8	5.1	6.0	5.5								
15	1.5	3.1	5.1	7.0	8.2	8.8	9.5	9.8	10.1					
16	1.5	3.2	4.8	5.7	6.7	6.9	7.2	7.7	8.1					
17	1.4	3.0	3.5	4.8	4.9	5.5	6.8	7.2						
19	1.5	2.9	4.4	5.8	6.7	7.3	8.1	8.2	8.7	8.5				
20	1.5	2.4	3.5	4.5	5.3	6.3	6.7	6.7	7.0	7.4	7.7			
21	1.6	2.6	3.6	4.6	5.4	6.2	6.7	7.2	7.7	7.8	7.5			
22	1.5	2.5	3.5	4.6	5.8	6.3	6.9	7.2	7.6	7.8	7.2			
23	1.5	2.2	3.1	4.0	5.1	5.9	6.4	6.8	7.1	7.7	8.1	9.2	9.2	
24	1.6	2.7	3.8	4.8	5.6	6.1	6.5	6.6	7.4	7.4				
25	1.6	2.6	3.7	4.9	5.7	6.4	6.6	7.0	7.0	7.2	7.4	7.3		
26	1.9	3.5	5.1	6.0	7.4	9.2								
27	1.5	2.5	3.5	4.7	5.7	6.3	6.9	7.4	7.8	8.0	7.8	8.3		
28	1.6	2.5	3.5	4.7	5.6	6.2	6.7	7.2	7.4	6.9	7.1	7.0		
29	1.5	2.4	3.3	4.1	5.0	5.8	6.3	6.6	6.9	7.1	7.7	8.7	9.2	9.4
30	1.7	3.1	4.4	5.3	5.7	6.1	6.2	6.3	6.6	7.2				
31	1.6	2.5	3.5	4.6	5.6	6.3	6.8	7.3	7.4	7.2	8.5			
32	1.5	2.2	2.9	3.7	4.4	5.2	5.8	6.1	6.5	6.5	6.0	6.1		
33	1.6	2.6	3.9	5.0	6.1	6.8	7.5	8.3						
34	1.7	3.1	4.4	5.4	6.1	6.8	7.2	7.2	6.8	6.9	7.8			
35	1.6	2.6	3.7	4.5	5.4	6.1	6.6	6.9	7.6	7.3	8.0			
36	1.7	2.8	3.9	4.9	5.8	6.4	6.6	7.0	7.2	7.3	7.4	7.7		
37	1.9	3.1	4.3	5.3	6.1	6.5	6.7	7.0	7.5	7.5	8.7			
38	1.7	2.9	4.0	4.9	5.6	6.0	6.1	6.1	6.4	7.5				
39	1.7	2.9	4.2	5.3	6.3	6.9	7.2	7.7	8.1	7.5	8.7	8.1	8.7	8.9
40	1.8	3.2	4.4	4.9	5.7	5.8	6.3	7.0	7.1					
41	1.8	3.9	5.6	6.3	7.0	7.4	7.7	8.4	9.4	9.7	10.0			
42	1.9	3.4	4.8	5.9	6.3	7.1	7.5	8.1	7.9					
43	1.8	3.7	5.2	6.1	6.8	7.1	7.6	6.8	7.4					

Minnesota Department of Natural Resources
Investigational Report 458

BLUEGILL GROWTH RATES IN MINNESOTA[1]

by

Cynthia M. Tomcko and Rodney B. Pierce
Fisheries Biologists

Minnesota Department of Natural Resources
Section of Fisheries
500 Lafayette Road
St. Paul, MN 55155-4012

Abstract.--Median growth rates of bluegill in Minnesota were determined for 41 of 43 lake classes. Growth rates varied by lake class and most were lower than the statewide mean derived from pre-1970 surveys. Little evidence was found of a density dependent growth response to one or two poor year classes. Three variables (secchi depth, maximum depth, and total alkalinity) explained 17-32% of the variation in growth for bluegill through their first five years.

Introduction

Different growing conditions for bluegill exist in Minnesota's many lakes because of differing physical characteristics, water chemistry, and fish communities. As a result, bluegill growth rates in Minnesota lakes are highly variable and a single statewide average growth rate that was developed as a reference standard for growth comparisons (Dobie 1970) was found to be too high by many fisheries managers. A more useful measure would summarize growth, not for the entire state, but for groups of similar lakes. Schupp (1992) grouped lakes in Minnesota into 43 lake classes based on water chemistry, lake morphometry, and length of growing season, variables which are expected to affect bluegill growth. Thus, lake classes should provide a suitable framework for grouping bluegill growth rates in Minnesota.

To best manage lakes containing bluegill, it is not enough to know median bluegill growth rates by lake class and the variation possible in growth rates. We also need to

[1]This project was funded in part by the Federal Aid in Sport Fish Restoration (Dingell-Johnson) Program, Study 610, D-J Project F-26-R Minnesota.

evaluate causes of variation in bluegill growth, such as lake morphometry, water chemistry, and population density, to better understand how bluegill populations might be manipulated to produce size structures desired by anglers. Lake morphometry and water chemistry variables are routinely measured and are readily available from Minnesota lakes. In contrast, changes in population density are difficult to measure, especially in the large number of lakes needed for a suitable sample size. Bluegill growth has been found to be density dependent (Gerking 1962; Latta and Merna 1977; Wiener and Hanneman 1982; Osenberg et al. 1988; Snow and Staggs 1994), but rarely for many lakes leaving uncertain the generality of the density dependence of bluegill growth. 'Missing' year classes, resulting from inconsistent recruitment, are a population density change that may evoke measurable growth responses in bluegill populations and may occur frequently enough to allow evaluation of the response in a large number of lakes.

In this study, the objectives were to 1) summarize bluegill growth as median lengths at age by lake class; 2) corroborate the method of aging bluegill based on scales and evaluate bias due to gear selectivity and Lee's phenomenon; 3) evaluate if bluegill growth responses were dependent on population density change; and 4) regress growth on lake physical and chemical variables and evaluate the relative importance of variables.

Methods

Bluegill growth rates and aging

Growth rates were estimated from scales taken from 77,485 bluegill during 1,947 lake surveys conducted from 1982-1994 by the staff of the 28 fisheries management areas in Minnesota. Bluegill were usually sampled with 19 mm mesh trap nets and less frequently by electroshocking, seining (6 and 10 mm mesh), and gill netting (19, 25, 38, 50, and 64 mm bar measure).

Staff from each management area aged bluegill, measured scale annuli distances, and digitized annuli measurements to DISBCAL computer files (Frie 1982), resulting in one file per survey and one record per bluegill. Files containing few records were retained in the analysis to avoid bias due to lake size and bluegill population density. Six files were not analyzed because 1) a lake's assignment to a single lake class was questionable because it was multi-basined and the basins had distinctly different qualities, 2) bluegill were not typically found in the lake but were recently introduced and comprised a rapidly expanding population, or 3) the lake was recently reclaimed and fish populations restocked.

Errors found in DISBCAL files included annuli measurements greater than edge measurements and backcalculated lengths or growth increments less than or equal to zero. Errored records were removed from files. The percentage of errored records in each lake class, which were removed from analysis, varied from 0-4%. Extremely fast growth measurements (greater than 75 mm/yr) and annuli measurements equaling the edge measurement were retained in files after verification from area fisheries personnel.

Median growth rates for bluegill in each lake class were estimated from mean backcalculated lengths at age for each lake survey. Mean backcalculated lengths and annual growth increments were determined from scale measurements using the Lee direct proportion method (Carlander 1981) and a body-scale constant of 20.3 mm (Schlagenhaft 1993) in a BASIC program. Mean lengths at age were calculated using all annuli measurements to ensure adequate growth information on young bluegill and provide growth rates in the same format as historically used by Minnesota's fish managers. Calculation of mean lengths at age for each survey rather than a median per survey was justified because the distribution of individual fish lengths at age for each lake survey was typically normal. First and 3rd quartiles were calculated to provide information on variation about the mean.

The number of analyzed surveys varied among lake classes. Less than 10 surveys were available in Lake Classes 1, 3, 4, 6, 8, 14, 15, 17, 26. Over 100 surveys were used for Lake Classes 22, 23, 24, 25, 27, 31, 34. The number of surveys analyzed per lake class was similar to the number of lakes analyzed per lake class because in most cases, only one survey was done per lake. Median growth rates were calculated for 41 of the 43 lake classes. No bluegill annuli measurement files were available for Lake Classes 9 and 18.

To determine if median lengths at age were different between lake classes, a Kruskal-Wallis one-way nonparametric analysis of variance was performed for ages 1 through 6 on mean backcalculated length at age per survey. Lake class was the main effect. Mean length for age 1 bluegill was calculated using all increments to ensure sufficient numbers for analysis. Mean lengths for ages 2-6 were calculated using only the last increments to reduce the effect of Lee's phenomenon (Gutreuter 1987). Parametric one-way ANOVAs were not used because Bartlett's tests of equal variances were significant ($P=0.0000$ for age 1 through 4, $P=0.004$ for age 5) for all but age 6 ($P=0.06$), indicating unequal variances. Furthermore, scatter plots of residuals showed no pattern to suggest an appropriate transformation for stabilizing the variance.

Back-calculated lengths at age were corroborated in four lakes for bluegill of ages 1, 2, and 3. Lengths at age were compared to modes of length frequency distributions using 15 scale collections made in years 1990, 1991, and 1994 from Dock Lake (Itasca County), 1987-1992, and 1994-1995 from Sand Lake (Cass County), and 1988 and 1993 from Medicine and North Twin Lakes (Beltrami County).

One possible bias in growth estimates was gear selectivity. Size selectivity of trap nets was evaluated for bluegill less than 120 mm. Length at age was compared for fish taken in 19 mm mesh trap nets (bar measure) and by electroshocking (using 0.01 mm knotless mesh dip nets) from Sand Lake (Cass County) in 1996. Rank sum 2-sample tests were used for comparisons because of non-normality in data distributions.

Because of trap net size selection, bluegill less than 90 mm were not used when calculating median growth rates by lake class, examining the density dependence of bluegill growth, or examining the relationship of bluegill growth to lake physical and chemical characteristics. Bluegill less than 90 mm were 0-20% of the samples in lakes in all lake classes but Lake Class 38, where the percentage was 40%.

Another possible bias in growth estimates was Lee's phenomenon, defined as tendencies for back-calculations of length at given ages to be smaller as fish age (Tesch 1971). To evaluate Lee's phenomenon, median backcalculated lengths at age derived from all annuli, which should exhibit Lee's phenomenon, were compared to medians derived from the most recent annuli, which should exhibit the least amount of Lee's phenomenon. Differences in paired medians by lake class for ages 1 through 6 were evaluated with the Wilcoxon signed rank test. Too little information was available to evaluate age groups older than 6.

Density dependence in bluegill growth

The effect of population density changes on bluegill growth was examined for 11 lakes. Though thousands of lakes were available for analysis of density dependent growth, only 11 lakes were selected because trap net catches in each lake showed weak 1985 year classes and for those lakes, sufficient growth information was available covering the appropriate time period. To remove possible biases from gear selectivity, only bluegill sampled with trap nets were included. Growth was examined for the two year classes preceding (1983, 1984) and following (1986, 1987) a poorly recruited 1985 year class. I hypothesized that adjacent year classes (0-, 1-, or 2-year old juvenile bluegill) would most likely share resources with the poor year class (0-, 1-, or 2-year old juvenile bluegill) because they share littoral vegetation habitat. Null hypotheses were that growth of adjacent year classes was not affected by the poorly recruited 1985 year class. Growth comparisons were made using Weisberg's (1993) linear growth model, which partitions variation in annual scale growth due to a fish's age and due to the year and environment in which it was growing. Mean growth increments of bluegill from adjacent year classes, 1983-84 and 1986-87, were compared to the mean growth increment of same-aged fish in the same lake for all year classes (including the affected year class). Wilcoxon signed rank tests were used to determine significance of the difference between paired growth increments.

Poorly recruited year classes of bluegill were apparent in 1992 and 1993. However, insufficient growth data was available to evaluate the effect in all but one lake, Sand Lake, Cass County (1987-1996). Poor year classes in Sand Lake were indicated by low catches of bluegill with all gear types. Average scale increments were compared for affected year classes. Growth coefficient estimates and standard errors from Weisberg's additive model were also compared.

Bluegill growth versus lake physical and chemical characteristics

Relationships were examined between bluegill growth and the physical and chemical characteristics of lakes in Minnesota using correlation and regression techniques. The growth variables were mean back-calculated lengths at ages 1 (from all increments) and 2, 3, 4, 5, and 6 (from last increments only) for each survey. English units were used as most of the survey data were in these units. Physical and water chemistry variables were lake area (acres), percent littoral area (percent of lake area $\leq$15 ft. deep), maximum depth (ft.), secchi depth (ft.), total alkalinity (mg $CaCO_3$/l), and shoreline development factor (ratio of shoreline length to the circumference of a circle having the same area as the lake). The null hypotheses were that lake physical and chemical variables do not affect bluegill growth. Pearson's correlation coefficients were calculated for mean backcalculated lengths at each age versus transformed physical and chemical variables. The transformations used were $\log_e$ for lake area and maximum depth, square root for secchi depth and total alkalinity, and $\log_{10}$ for shoreline development factor. Percent littoral area was not transformed. Transformations were as suggested by Schupp (1992), and based on frequency distributions. The distribution of percent littoral was similar to the one described in Schupp (1992) and prompted separate analysis for lakes that had < 90% littoral (82% of the lakes) and $\geq$ 90% littoral. Best subset regressions were derived for predicting growth from physical and chemical variables.

Results

Bluegill growth rates and aging

Bluegill median backcalculated lengths at age varied considerably by lake class (Table 1). In Lake Class 41 waters, bluegill grew faster than average throughout much of their life. In Lake Class 32 waters, bluegill grew slower on average throughout much of their life. Bluegill mean backcalculated lengths were significantly different among lake classes for age 1 through 6 (Kruskal-Wallis one-way ANOVA, $P<0.0000$).

Bluegill ages were partially validated. Assigned ages for bluegill in 15 trap net samples were corroborated for the 4 lakes studied. Of the 30 mean backcalculated lengths estimated at ages 1 through 3, 23 agreed with the corresponding length frequency modes (Figure 1).

Trap nets were selective for some ages of bluegill. Trap nets selected for faster growing one-year-old bluegill in Sand Lake in 1996 but not for bluegill taken by electroshocking. One-year-olds taken in trap nets were longer ($\bar{x}$ = 82.2mm, SE=1.1, N=9) than those taken by electroshocking ($\bar{x}$ =75.9mm, SE=1.9, N=16; rank sum 2-sample test $P=0.048$). In contrast, trap nets did not appear to be size selective for 2-year-olds. Mean length for 2-year-olds caught in trap nets was 103.2 mm (SE=2.1, N=32) compared to mean length of 107.9 mm (SE=4.3, N=7) for electrofishing (rank sum 2-sample test, $P=0.442$). All two-year-old bluegill were large enough to be retained by trap nets.

Lee's phenomenon was evident in backcalculated lengths at age. In general, median lengths backcalculated from all annuli were less than lengths backcalculated using only last annuli. Wilcoxon signed rank tests showed significant differences in backcalculated lengths for ages 2, 3, 5, and 6 ($P<0.05$), but not for age 4 ($P=0.06$).

Table 1. Median backcalculated total lengths (mm) at age by lake class for bluegill. Samples were taken from Minnesota lakes during 1982-1994. Also listed for purpose of comparison, is an unweighted grand mean based on mean bluegill length per survey (1,947 surveys) and a weighted mean calculated from individual bluegill lengths (77,485 bluegill); a mean for Minnesota lakes from Dobie (1970); and a means of means for Minnesota lakes from Carlander (1977; pages 88-93).

Lake	Number of	Age													
Class	surveys	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	3	42	72	100	129	142	158								
2	10	38	63	94	125	152	177	196	197						
3	7	37	65	96	122	143	163	188	190						
4	1	43	79	115	122	148	162	193							
5	55	37	58	88	121	146	157	173	172	179	173	170	166	170	174
6	2	38	68	97	121	139	186	204							
7	22	38	72	108	145	160	181	199	191	199	206	214	221		
8	2	46	70	103											
10	17	39	66	94	119	143	163	174	176	196	186	181			
11	34	37	66	100	132	154	168	177	188	202	202	228	228		
12	15	38	64	88	119	143	160	182	185	220	196				
13	14	41	70	108	154	160	151	161	174	186	211	228			
14	6	40	66	98	130	154	140								
15	5	40	79	30	178	210	225	243	250	257					
16	14	39	82	122	146	171	176	183	196	208					
17	5	36	77	89	122	126	142	173	185						
19	18	39	75	114	149	172	187	206	209	222	217				
20	37	39	62	89	116	137	162	172	171	179	188	197			
21	29	41	66	92	117	138	158	171	185	197	199	191			
22	133	40	64	89	118	148	162	176	185	194	199	185			
23	106	38	58	80	103	130	151	164	173	181	196	206	236	234	
24	153	42	70	98	124	144	156	165	168	189	190				
25	134	41	68	96	125	146	163	170	180	179	185	189	186		
26	2	49	89	130	154	188	235								
27	137	40	64	90	120	147	161	176	189	198	204	199	211		
28	61	41	64	90	121	144	159	171	183	190	177	181	180		
29	92	39	61	84	106	128	148	162	170	177	182	196	223	235	240
30	77	44	79	112	137	147	157	158	162	170	184				
31	144	41	65	91	117	144	162	173	187	189	185	216			
32	69	38	56	76	95	114	133	148	157	166	167	154	155		
33	27	42	68	100	129	157	175	192	211						
34	108	45	80	112	139	157	175	184	185	175	176	200			
35	29	42	67	94	116	139	155	169	177	193	186	205			
36	34	44	71	99	125	148	163	168	178	184	186	188	197		
37	22	49	81	111	136	155	166	172	179	191	192	221			
38	62	45	76	102	125	144	153	155	155	164	192				
39	62	44	75	108	136	160	177	185	197	208	191	223	208	223	228
40	36	46	83	114	126	146	149	161	178	182					
41	71	48	100	144	162	179	189	197	214	240	247	256			
42	37	49	87	124	150	162	181	192	208	202					
43	54	48	94	132	157	174	182	194	174	188					
unweighted		43	72	102	128	148	163	174	181	187	191	197	198	207	214
weighted		42	68	93	115	135	151	163	172	182	189	194	195	201	214
Dobie (1970)			48	86	124	155	180	198	211	218	231	244			
Carlander (1977)		83	118	133	160	184	200	204	210						

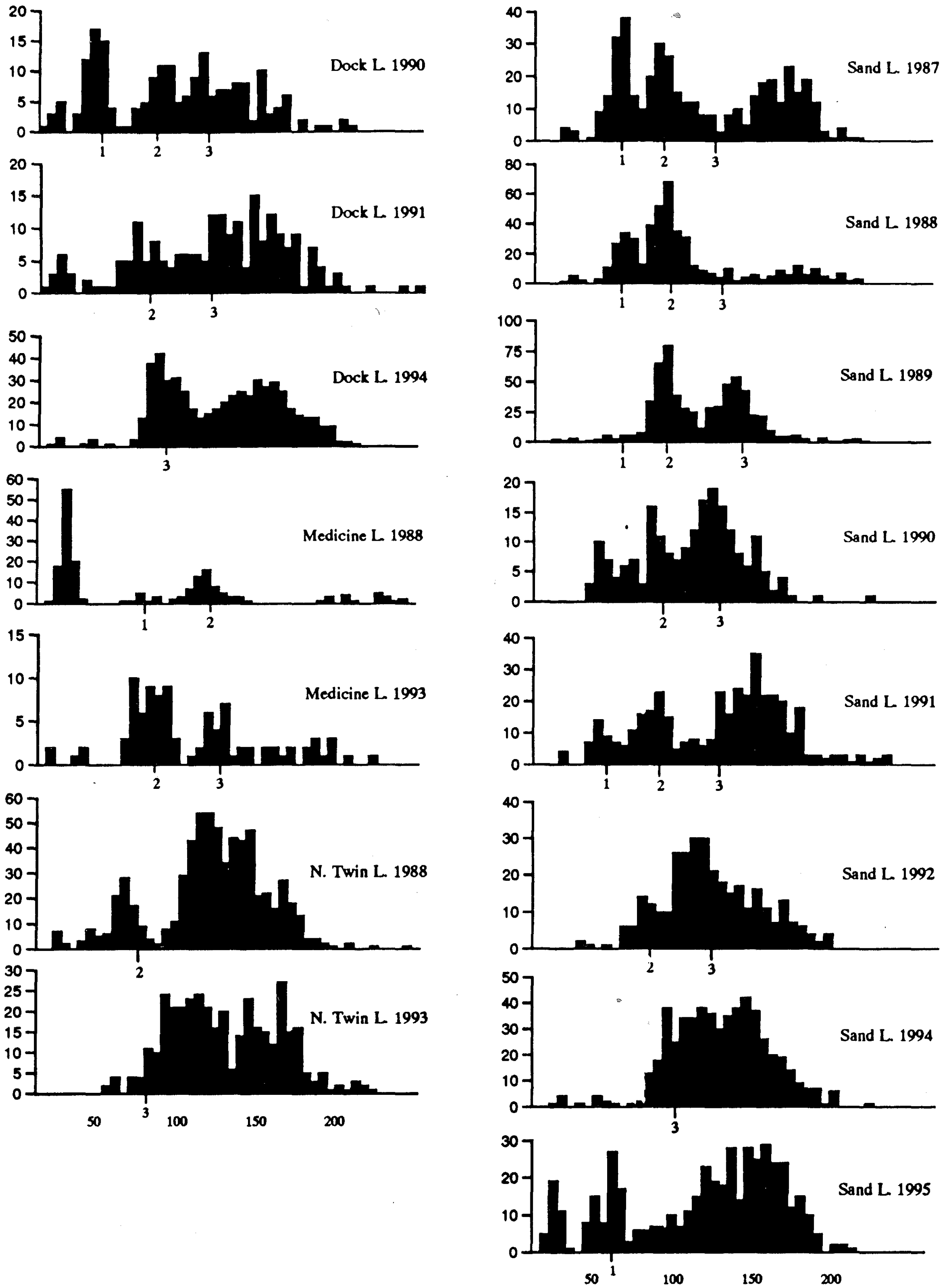

Figure 1. Length frequency of bluegill sampled in Dock Lake (Itasca County), Medicine and North Twin (Beltrami County), and Sand Lake (Cass County), 1987-1995. Tick marks on the X-axis denote the mean backcalculated lengths for age groups 1-3. Mean backcalculated lengths are shown only for age groups for which at least 10 bluegill were aged.

Density dependence in bluegill growth

The growth of bluegill which shared resources with a poorly recruited 1985 year class provided little evidence for density dependent growth in 11 lakes. With one exception (the 1986 year class at age 1), growth of bluegill in affected year classes was not significantly different than growth of same age bluegill from the same lake on the average (Table 2).

The effects of poor year classes on bluegill growth in Sand Lake in 1992 and 1993 were obscured by cool temperatures, which apparently retarded bluegill growth. June mean daily air temperatures were 15.7°C in 1992 and 15.4°C in 1993 at Deep Portage Conservation Reserve (data from Minnesota State Climatology Office), which is located less than 8 km from Sand Lake. Mean June air temperatures were approximately 2°C below the grand mean air temperature (17.5°C) for June during 1985-1994 and 1996. Bluegill did not grow faster than average as a result of low densities contributed by the 1992 and 1993 year classes. Rather, age-0, -1, and -2 bluegill formed smaller scale increments in 1992 and 1993 than did 0-, 1-, and 2-year-olds from other year classes (Figure 2). Three-year-old and older bluegill showed no pattern. Growth coefficient estimates from Weisberg's linear growth model for Sand Lake also illustrated that growth of bluegill was slower in 1992 and 1993 than in other years during 1980-1994 (Figure 3).

Bluegill growth vs. lake physical and chemical characteristics

Bluegill growth was related to physical characteristics and water chemistry of Minnesota lakes. Mean bluegill backcalculated lengths for ages 1-6 were correlated with maximum depth, littoral area, total alkalinity, and secchi depth ($P<0.05$, Table 3). Mean backcalculated lengths at all but age 1 were correlated significantly with shoreline development factor, and at all but ages 1, 2 and 3 with lake area. All correlations were consistently positive or negative. Correlations with lake area, littoral area, total alkalinity, and shoreline development factor were positive. Correlations with maximum depth and secchi depth were negative. Secchi depth yielded the strongest correlations at all ages.

In best subset regression analyses, secchi depth yielded the highest r^2 in single variable models, explaining 11-26% of the variation in growth of bluegill ages 1-6 (Table 4). The best two-variable models included some combination of secchi depth (in all but age 1), maximum depth, and total alkalinity, explaining 15-29% of the variation. The best three-variable models included secchi depth, maximum depth, and total alkalinity and explained 17-32% of the variation for ages 1-5. For age-6 bluegill, shoreline development factor replaced maximum depth. Analyses for lakes with littoral area < 90% gave similar results. In contrast, the lakes with littoral area

Table 2. Probabilities from Wilcoxon signed rank tests, which compared growth of age-0, -1, and -2 bluegill sharing resources with the poorly recruited 1985 bluegill year class and growth of same age bluegill from the same lake on the average. Growth data were derived from scale samples taken during surveys of 11 Minnesota lakes.

	Year class				
Age	1983	1984	1985	1986	1987
0				0.56	0.12
1		0.23	0.34	0.02	
2	0.48	0.76			

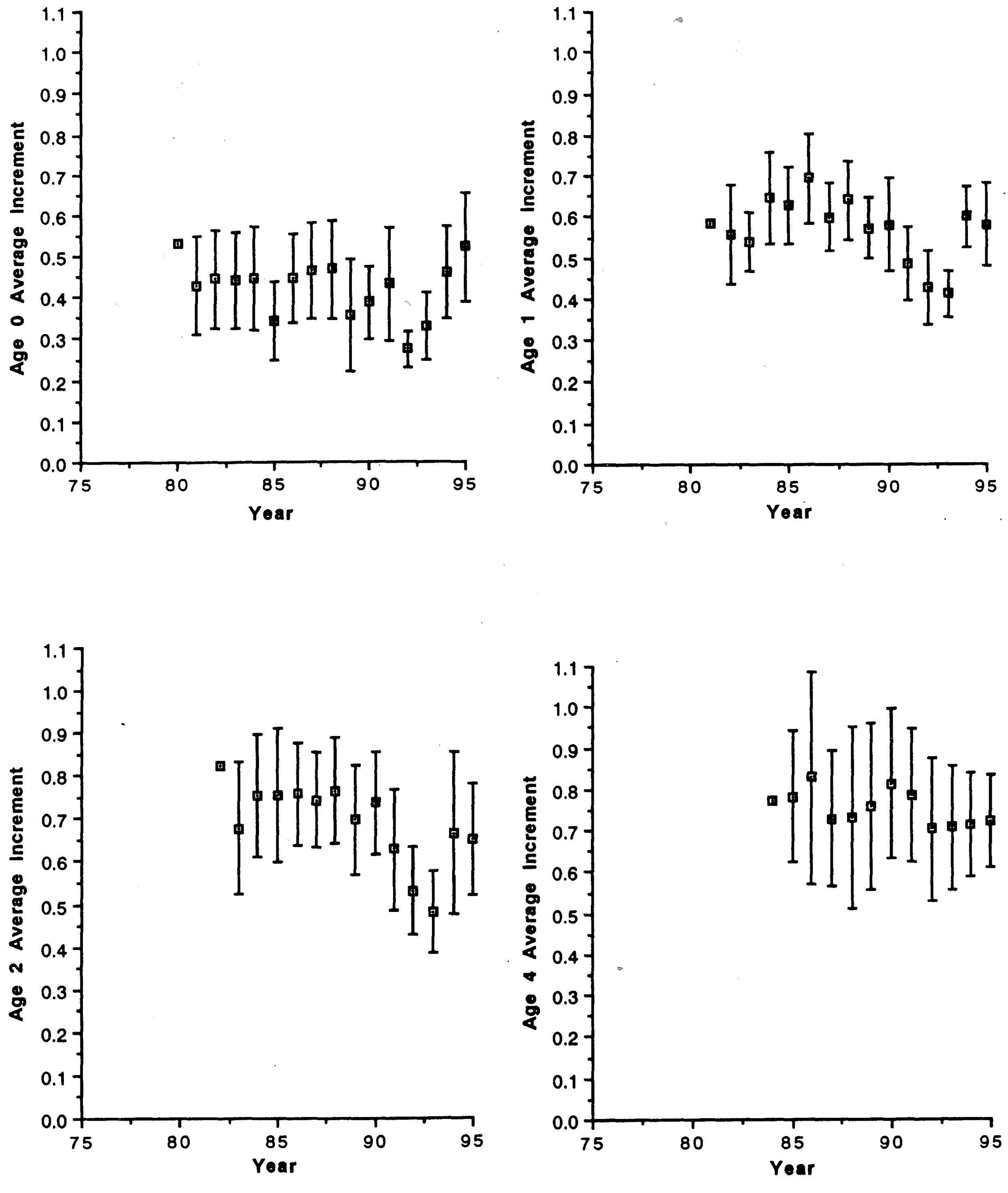

Figure 2. Average scale increments (± 1 SD) for 0-, 1-, 2-, and 4-year-old bluegill of year classes 1987-95 from Sand Lake, Cass Co., Minnesota.

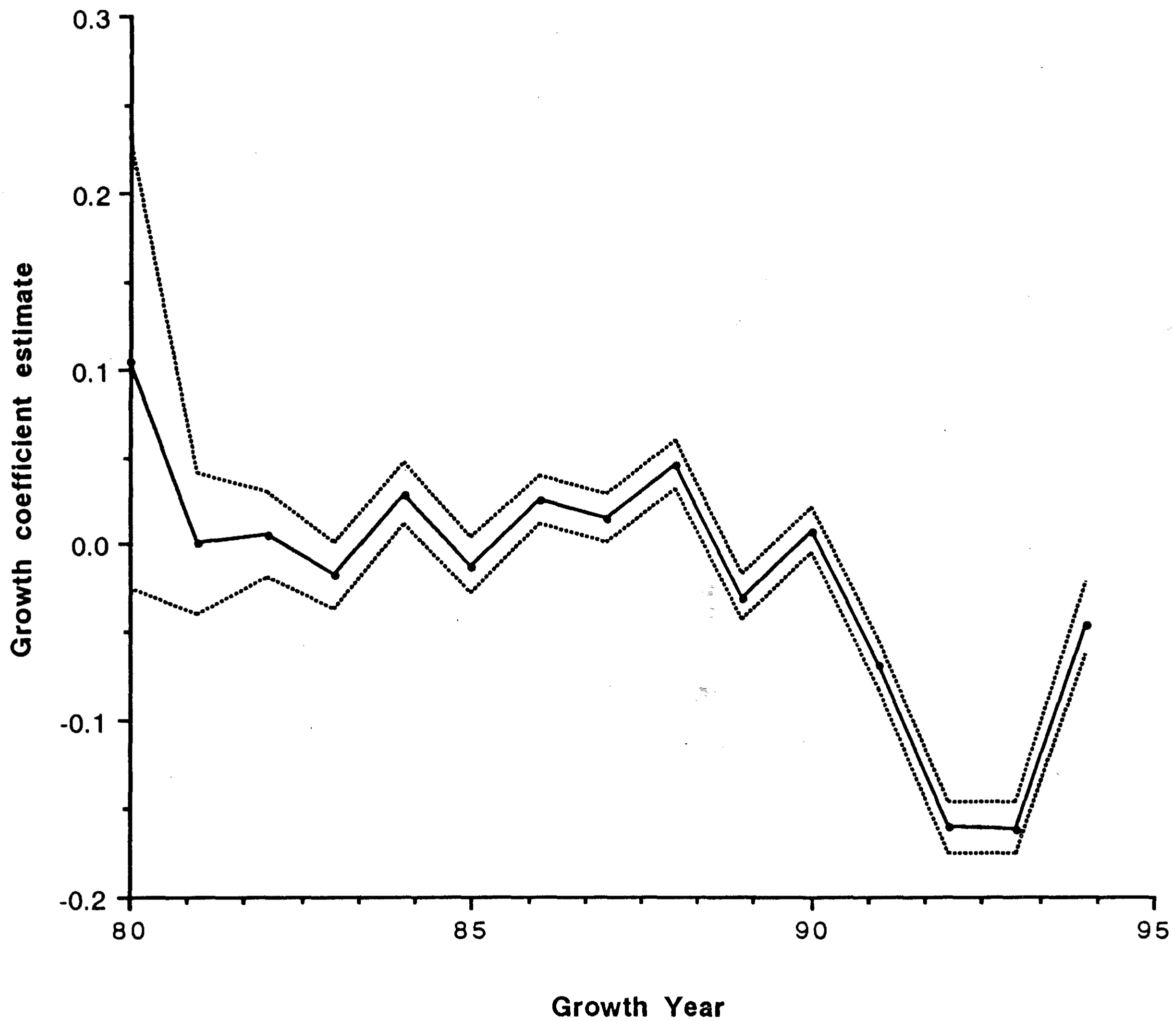

Figure 3. Bluegill growth coefficient estimates (± 1 SE) relative to 1995, from Weisberg's (1993) linear growth model. Bluegill growth was estimated from scales. Bluegill were sampled from Sand Lake, Cass Co., Minnesota, 1987-1996.

Table 3. Pearson correlation coefficients (r) for mean back-calculated lengths of bluegill, 1982-1995, and lake characteristic variables. Back-calculated lengths were determined using all annuli for lengths at age 1 or most recent annuli for lengths at ages 2-6. Lake variables included percent littoral area and five transformed variables, $\log_e$ of lake area (acre) and maximum depth (ft.), square root of total alkalinity (mg $CaCO_3$ /l) and secchi depth (ft.), and $\log_{10}$ of shoreline development factor (SDF). Significant correlations are designated by * (P<0.05).

Length at	$\log_e$ (lake area)	$\log_e$ (max. depth)	Percent littoral area	Sqrt. (total alkal.)	Sqrt. (secchi depth)	$\log_{10}$ (SDF)	N
Age 1	0.0020	-0.2860*	0.2614*	0.2191*	-0.3259*	0.0286	1831
Age 2	0.0149	-0.4129*	0.3248*	0.1947*	-0.4472*	0.0942*	1160
Age 3	0.0175	-0.3983*	0.3411*	0.1838*	-0.5133*	0.0718*	1583
Age 4	0.0668*	-0.3334*	0.2864*	0.1884*	-0.4808*	0.0720*	1606
Age 5	0.1122*	-0.2583*	0.2195*	0.1774*	-0.4362*	0.0654*	1553
Age 6	0.1255*	-0.1784*	0.1536*	0.1980*	-0.3404*	0.0800*	1356

Table 4. Best subset regression model variables and r^2 for bluegill mean backcalculated lengths at age 1, 2, 3, 4, 5, and 6 versus lake physical and water chemistry characteristics for Minnesota lakes: $\log_e$ area (A), percent littoral area (B), $\log_e$ maximum depth (C), sqrt. secchi depth (D), sqrt. total alkalinity (E), $\log_{10}$ shoreline development factor (F).

Age	One variable model	r^2	Two variable model	r^2	Three variable model	r^2
1	D	0.106	C,E	0.148	C,D,E	0.173
2	D	0.170	C,D	0.244	C,D,E	0.290
3	D	0.264	C,D	0.287	C,D,E	0.316
4	D	0.231	D,E	0.254	C,D,E	0.273
5	D	0.190	D,E	0.214	C,D,E	0.220
6	D	0.116	D,E	0.151	D,E,F	0.159

≥ 90% showed no discernable pattern in results. Physical and chemical variables showed limited ranges in the relatively small number of lakes with littoral area ≥ 90%.

Discussion

Bluegill growth rates and aging

Most median growth rates estimated by lake class were lower than statewide standard average growth rates for bluegill compiled by Dobie (1970, Table 1, Figure 4) and a mean of means calculated for Minnesota by Carlander (1977, Table 1, Figure 4). Only a few lake classes produced comparable-sized bluegill and for some of those, median growth rates were based on small sample sizes. Marked changes in habitat and exploitation are the most likely causes for the apparent decline in bluegill growth since pre-1980. Alternatively, the 'decline' may have been the result of introduced error in the estimation of growth rates by Dobie and Carlander due to unknown biases in their data sets.

Agreement of bluegill lengths at age and length frequency modes in this study supported the use of the scale technique for aging bluegill. Further support comes from Regier (1962) who validated the scale method for bluegill sampled in New York. Though validation based on known age fish is recommended (Beamish and McFarlane 1983), it appears that using scales to age bluegill in Minnesota is justified, at least for ages 1-3.

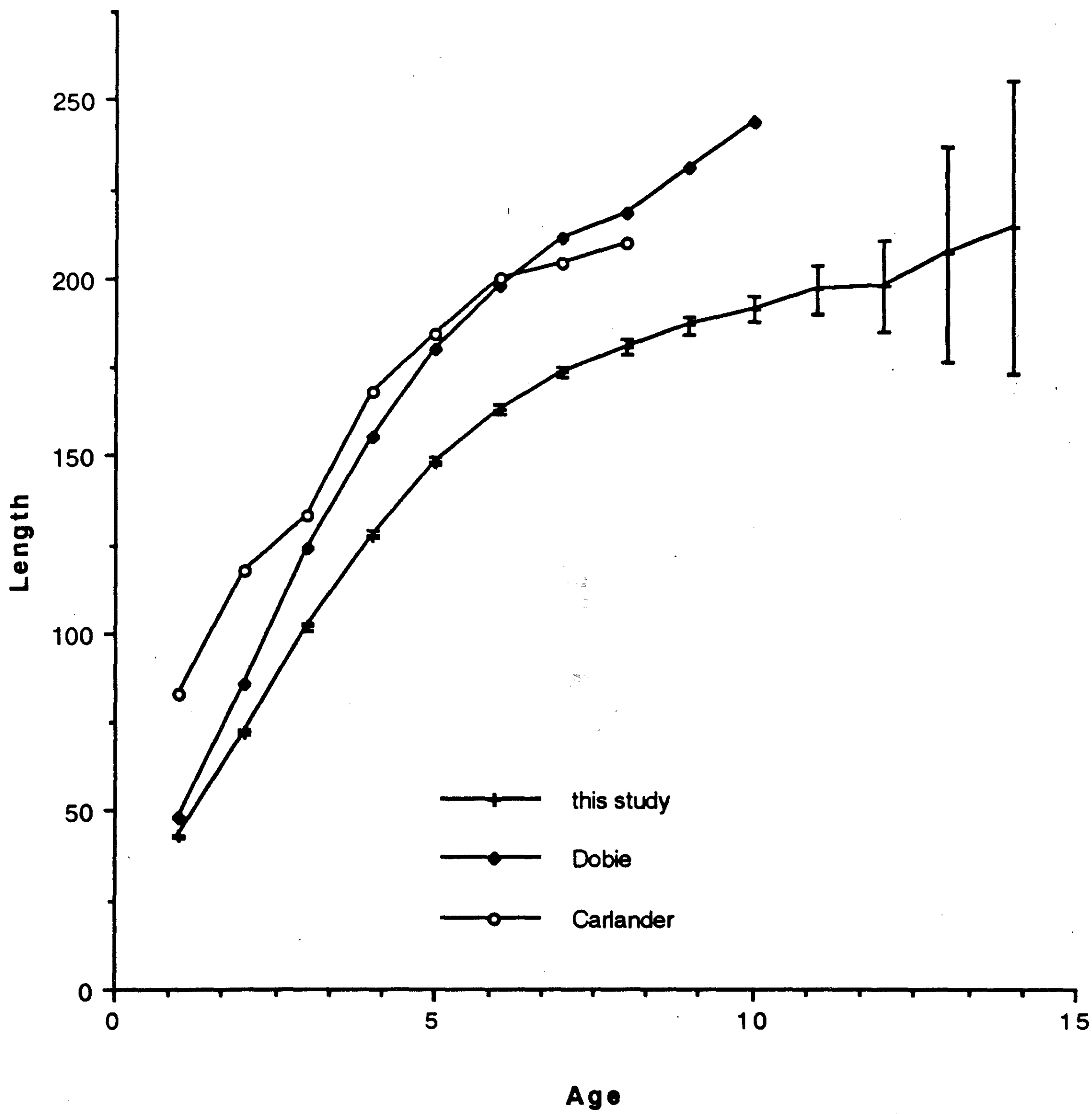

Figure 4. Grand mean backcalculated length at age (± .2 SE) of bluegill sampled in Minnesota lakes based on mean backcalculated length per survey (this paper), compared to other states (Carlander 1977), and an earlier Minnesota standard growth rate (Dobie 1970).

Density dependence in bluegill growth

Temperature effects on bluegill growth may be stronger than effects of density changes due to poor year classes. Water temperature in Sand Lake retarded bluegill growth compared to growth in reference years and masked any effect that the weak 1992 and 1993 year classes might have had. It may be difficult to control for temperature and isolate density effects on growth in field experiments conducted on many lakes at one time.

Water temperature has been shown to have a strong effect on growth of other species than bluegill, such as yellow perch. Le Cren (1958) found that Lake Windermere perch exhibited most of their annual growth from June to September - when littoral water temperatures exceed 14°C. Temperature records from 1935, converted to degree-days in excess of 14°C, showed strong correlation with year-to-year fluctuation in growth of various year classes. Le Cren ascribed two-thirds of the year-to-year variations in growth to temperature.

Density changes due to poor year classes may affect bluegill growth weakly or may have their greatest effect between certain year classes. Only age 1 bluegill in the 1986 year class grew significantly better than other age 1 bluegill, presumably because competition for littoral food resources was lessened due to low densities of the bluegill in the poor 1985 year class. However, other year classes showed no growth response though they should have also experienced lessened competition, for example, age-2 bluegill of the 1984 year class or age-1 survivors of the 1985 year class.

Young-of-the-year bluegill may not have shared food resources with other year classes for a long enough period to have an effect. Young-of-the-year bluegill inhabit the limnetic zone for 30-45 days after dispersion (Beard 1982) and thus would not provide as much competition for the littoral food resources as do age-1 and age-2 bluegill. These older bluegill inhabit the littoral zone until they are large enough to avoid large predators (Werner et al. 1983), usually the entire summer.

Bluegill growth vs. lake physical and chemical characteristics

Secchi depth, maximum depth, and total alkalinity explained a small portion of the variation in bluegill mean backcalculated length through age 5. In this study, fast bluegill growth was correlated with low water clarity, shallow maximum depth, and high total alkalinity. Another study by Snow and Staggs (1994) on 115 lakes in Wisconsin found similar correlations. They found that secchi depth was negatively associated with bluegill length at age and that fast-growing bluegill populations occurred in turbid, productive lakes with high MEI (morphoedaphic index, total alkalinity/mean depth), high alkalinity, and high conductivity. The average deviations of bluegill length-at-age were subjected to a stepwise regression analysis. Their resulting seven variable model included secchi disk transparency and MEI and explained 46.4% of variance.

Secchi depth, maximum depth, and total alkalinity may have explained a small portion of the variability of bluegill growth in this study because they indirectly affect bluegill growth. Secchi depth has been negatively associated, and total alkalinity has been positively associated with lake productivity (Wetzel 1975). Lake productivity has been associated with fish yields through such measures as MEI (Ryder et al. 1974). High total alkalinity supported increased growth of both phytoplankton and submerged vegetation (Wetzel 1975), which support bluegill foods and thus indirectly affect bluegill growth.

In addition to temperature, variables such as food resources, species interactions, and exploitation, may strongly affect bluegill growth and explain more variation than lake characteristics and density changes due to poor year classes. Other literature has shown that important food resources for bluegill growth vary by bluegill size. Zooplankton were a main diet component for adult bluegill (Mittelbach 1981; Werner et al. 1983) so adult bluegill grew better when zooplankton food resources were not shared with smaller size classes of bluegill (Werner et al. 1983). Juvenile bluegill consumed mainly macroinvertebrates (Beard 1982). Benthic macroinvertebrates were more abundant in submerged vegetation than open sediments (Gilinsky 1984). Littoral vegetation increased abundance of juvenile foods (Schramm and Jirka 1989) and promoted bluegill growth (Crowder and Cooper 1982; Engel 1985; Schneider 1993).

Competition affects bluegill growth by altering food density and can be reduced or intensified by vegetation. Littoral vegetation may reduce intraspecific competition by leaving zooplankton food resources solely to adult bluegill (Werner et al. 1983). Juvenile bluegill confined to littoral vegetation (Dimond and Stork 1985), could experience increased competition among all residents sharing food resources. Thus, the growth rate of pumpkinseed, yellow perch, and largemouth bass juveniles declined with increasing density of juvenile bluegill (Osenberg et al. 1994).

Predators affect bluegill growth by altering bluegill density and may consume enough bluegill to have a bigger effect on growth than do missing year classes. Predators may also affect bluegill growth if their presence confines juvenile bluegill (Werner et al. 1983) to areas with poor food resources. Predation outcomes are altered by the surrounding vegetation. Littoral vegetation reduced risk of predation (Werner et al. 1983). Overly dense vegetation can reduce bluegill growth (Theiling 1990) and can also reduce predator effectiveness (Savino and Stein 1982; Smith 1995). Dense bluegill populations cropped their food supply and their growth slowed (Gerking 1962). High abundance of young walleye, a potential predator, was found to be correlated with good bluegill growth (Snow and Staggs 1994). Yellow perch are also a potential bluegill predator. In a lake stocked with northern pike for 10 years, Anderson and Schupp (1986) found low abundance and small average size of yellow perch coupled with high abundance and small average size of bluegill, which the authors noted may be a symptom of excessive pike predation on perch. Yellow perch of various sizes may consume or compete with bluegill fry and juveniles, control bluegill density, and promote good bluegill growth.

Recreational fishing may affect bluegill growth by altering bluegill densities. Exploitation has reduced bluegill density and average size (Coble 1988), affected size structure (Olson and Cunningham 1989), and reduced mean age and increased mortality rate (Goedde and Coble 1981). Goedde and Coble (1981) noted that bluegill growth rates were slower on a lake where angling was allowed than on a lake where it was not. Exploitation may also affect energy allotment to growth in bluegills. Bluegills in heavily exploited populations matured earlier and at a smaller size, and grew slower when surplus energy was directed at gonadal rather than somatic growth (Drake et al. 1997).

Modeling of bluegill growth could be enhanced by including variables other than lake physical morphology and water chemistry. However, some of those variables, such as species interactions, are difficult to document and others, such as vegetation area and density, daily water temperature, and recreational fishing pressure, would be expensive and difficult to collect from many lakes. Easily measured substitutes might be yellow perch, walleye, largemouth bass, pumpkinseed, and bluegill relative abundance or weight in survey netting, statewide atmospheric isopleths, and fishing effort estimates using periodic angler counts from a limited creel survey or by remote camera recording.

Management Implications and Recommendations

First, median, and third quartile growth rates of bluegill by lake class can be used as references to better assess bluegill growth in various Minnesota lakes (Table 1). With these measures, we can more effectively compare bluegill growth rates between individual lakes within a lake class and between lakes in different regions of the state. With these growth data, we can also evaluate bluegill growth changes due to management or other human activities.

Bluegill growth rates should be compared within lake classes because significant differences in mean lengths at age were found between lake classes. Growth comparisons will be more valid, and atypical growth will be more readily identified by referring to growth characteristics of bluegill populations from similar lakes. Bluegill growth rates were related to lake physical and chemical characteristics which were the core of the lake classification system (Schupp 1992).

Those aging bluegill might reduce aging errors of older bluegill by analyzing scales from age-0 and -1 bluegill taken by seining, electroshocking, or small mesh trap nets. Aging small bluegill will help to determine the position of the first annulus.

A notation of gear should be included in the text portion of DISBCAL .ANU files whenever non-standard gear is used. This would facilitate attempts to reduce bias due to gear selectivity when analyzing bluegill growth in large data sets.

Water temperature strongly influenced bluegill growth. Therefore, water temperatures should be recorded regularly in evaluations of management activity that might affect bluegill growth.

References

Anderson, D.W., and D.H. Schupp. 1986. Fish community responses to northern pike stocking in Horseshoe Lake, Minnesota. Minnesota Department of Natural Resources, Section of Fisheries Investigational Report 387, St. Paul.

Beamish, R.J., and G.A. McFarlane. 1983. The forgotten requirement for age validation in fisheries biology. Transaction of American Fisheries Society 112:735-743.

Beard, T.D. 1982. Population dynamics of young-of-the-year bluegill. Wisconsin Department of Natural Resources Technical Bulletin 127, Madison.

Carlander, K.D. 1977. Handbook of Freshwater Fishery Biology. Volume 2. The Iowa State University Press, Ames.

Carlander, K.D. 1981. Caution on the use of the regression method of back-calculation lengths from scale measurements. Fisheries (Bethesda) 6:2-4.

Coble, D.W. 1988. Effects of angling on bluegill populations: management implications. North American Journal of Fisheries Management 8:277-283.

Crowder, L.B., and W.E. Cooper. 1979. Structural complexity and fish-prey interactions in ponds: a point of view. Pages 2-10 *in* D.L. Johnson and R.A. Stein, editors, Response of fish to habitat structure in standing water. North Central Division, American Fisheries Society Special Publication 6, Bethesda, Maryland.

Dimond, W.F., and T.W. Stork. 1985. Abundance, spatiotemporal distribution, and growth of bluegill and redear sunfish fry in 0.6-ha pond. Journal of Freshwater Ecology 3:93-102.

Dobie, J. 1970. Fisheries manager's handbook. Minnesota Department of Conservation, Section of Fisheries Special Publication 82, St. Paul.

Drake, M.T., J.E. Claussen, D.P. Philipp, and D.L. Pereira. 1997. A comparison of bluegill reproductive strategies and growth among lakes with different fishing intensities. North American Journal of Fisheries Management 17:496-507.

Engel, S. 1985. Aquatic community interactions of submerged macrophytes. Wisconsin Department of Natural Resources Technical Bulletin 156, Madison.

Frie, R.V. 1982. Measurement of fish scales and back-calculations of body lengths using a digitizing pad and microcomputer. Fisheries (Bethesda) 7(6):5-8.

Gerking, S.D. 1962. Production and food utilization in a population of bluegill sunfish. Ecological Monographs 32:31-78.

Gilinsky, E. 1984. The role of fish predation and spatial heterogeneity in determining the benthic community structure. Ecology 65:455-468.

Goedde, L.E., and D.W. Coble. 1981. Effects of angling on a previously fished and unfished warmwater fish community in two Wisconsin lakes. Transactions of American Fisheries Society 110:594-603.

Gutreuter, S. 1987. Considerations for estimation and interpretation of annual growth rates. Pages 115-126 *in* R.C. Summerfelt and G.E. Hall, editors. The age and growth of fish. The Iowa State University Press, Ames.

Jacobson, P.C. 1993. Analysis of factors affecting growth of northern pike in Minnesota. Minnesota Department of Natural Resources, Section of Fisheries Investigational Report 424, St. Paul.

Latta, W.C., and J.W. Merna. 1977. Some factors influencing size of the year class of bluegills (*Lepomis macrochirus*) in ponds. Michigan Academician 9:483-502.

Le Cren, E.D. 1958. Observations on the growth of perch (*Perca fluviatilis* L.) over twenty-two years, with special reference to the effects of temperature and changes in population density. Journal of Animal Ecology 27:287-334.

Mittelbach, G.G. 1981. Foraging efficiency and body size: a study of optimal diet and habitat use by bluegills. Ecology 62:1370-1386.

Olson, D.E., and P.K. Cunningham. 1989. Sport fishing trends over a 58-year period shown by an annual Minnesota fishing contest. North American Journal of Fisheries Management 9:287-297.

Osenberg, C.W., M.H. Olson, and G.G. Mittelbach. 1994. Stage structure in fishes: resource productivity and competition in gradients. Pages 151-170 *in* D.J. Stouder, K.L. Fresh and R.J. Feller, editors. Theory and application in fish feeding ecology. University of South Carolina Press, Columbia.

Osenberg, C.W., E.E. Werner, G.G. Mittelbach, and D.J. Hall. 1988. Growth patterns in bluegill (*Lepomis macrochirus*) and pumpkinseed (*L. gibbosus*) sunfish: environmental variation and the importance of ontogenetic niche shifts. Canadian Journal of Fisheries and Aquatic Sciences 45:17-26.

Regier, H.A. 1962. Validation of the scale method for estimating age and growth of bluegills. Transactions of the American Fisheries Society 91(4):362-374.

Ryder, R.A., S.R. Kerr, K.H. Loftus, and H.A. Regier. 1974. The morphoedaphic index, a fish yield estimator - review and evaluation. Journal Fisheries Research Board Canada 31: 663-88.

Savino, J.F., and R.A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. Transactions of the American Fisheries Society 111:255-266.

Schlagenhaft, T. 1993. Manual of instructions for lake survey. Minnesota Department of Natural Resources, Section of Fisheries Special Publication 147, St. Paul.

Schneider, J.C. 1993. Dynamics of good bluegill population in two lakes with dense vegetation. Michigan Department of Natural Resources Fisheries Research Report 1991, Lansing.

Schramm, H.L., Jr., and K.J. Jirka. 1989. Epiphytic macroinvertebrates as a food resource for bluegills in Florida lakes. Transactions of the American Fisheries Society 118:416-426.

Schupp, D.H. 1992. An ecological classification of Minnesota lakes with associated fish communities. Minnesota Department of Natural Resources, Section of Fisheries Investigational Report 417, St. Paul.

Smith, K.D. 1995. Vegetation-open water interface and the predator-prey interaction between largemouth bass and bluegills: a field experiment. Michigan Department of Natural Resources Fisheries Research Report 2000, Lansing.

Snow, H.E., and M.D. Staggs. 1994. Factors related to fish growth in northwestern Wisconsin lakes. Wisconsin Department of Natural Resources Bureau of Fish Management Report 162, Madison.

Tesch, F.W. 1971. Age and growth. Pages 98-130 *in* W.E. Ricker, editor. Methods for assessment of fish production in fresh waters. Blackwell Scientific Publications, Oxford, England.

Theiling, C.H. 1990. The relationships between several limnological factors and bluegill growth in Michigan lakes. Michigan Department of Natural Resources Fisheries Research Report 1970. Ann Arbor.

Weisberg, S. 1993. Using hard-part increment data to estimate age and environmental effects. Canadian Journal of Fisheries and Aquatic Sciences 50:1229-1237.

Werner, E.E., J.F. Gilliam, D.J. Hall, and G.G. Mittelbach. 1983. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64:1540-1548.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Co., Philadelphia.

Wiener, J.G., and W.R. Hanneman. 1982. Growth and condition of bluegills in Wisconsin lakes: effects of population density and lake pH. Transactions of American Fisheries Society 111:761-767.

Appendix 1. Median backcalculated total lengths (inches) at age by lake class for bluegill. Samples were taken from Minnesota lakes during 1982-1994.

	Age													
Lake Class	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.6	2.8	3.9	5.0	5.5	6.2								
2	1.5	2.4	3.7	4.9	5.9	6.9	7.7	7.7						
3	1.4	2.5	3.7	4.8	5.6	6.4	7.4	7.4						
4	1.6	3.1	4.5	4.8	5.8	6.3	7.6							
5	1.4	2.2	3.4	4.7	5.7	6.1	6.8	6.7	7.0	6.8	6.6	6.5	6.6	6.8
6	1.5	2.6	3.8	4.7	5.4	7.3	8.0							
7	1.5	2.8	4.2	5.7	6.3	7.1	7.8	7.5	7.8	8.1	8.4	8.7		
8	1.8	2.7	4.0											
10	1.5	2.6	3.7	4.6	5.6	6.4	6.8	6.9	7.7	7.3	7.1			
11	1.4	2.6	3.9	5.2	6.0	6.6	6.9	7.4	7.9	7.9	8.9	8.9		
12	1.5	2.5	3.4	4.6	5.6	6.3	7.1	7.2	8.6	7.7				
13	1.6	2.7	4.2	6.0	6.3	5.9	6.3	6.8	7.3	8.3	8.9			
14	1.5	2.6	3.8	5.1	6.0	5.5								
15	3.1	5.1	7.0	8.2	8.8	9.5	9.8	10.1						
16	1.5	3.2	4.8	5.7	6.7	6.9	7.2	7.7	8.1					
17	1.4	3.0	3.5	4.8	4.9	5.5	6.8	7.2						
19	1.5	2.9	4.4	5.8	6.7	7.3	8.1	8.2	8.7	8.5				
20	1.5	2.4	3.5	4.5	5.3	6.3	6.7	6.7	7.0	7.4	7.7			
21	1.6	2.6	3.6	4.6	5.4	6.2	6.7	7.2	7.7	7.8	7.5			
22	1.5	2.5	3.5	4.6	5.8	6.3	6.9	7.2	7.6	7.8	7.2			
23	1.5	2.2	3.1	4.0	5.1	5.9	6.4	6.8	7.1	7.7	8.1	9.2	9.2	
24	1.6	2.7	3.8	4.8	5.6	6.1	6.5	6.6	7.4	7.4				
25	1.6	2.6	3.7	4.9	5.7	6.4	6.6	7.0	7.0	7.2	7.4	7.3		
26	1.9	3.5	5.1	6.0	7.4	9.2								
27	1.5	2.5	3.5	4.7	5.7	6.3	6.9	7.4	7.8	8.0	7.8	8.3		
28	1.6	2.5	3.5	4.7	5.6	6.2	6.7	7.2	7.4	6.9	7.1	7.0		
29	1.5	2.4	3.3	4.1	5.0	5.8	6.3	6.6	6.9	7.1	7.7	8.7	9.2	9.4
30	1.7	3.1	4.4	5.3	5.7	6.1	6.2	6.3	6.6	7.2				
31	1.6	2.5	3.5	4.6	5.6	6.3	6.8	7.3	7.4	7.2	8.5			
32	1.5	2.2	2.9	3.7	4.4	5.2	5.8	6.1	6.5	6.5	6.0	6.1		
33	1.6	2.6	3.9	5.0	6.1	6.8	7.5	8.3						
34	1.7	3.1	4.4	5.4	6.1	6.8	7.2	7.2	6.8	6.9	7.8			
35	1.6	2.6	3.7	4.5	5.4	6.1	6.6	6.9	7.6	7.3	8.0			
36	1.7	2.8	3.9	4.9	5.8	6.4	6.6	7.0	7.2	7.3	7.4	7.7		
37	1.9	3.1	4.3	5.3	6.1	6.5	6.7	7.0	7.5	7.5	8.7			
38	1.7	2.9	4.0	4.9	5.6	6.0	6.1	6.1	6.4	7.5				
39	1.7	2.9	4.2	5.3	6.3	6.9	7.2	7.7	8.1	7.5	8.7	8.1	8.7	8.9
40	1.8	3.2	4.4	4.9	5.7	5.8	6.3	7.0	7.1					
41	1.8	3.9	5.6	6.3	7.0	7.4	7.7	8.4	9.4	9.7	10.0			
42	1.9	3.4	4.8	5.9	6.3	7.1	7.5	8.1	7.9					
43	1.8	3.7	5.2	6.1	6.8	7.1	7.6	6.8	7.4					

Appendix 2. First quartile (1Q), median backcalculated lengths (MD), 3rd quartile (3Q), number of surveys used to calculate medians (Ns), and number of individual fish in the total surveys for that lake class (Nf), for bluegill in 43 Minnesota lake classes.

	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lake class 1														
1Q	41.6	63.6	80.4	94.9	106.7	M								
MD	41.9	71.2	100.0	129.0	141.8	157.6								
3Q	42.5	76.6	114.4	144.7	162.5	M								
Ns	3	3	3	3	3	1								
Nf	14	14	12	11	9	1								
Lake class 2														
1Q	36.0	62.2	88.5	116.9	142.3	167.5	182.3	M						
MD	37.7	63.1	94.0	125.2	152.1	177.4	196.5	197.1						
3Q	38.3	66.0	100.4	133.6	165.0	186.5	203.2	M						
Ns	10	10	10	10	10	10	8	1						
Nf	924	917	816	679	447	226	82	2						
Lake class 3														
1Q	35.9	64.0	91.6	114.2	140.1	146.8	M	M						
MD	37.1	64.8	96.0	122.0	142.6	163.2	188.5	189.8						
3Q	39.2	70.1	105.9	126.4	153.4	181.8	M	M						
Ns	7	7	7	7	7	6	2	1						
Nf	159	159	145	87	48	10	3	1						
Lake class 4														
1Q	M	M	M	M	M	M	M							
MD	42.7	79.0	115.2	122.0	147.6	162.0	193.2							
3Q	M	M	M	M	M	M	M							
Ns	1	1	1	1	1	1	1							
Nf	28	28	16	3	2	2	1							
Lake class 5														
1Q	35.0	53.4	72.6	91.2	111.6	133.0	140.8	159.8	165.7	155.0	157.8	164.8	M	M
MD	36.7	58.5	87.9	121.4	145.8	157.1	173.4	171.8	179.4	172.7	169.7	166.1	170.5	173.6
3Q	39.6	73.0	112.7	150.4	173.9	185.0	197.9	202.1	211.9	219.4	219.3	178.0	M	M
Ns	54	54	54	53	49	46	44	31	23	10	6	3	2	1
Nf	2135	2124	1920	1447	1047	682	400	167	83	39	19	8	4	1
Lake class 6														
1Q	M	M	M	M	M	M	M							
MD	38.4	67.8	97.0	120.8	139.2	185.8	204.5							
3Q	M	M	M	M	M	M	M							
Ns	2	2	2	2	2	1	1							
Nf	26	26	25	11	4	1	1							

Appendix 2. Continued.

	Age													
	age1	age2	age3	age4	age5	age6	age7	age8	age9	age10	age11	age12	age13	age14
Lake class 7														
1Q	35.5	61.6	92.2	117.7	143.3	157.7	167.4	175.2	191.8	205.1	M	M		
MD	38.3	71.6	108.4	144.9	159.6	181.4	199.4	191.1	199.2	206.2	214.5	220.9		
3Q	42.2	79.8	121.2	156.0	176.0	200.1	206.5	204.4	208.6	214.2	M	M		
Ns	20	20	20	20	18	15	11	8	7	3	2	2		
Nf	763	763	716	577	516	312	152	90	39	14	4	2		
Lake class 8														
1Q	M	M	M											
MD	46.0	69.8	103.2											
3Q	M	M	M											
Ns	2	2	2											
Nf	9	9	5											
Lake class 10														
1Q	36.7	60.4	86.5	112.6	131.0	149.2	152.4	164.2	182.8	M	M			
MD	39.0	66.0	94.0	119.2	143.2	162.7	174.0	175.6	195.8	185.9	181.3			
3Q	40.4	73.4	108.6	143.6	162.7	180.5	188.7	191.7	199.6	M	M			
Ns	17	17	17	17	15	15	10	7	4	1	1			
Nf	570	569	512	399	260	125	65	21	9	6	1			
Lake class 11														
1Q	35.3	60.4	88.7	114.8	135.2	150.3	161.8	165.6	171.6	186.0	M	M		
MD	37.4	65.7	99.5	132.5	154.3	168.2	177.2	188.0	201.8	202.0	228.0	228.5		
3Q	38.8	71.6	112.7	154.6	172.8	192.7	202.2	205.5	223.5	219.4	M	M		
Ns	33	33	33	31	29	26	20	13	7	5	1	1		
Nf	828	825	738	521	351	193	105	50	16	6	2	1		
Lake class 12														
1Q	36.0	57.4	79.5	108.8	117.7	144.7	156.8	165.4	190.6	M				
MD	37.7	64.4	88.5	118.8	142.8	159.8	181.6	184.8	219.7	195.6				
3Q	41.0	76.4	100.8	135.0	163.0	186.2	199.9	214.3	226.1	M				
Ns	10	10	9	9	7	6	6	5	3	1				
Nf	179	168	137	104	55	43	16	5	3	1				
Lake class 13														
1Q	38.2	64.2	88.2	111.5	126.3	140.5	155.6	166.6	M	M	M			
MD	40.9	70.0	108.3	154.2	160.0	150.7	161.3	174.4	185.6	210.8	227.7			
3Q	43.5	88.3	128.9	162.4	187.3	205.6	224.5	176.3	M	M	M			
Ns	14	14	14	13	11	7	6	3	1	1	1			
Nf	431	431	395	242	119	63	33	15	2	1	1			

Appendix 2. Continued.

	Age													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lake class 14														
1Q	35.7	62.1	93.4	117.6	M	M								
MD	39.6	65.6	97.7	129.7	153.7	139.9								
3Q	40.3	80.9	147.3	181.2	M	M								
Ns	4	4	3	3	2	1								
Nf	71	71	56	26	19	1								
Lake class 15														
1Q	38.2	73.6	110.6	172.9	192.0	M	M	M	M					
MD	39.5	78.9	129.6	177.8	210.1	225.1	243.2	249.8	257.2					
3Q	60.3	111.1	158.1	187.0	215.7	M	M	M	M					
Ns	4	4	4	4	3	2	2	2	2					
Nf	85	85	78	51	13	3	3	2	2					
Lake class 16														
1Q	35.6	65.8	96.5	129.1	146.5	163.6	176.4	168.8	173.6					
MD	39.0	81.6	122.5	145.8	171.3	176.0	182.7	195.6	207.6					
3Q	43.5	86.5	134.9	174.7	183.0	189.4	199.0	216.1	231.0					
Ns	14	14	14	13	11	8	7	5	4					
Nf	378	377	344	281	186	124	88	46	13					
Lake class 17														
1Q	M	M	M	M	M	M	M	M						
MD	36.1	77.0	88.8	121.7	126.0	142.5	174.7	185.1						
3Q	M	M	M	M	M	M	M	M						
Ns	2	2	1	1	1	1	1	1						
Nf	32	32	23	20	7	3	3	1						
Lake class 19														
1Q	36.7	64.7	106.4	139.0	164.4	178.7	191.4	199.7	M	M				
MD	39.0	74.9	114.3	148.9	171.5	187.4	205.5	208.6	222.5	216.8				
3Q	43.8	90.0	139.4	157.7	194.5	213.8	224.4	229.8	M	M				
Ns	18	18	18	16	14	13	8	7	2	1				
Nf	499	499	401	265	170	97	24	13	4	2				
Lake class 20														
1Q	36.0	56.3	78.0	101.9	124.0	142.9	155.0	157.3	163.2	170.6	184.7			
MD	38.6	62.2	89.2	115.9	137.4	162.3	171.7	170.9	179.2	187.8	197.3			
3Q	41.4	65.8	92.3	124.2	149.4	170.0	185.4	191.9	190.3	200.3	203.4			
Ns	37	37	36	36	36	35	31	21	11	6	4			
Nf	2050	2050	1932	1499	1026	582	299	132	58	20	5			

Appendix 2. Continued.

	Age													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lake class 21														
1Q	38.2	58.9	81.4	101.2	128.7	138.7	153.6	158.7	169.3	178.2	M			
MD	40.8	65.8	92.1	116.8	137.8	158.1	171.1	185.2	196.6	199.2	190.8			
3Q	43.8	71.8	100.4	130.6	154.5	174.2	187.6	200.6	220.4	231.2	M			
Ns	27	27	27	27	26	22	21	19	13	4	1			
Nf	1545	1545	1471	1175	776	394	182	84	21	5	1			
Lake class 22														
1Q	37.5	57.8	80.2	104.2	128.3	149.0	166.0	176.8	174.8	177.5	M			
MD	40.2	64.0	89.3	118.1	148.2	162.2	176.2	184.6	193.7	199.1	184.9			
3Q	44.0	73.0	108.2	142.3	169.3	178.4	191.0	196.1	211.6	225.1	M			
Ns	129	129	129	126	120	102	80	52	22	10	2			
Nf	5377	5310	4891	3686	2325	1287	506	176	57	14	2			
Lake class 23														
1Q	35.9	52.9	71.8	91.7	112.9	133.4	149.4	160.9	174.3	180.9	188.8	227.6	M	
MD	38.5	58.2	80.0	103.4	130.0	151.2	164.2	173.2	181.0	195.6	206.1	236.2	234.5	
3Q	42.0	69.7	93.7	121.4	146.2	166.0	181.3	188.4	194.8	208.3	218.1	246.0	M	
Ns	106	106	106	106	106	98	84	58	33	16	8	3	1	
Nf	4623	4623	4474	3944	2899	1800	901	380	118	34	12	3	1	
Lake class 24														
1Q	38.7	62.7	86.3	109.6	132.4	146.2	151.9	156.3	166.2	M				
MD	42.3	69.9	98.0	123.7	144.4	156.0	164.9	167.7	188.7	189.6				
3Q	48.4	86.5	125.7	151.6	166.8	168.2	176.6	182.4	202.2	M				
Ns	153	152	152	147	136	115	74	39	11	2				
Nf	8280	8134	7404	5876	3494	1463	471	104	24	3				
Lake class 25														
1Q	38.1	58.0	79.2	103.4	125.9	145.0	156.4	162.3	166.5	180.1	176.1	M		
MD	40.9	67.7	95.7	124.7	146.0	163.1	169.8	180.4	178.9	185.4	188.6	186.5		
3Q	46.2	78.7	113.8	148.1	169.5	181.7	185.4	193.1	204.0	200.8	249.1	M		
Ns	134	134	134	134	129	115	87	65	36	17	4	1		
Nf	5126	5098	4705	3722	2540	1491	730	307	102	33	4	1		
Lake class 26														
1Q	M	M	M	M	M	M								
MD	48.8	89.1	130.1	153.8	187.8	235.2								
3Q	M	M	M	M	M	M								
Ns	2	2	2	2	2	1								
Nf	58	58	49	25	9	1								

Appendix 2. Continued.

	Age													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lake class 27														
1Q	37.3	56.7	78.6	102.3	128.0	150.0	169.6	178.1	183.8	196.4	194.7	204.8		
MD	39.6	64.2	89.9	119.8	146.9	161.1	176.4	189.0	197.7	203.6	198.8	211.0		
3Q	44.8	74.8	107.0	139.2	165.2	180.6	192.0	200.8	209.0	217.3	206.1	212.3		
Ns	136	136	136	135	132	114	92	60	35	7	3	3		
Nf	5833	5813	5434	4235	2845	1640	746	296	99	18	4	3		
Lake class 28														
1Q	38.5	60.2	82.9	104.4	124.9	143.1	159.8	166.4	168.1	169.2	179.5	M		
MD	41.2	64.3	89.7	121.0	144.4	159.4	170.6	182.6	190.5	176.7	180.6	179.7		
3Q	45.6	79.6	113.3	141.3	161.7	175.5	181.1	195.2	202.0	187.4	188.0	M		
Ns	61	61	61	61	54	46	35	29	17	5	3	1		
Nf	2131	2114	1927	1590	1149	739	370	151	43	10	5	1		
Lake class 29														
1Q	36.6	57.1	77.4	97.5	116.0	135.1	144.4	153.5	164.1	169.2	156.0	M	M	M
MD	38.6	61.0	84.1	105.7	127.6	148.0	161.7	169.8	177.1	181.7	196.4	223.3	235.0	240.5
3Q	43.0	67.2	92.3	118.1	141.4	158.9	172.1	184.4	195.8	201.7	220.7	M	M	M
Ns	91	91	91	91	88	82	75	52	34	13	5	1	1	1
Nf	3897	3871	3753	3199	2372	1535	834	388	170	73	21	4	2	1
Lake class 30														
1Q	41.2	68.7	90.6	107.6	124.0	137.9	146.1	154.4	159.2	M				
MD	43.8	79.1	111.5	137.1	147.1	157.0	158.4	162.3	170.2	183.7				
3Q	48.0	88.8	124.9	152.0	165.0	176.2	180.7	189.7	176.2	M				
Ns	77	76	75	72	67	57	37	8	3	1				
Nf	4189	4127	3723	2765	1293	429	132	17	6	1				
Lake class 31														
1Q	37.6	58.0	78.9	100.6	124.0	143.5	157.5	168.2	172.2	167.6	172.1			
MD	40.9	65.4	91.1	117.2	144.3	162.3	173.1	186.7	189.0	184.9	215.5			
3Q	44.9	74.0	105.3	134.1	156.9	177.0	187.5	198.4	202.5	209.1	222.6			
Ns	144	144	143	140	137	129	113	69	37	17	5			
Nf	5440	5431	5095	4184	3068	1784	846	366	133	34	8			
Lake class 32														
1Q	36.4	53.5	71.7	89.9	107.4	122.9	137.8	145.0	154.5	154.5	152.4	145.4		
MD	37.9	56.3	75.8	94.9	114.2	132.9	148.3	156.9	165.5	166.6	154.4	155.1		
3Q	40.8	63.0	86.0	112.3	135.9	152.6	168.2	171.6	177.1	181.6	183.5	169.0		
Ns	69	69	69	69	69	69	63	51	38	13	7	4		
Nf	3541	3541	3482	3043	2332	1715	1090	524	162	39	10	4		

Appendix 2. Continued.

	Age													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lake class 33														
1Q	37.4	61.6	90.3	118.9	147.8	158.3	177.9	182.9						
MD	41.7	67.8	100.2	128.9	157.3	175.0	191.7	211.3						
3Q	45.1	80.3	114.2	146.7	169.4	188.8	205.0	222.5						
Ns	27	27	27	27	25	18	12	4						
Nf	847	839	760	544	323	121	39	6						
Lake class 34														
1Q	40.8	66.9	94.6	121.8	141.9	153.2	162.9	166.3	168.3	170.0	M			
MD	44.9	80.0	112.2	139.1	156.8	174.8	183.8	185.2	174.9	175.6	200.4			
3Q	49.7	94.7	130.0	163.6	177.4	195.4	196.7	200.7	205.8	196.4	M			
Ns	108	108	106	99	83	68	44	24	7	4	2			
Nf	3470	3388	2882	1970	1097	547	204	82	31	13	4			
Lake class 35														
1Q	37.9	61.6	84.4	107.0	128.6	144.9	160.3	168.4	181.2	179.1	M			
MD	42.1	66.8	93.5	116.1	138.9	154.8	168.8	177.4	192.7	185.6	205.2			
3Q	47.7	84.4	119.7	148.7	178.0	189.5	178.6	194.2	216.2	204.2	M			
Ns	31	31	31	30	30	29	23	18	13	6	2			
Nf	1113	1103	1020	845	670	468	322	159	33	10	4			
Lake class 36														
1Q	40.4	65.7	89.0	109.7	128.3	145.8	157.5	167.4	179.3	181.2	M	M		
MD	44.3	71.4	99.4	125.0	148.3	162.7	167.9	177.9	183.5	186.1	187.7	196.8		
3Q	46.2	83.5	115.2	145.2	168.0	182.3	181.6	184.8	193.5	197.1	M	M		
Ns	34	34	34	33	30	26	17	13	10	4	2	1		
Nf	1162	1149	1043	815	530	323	196	84	22	4	2	1		
Lake class 37														
1Q	45.0	73.0	96.0	118.7	139.1	154.6	165.4	164.2	181.6	188.5	M			
MD	49.0	81.3	110.6	135.9	154.6	166.4	172.1	179.0	190.8	191.8	220.9			
3Q	54.5	92.9	128.2	160.9	187.3	190.2	202.5	200.8	196.0	207.2	M			
Ns	21	21	21	21	19	17	14	8	5	4	1			
Nf	601	574	503	428	323	215	119	60	22	6	1			
Lake class 38														
1Q	42.6	67.7	89.1	110.1	126.4	136.3	142.8	148.3	153.0	M				
MD	45.0	75.9	101.7	124.6	143.8	152.9	155.3	154.9	163.8	191.9				
3Q	48.6	85.1	124.4	147.6	163.6	174.0	177.6	171.0	186.8	M				
Ns	62	62	62	60	55	47	31	19	7	2				
Nf	4063	4013	3694	1992	1309	787	351	80	16	2				

Appendix 2. Continued.

	Age													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lake class 39														
1Q	41.3	68.7	94.6	120.8	141.8	163.0	173.5	173.2	179.7	184.0	187.9	M	M	M
MD	44.0	75.4	108.5	135.9	160.2	177.0	185.0	197.0	207.5	191.3	222.7	208.1	222.9	228.3
3Q	48.3	85.1	123.1	153.7	183.4	200.3	213.9	225.2	230.3	236.7	254.2	M	M	M
Ns	62	62	62	59	58	54	46	27	13	7	4	2	1	1
Nf	1829	1787	1583	1181	777	426	193	58	20	9	5	2	1	1
Lake class 40														
1Q	44.2	75.3	99.6	118.7	134.4	142.9	154.0	165.5	M					
MD	46.1	82.8	114.0	126.0	146.4	148.7	161.2	178.2	181.5					
3Q	54.0	120.9	151.5	161.0	180.8	163.4	177.2	203.2	M					
Ns	35	35	34	27	26	15	9	6	2					
Nf	1271	1155	934	484	280	127	50	14	2					
Lake class 41														
1Q	42.1	78.4	111.0	142.5	160.2	165.6	175.1	185.6	M	M	M			
MD	47.6	99.6	144.5	162.1	179.0	189.0	196.7	214.5	239.6	247.3	256.3			
3Q	56.6	118.9	166.0	196.6	216.4	211.5	228.4	238.4	M	M	M			
Ns	62	62	55	47	38	22	15	8	2	2	1			
Nf	1622	1483	1037	630	350	154	59	26	12	4	1			
Lake class 42														
1Q	45.2	80.6	114.1	138.5	151.8	170.2	185.4	185.7	M					
MD	49.2	86.7	123.6	150.2	162.0	180.7	191.7	207.6	202.3					
3Q	54.2	101.0	134.2	157.1	172.3	189.8	202.0	216.5	M					
Ns	35	35	35	33	24	20	12	5	1					
Nf	952	919	712	467	255	119	51	18	1					
Lake class 43														
1Q	41.9	79.8	116.4	141.6	158.3	164.6	165.6	167.5	M					
MD	47.5	94.0	131.6	157.4	173.5	181.5	194.0	173.8	187.7					
3Q	54.3	107.0	151.4	178.4	185.5	193.6	200.8	194.6	M					
Ns	54	53	52	51	40	23	15	7	1					
Nf	1334	1231	948	576	306	158	58	16	2					

Acknowledgements

The BASIC program used in backcalculating bluegill lengths was originally developed by Peter Jacobson (Minnesota Department of Natural Resources). Area Fisheries staff helped this study by sending annuli measurement files and reviewing possibly errored records. Peter Jacobson, Farrell Bandow, and Melissa Drake reviewed the manuscript and provided insightful comments.

SH 328 .I58 no. 458
Tomcko, Cynthia M.
Bluegill growth rates in
Minnesota

Edited by:
D.H. Schupp, Fisheries Research Supervisor
P.J. Wingate, Fisheries Research Manager

INVESTIGATIONAL REPORTS*

No. 448 The Two-Story Rainbow Trout Fishery and Its Effect on the Zooplankton Community in a Minnesota Lake, by L. Wang, K. Zimmer, P. Diedrich, and S. Williams. Reprint from *Journal of Freshwater Ecology* Volume 11, Number 1:67-80.

No. 449 Seasonal Habitat Use and Movements of Muskellunge in the Mississippi River. By J.A. Younk, M.F. Cook, T.J. Goeman, and P.D. Spencer. July 1996.

No. 450 Trophy and Consumptive Value-per-Recruit Analysis for a Walleye Fishery. P.C. Jacobson. Reprint from *North American Journal of Fisheries Management* 16:75-80, 1996.

No. 451 Seasonal and Diel Variation in Electrofishing Size-selectivity and Catch-per-hour of Largemouth Bass in Minnesota Lakes. By M.C. McInerny and T.K. Cross. November 1996.

No. 452 Observations on Predation on Small Bluegill in a Minnesota Centrarchid Lake. By J.R. Reed and B.G. Parsons. November 1996.

No. 453 Comparative Survival of Naturalized Steelhead, Feral Kamloops, and Their Hybrids During Egg and Fry Stages. By M.T. Negus. November 1996.

No. 454 Initial Effects of Slot Length Limits for Northern Pike in Five North-Central Minnesota Lakes. By R.B. Pierce and C.M. Tomcko. January 1997.

No. 455 An Indexed Bibliography of Creel Surveys, Fishing License Sales, and Recreational Surface Use of Lakes and Rivers of Minnesota. By M.F. Cook, J.A. Younk, and D.H. Schupp. February 1997.

No. 456 Multiple Catches of Smallmouth Bass in a Special Regulation Fishery. By M.C. Hayes, L.F. Gates, and S.A. Hirsch. Reprint from *North American Journal of Fisheries Management* 17:182-187, 1997.

No. 457 Thermal Marking of Lake Trout Otoliths, and Evaluation of Methods for Stocking Fry. By M.T. Negus. May 1997.

*Complete list of all publications in the series available from Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Box 12, 500 Lafayette Road, St. Paul, Minnesota 55155-4012.