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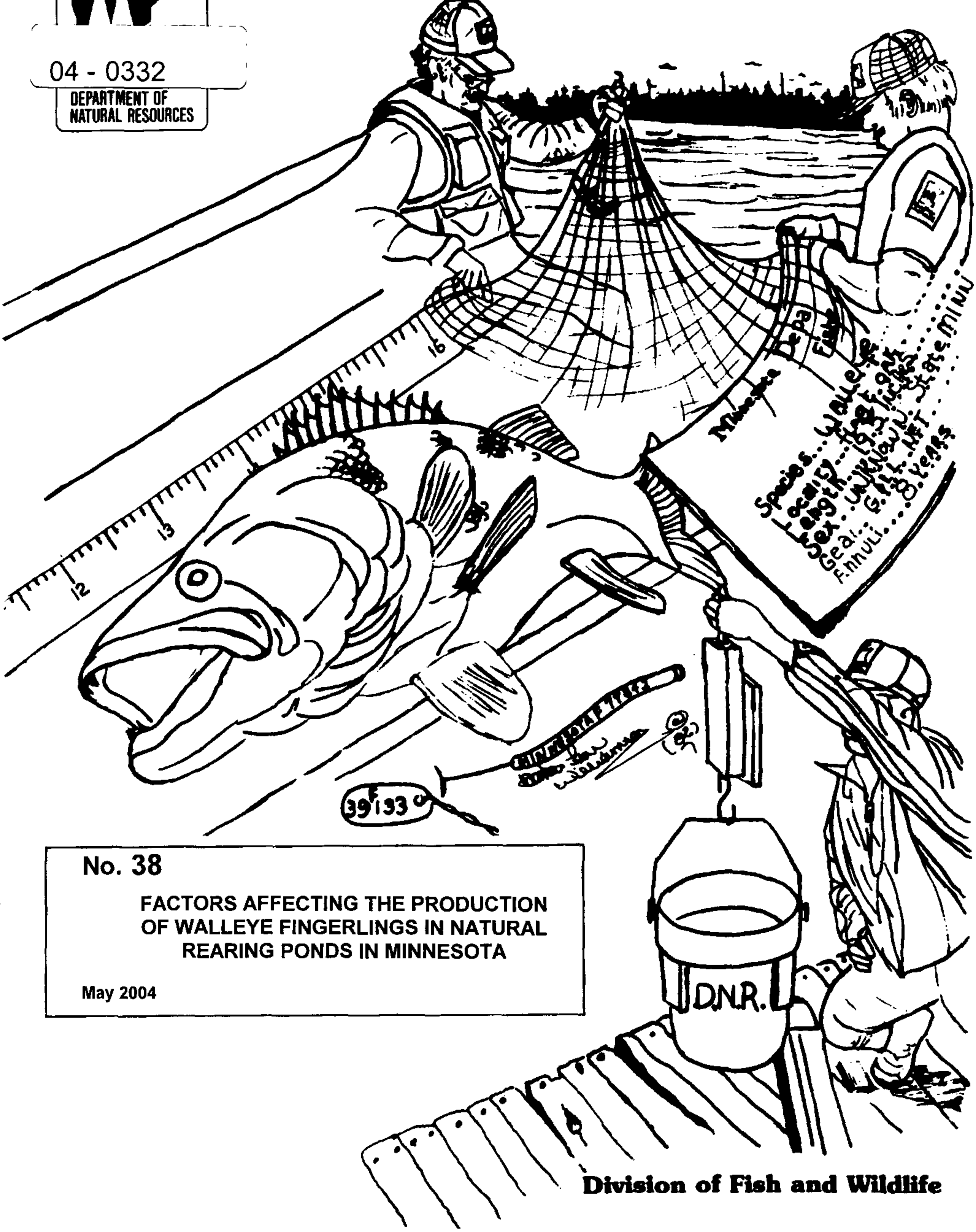

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FACTORS AFFECTING THE PRODUCTION OF WALLEYE FINGERLINGS IN NATURAL REARING PONDS IN MINNESOTA

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FACTORS AFFECTING THE PRODUCTION OF WALLEYE FINGERLINGS IN NATURAL REARING PONDS IN MINNESOTA.

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Abstract.--The Minnesota Department of Natural Resources raises walleye fingerlings extensively in undrainable, natural rearing ponds. Increased walleye stocking demands by the angling public, increased competition for ponds from a growing private baitfish and aquacultural industry, and decreased frequency of fish-removing winterkills due to recent milder winters have resulted in several years of walleye fingerling production levels insufficient to meet stocking goals in Minnesota. In an effort to better understand the factors that affect production of walleye fingerlings in natural, undrainable ponds, an analysis was made of pond morphometry, chemical, and ecological data from 466 rearing ponds used in Minnesota from 1999 through 2001. Correlation and multiple regression techniques suggested that the abundance of fathead minnow, black bullhead, and residual walleye (from previous production years) overwhelm most other variables, including chemical fertility. These other fish act as predators, and possibly competitors, on walleye fingerlings. Future management efforts should be directed at residual fish removal techniques (e.g. chemical rehabilitation, winterkill inducement), and protection of early life stages from predation (e.g. *in situ* cage culture of fry, transplanting drainable pond-raised small fingerlings).

Introduction

The Minnesota Department of Natural Resources (MNDNR) has raised walleye *Sander vitreus* fingerlings in natural, undrainable ponds for over 60 years (Smith and Moyle 1945). The existence of large numbers of potential ponds (generally Type 5 Wetlands of Shaw and Fredine 1956) in the glacial moraine topography throughout much of the state, coupled with the wide availability of easily obtained eggs from large, natural spawning runs, have made for a relatively inexpensive walleye aquaculture program that has met the stocking needs of the agency for most of those years. The relatively inexpensive fry are stocked into the ponds in the spring, allowed to feed on existing natural foods, and harvested by trap nets as large fingerlings of high quality in the fall, without supplemental feeding, fertilization or other labor intensive care (Daily 1996; Lilienthal 1996) – extensive aquaculture in its most effective form. However, increased walleye stocking demands by the angling public, increased competition for ponds from a growing private baitfish and aquacultural industry, and decreased frequency and intensity of fish-removing winterkills due to milder winters have resulted in several years of walleye fingerling production levels insufficient to meet stocking goals. An effort is now underway by the MNDNR to improve production from the finite number of natural ponds now available. One aspect of the effort is to better understand the factors that affect the production of walleye fingerlings in natural ponds.

Fingerling walleye production in natural ponds in Minnesota started in 1940 (Smith and Moyle 1945). During the first 5 years of walleye fingerling production, over 300 ponds were used (Moyle 1945). The ponds were generally small with a median size of 8 acres (Smith and Moyle 1945). Ponds used for walleye fingerling production today are considerably larger, with a median size of 35 acres (Table 1). The number of ponds in production has increased to 466 during the years 1999 - 2001. Statewide annual production for the years 1999 - 2001 averaged 121,000 pounds (2.4 million fish) of walleye fingerlings, and carried-over yearlings with a mean size of 20 fish per pound (a length of about 6 inches). Annual production (lbs/acre) of walleye in individual natural ponds is highly variable (Figure 1). The distribution of production is highly skewed, with almost 50% of ponds producing less than 2.5 lbs/acre. Occasionally high production occurs, with a maximum of 133 lbs/acre (Figure 1 only presents values to 50 lbs/acre). The mean of individual pond production weighted by pond size was 5.9 lbs/acre.

A number of possible factors could be the source of the wide variation in natural pond production. Ponds used for walleye fingerling production in Minnesota cover a wide geographical area and exhibit a wide range of chemical fertility (Table 1). Although many of the ponds exist in the relatively productive, prairie soils of western Minnesota (with total alkalinities as high as 337 mg $CaCO_3$/l) many others are in less productive, forested soils in central and northern Minnesota (with total alkalinities <10 mg $CaCO_3$/l). In the pioneering work of Moyle (1945), Smith and Moyle (1945) and Moyle (1947), chemical fertility was thought to affect walleye fingerling production only at low total alkalinities and low total phosphorus concentrations. Another important factor is the presence of other fish (other species and unharvested walleye from previous years) that are potential competitors or predators of walleye fry and fingerlings. Minnesota fisheries workers quickly noticed a significant decline in fingerling yield when residual yearling walleye were present in a pond (Moyle 1945; Daily 1996). After the mild winter of 1943-44, statewide walleye pond production dropped dramatically because of the over-winter survival of the previous years production. The presence of other fish species, especially black bullhead *Ameiurus melas*, northern pike *Esox lucius*, and fathead minnow *Pimephales promelas* was also suspected of reducing fingerling pond production (Daily 1996; Gunderson et al. 1996) In addition, high densities of undesirable fish species, especially black bullhead, can impede fingerling harvest by necessitating substantial sorting of the trap net catch. Vegetation characteristics have the potential to influence fingerling production. Abundant stands of emergent vegetation (primarily cattails *Typha spp.* and bulrush *Scirpus spp.*) are reported to impede fingerling harvest (Daily 1996). Excessively dense submersed vegetation can also impede fingerling harvest by reducing the efficiency of trap nets. Food resources within a pond would be expected to affect fingerling production as well. Daily (1996) suggested that amphipods (especially *Gammarus lacustris*) are an important food source for walleye fingerlings in natural ponds. Fry stocking density can affect production as well, although it might be more important in determining fingerling size than fingerling production (Daily 1996). Many additional factors influence the efficiency with which walleye fingerlings are harvested from a pond, adding much variability to the production from individual ponds in addition to the variability in the actual densities of walleye fingerlings present.

The objective of this analysis was to identify the factors important in determining walleye fingerling production in natural ponds. The analysis used existing data available from Area Offices (making for an observational study rather than a controlled experiment).

Table 1. Morphometry and chemical parameters of ponds used for rearing walleye fingerlings in Minnesota from 1999 through 2001.

Parameter	Unit	*N*	Minimum	Maximum	Mean	Median
Area	acres	466	2	1,340	66	35
Maximum depth	feet	355	3	38	9.1	8.0
Mean depth	feet	283	2	15	5.1	4.0
Total alkalinity	mg/l	94	1	337	70	29
Total phosphorus	µg/l	27	7	1,860	275	149
Percent of watershed forested	%	362	0	100	58.2	60

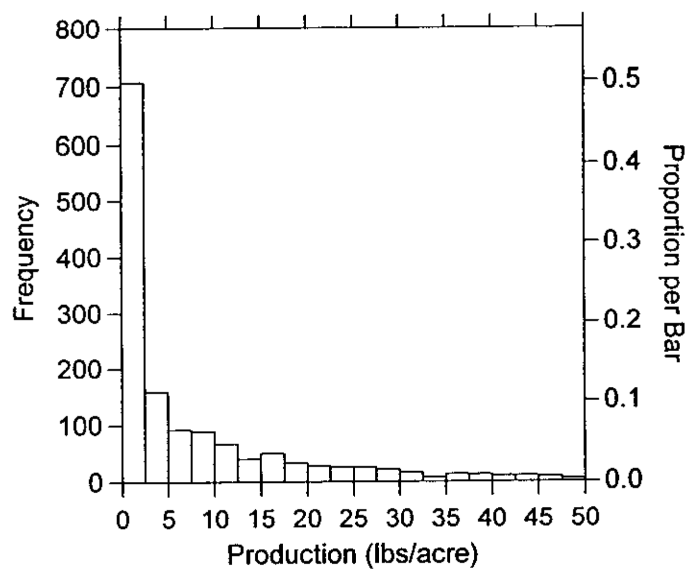

Figure 1. Histogram of annual production (lbs/acre) of individual walleye rearing ponds from 1996 through 2001 (1,417 data points illustrated, 56 data points larger than 50 lbs/acre not shown).

Methods

Physical, chemical, and biological information on 466 natural rearing ponds used in 1999, 2000, or 2001 was provided by MNDNR management personnel. Pond morphometry variables included mean and maximum depth, area, and percent of the watershed that is forested. Chemical variables included total alkalinity and total phosphorus (these water chemistry variables, when available, were usually from only one year). Biological variables included relative abundances of bullhead, northern pike, and fathead minnow, recorded as categorical variables: none, low, moderate and high, and transformed to numeric variables; 1-none to 4-high. Other biological variables included relative abundances of cattail, bulrush, and submersed macrophytes (many genera) with a scale of none, sparse, moderate, and dense transformed to the numeric metric of 1-none to 4-dense. Relative abundance of amphipods was also estimated with the same scale. All of the relative abundance variables were rated from visual observations by pond managers. Annual walleye production was partitioned into fingerlings (stocked as fry that spring), and yearlings (stocked as fry the previous spring). All walleye production values were expressed as pounds per acre.

Correlation analysis was used as an initial exploratory technique to identify variables that potentially affected fingerling production. Pearson correlation coefficients between annual fingerling production and pond variables were calculated using Systat 8.0 (Wilkinson 1998). A total of 790 pond/year pairs of data were available. An alpha of 0.05 was used to measure significance after Bonferroni adjustments for multiple comparisons. If necessary, variables were transformed so that distributions were normalized. The morphometry variables, area, maximum depth and mean depth were $\log_e$ transformed, and the chemical variables, total alkalinity and total phosphorous were square root transformed in accordance with Schupp (1992). The skewed distributions of walleye production variables (with some zeros) were normalized by a $\log_e+1$ transformation. Automatic (forward and backward) stepwise multiple regression (Wilkinson 1998) was used to develop initial models of fingerling production as a function of pond variables. Further manual multiple regressions were used to explore models that incorporated variables suggested by the automatic stepwise models and from biological considerations. Potential collinearity problems (common in large ecological observational studies) were also considered in variable selection. Generally, independent variables exhibiting high degrees of collinearity ($r > 0.6$) were not simultaneously added to the regression model, with the choice based on biological considerations (i.e., the most biologically appropriate variable of two closely related variables was selected). The goal of the multiple regression analysis was to develop a parsimonious model that predicted walleye fingerling production from the strongest effect variables.

Results

Seven pond variables were significantly correlated with walleye fingerling production (Table 2). The strongest correlation was pond area. Smaller ponds typically produced more walleye fingerlings per acre than larger ponds. Several potential piscine competitor/predator abundance variables (yearling walleye, bullhead, northern pike, and fathead minnow) were also correlated with fingerling production. The negative correlation coefficients of the competitor/predator variables indicated that their abundance impairs walleye fingerling production. Bulrush and cattail abundances were also negatively correlated with walleye fingerling production. Absent from the list of significant variables were the chemical fertility measures of total alkalinity and total phosphorus.

After exploratory runs with automatic stepwise regressions, and then with manual variable selection, five variables were included in the final model predicting fingerling

Table 2. Ranked Pearson correlation coefficients for variables affecting walleye fingerling production ($\log_e$+1) in Minnesota natural rearing ponds. Asterisks denote significance at the α=0.05 level after Bonferroni adjustment for multiple comparisons (α=0.003).

Variable	Transformation	*r*	*P*		*N*
Area	$\log_e$	-0.336	<0.001	*	798
Bullhead abundance	none	-0.249	<0.001	*	599
Yearling walleye production	$\log_e$+1	-0.142	<0.001	*	798
Northern pike abundance	none	-0.166	<0.001	*	559
Fathead minnow abundance	none	-0.163	<0.001	*	547
Bulrush abundance	none	-0.174	<0.001	*	679
Cattail abundance	none	-0.125	0.001	*	687
Fry stocking density	$\log_e$	0.075	0.034		790
Amphipod abundance	none	0.108	0.078		267
Maximum depth	$\log_e$	-0.062	0.129		607
Total alkalinity	sqrt	0.067	0.421		148
Total phosphorus	sqrt	-0.123	0.431		43
Submersed vegetation abundance	none	-0.025	0.511		683
Number of years used	none	-0.012	0.740		732
Mean depth	$\log_e$	-0.011	0.813		506
Percent of watershed forested	none	-0.008	0.844		640

Table 3. Multiple regression of variables affecting walleye fingerling production ($\log_e$+1), (N=381, R^2=0.228, F=22.1, P=<0.001).

Variable	Transformation	Coefficient	SE
Intercept	none	2.734	0.376
Area	$\log_e$	-0.476	0.068
Mean depth	$\log_e$	0.936	0.225
Fathead minnow abundance	none	-0.315	0.074
Yearling walleye production	$\log_e$+1	-0.341	0.093
Bullhead abundance	none	-0.151	0.069

production (Table 3). The initial automatic stepwise regressions produced similar models - the backward stepwise method included all five of the final model variables in addition to submersed vegetation abundance and fry stocking density, and the forward stepwise method resulted in the same five variables of the final model. These initial stepwise regressions were run with variables that had at least 500 observations coupled to fingerling production (Table 3). Although total alkalinity, total phosphorus, and amphipod abundance were manually introduced later, their entry never significantly improved any of the models. Submersed vegetation and fry stocking density were removed because the added model complexity was not justified by the small increases in r^2 they produced. The five variables in the final model included two morphometric variables (area and mean depth), and three piscine competitor/predator variables (fathead minnow abundance, yearling production, and bullhead abundance). Again, chemical fertility variables did not enter significantly into any of the models. Although the regression model was significant (F=22.1, N=381, P<0.001), overall the pond variables explained only 22.8% of the variability in fingerling production (r^2=0.228). Additional variables (and other models) did not increase r^2 significantly.

Some collinearity in the pond variables was noted (Table 4). The most obvious collinear variables were maximum and mean depth (r=0.659). Only mean depth was included in the final model (maximum depth was eliminated with most automatic variable selections). Another instance of collinearity that was potentially important was between area and bullhead abundance (r=0.412). The inclusion of area in the final multiple regression model may be partially due to the observation that bullhead tended to be more abundant in larger ponds (as did northern pike and fathead minnow). The abundance of fish competitor/predators may have exerted an effect through several correlated pond variables such as pond area.

Discussion

The abundance of fish competitors and predators appears to have a dominant influence on walleye fingerling production in natural rearing ponds in Minnesota. The variables associated with piscine competitor/predators (most notably fathead minnow abundance, bullhead abundance, and yearling production) were significantly correlated with walleye fingerling production. The detrimental effects of residual walleye, fathead minnow, and bullhead are well known by MNDNR pond managers, and hopes for complete pond "cleansing" winterkills are an often stated desire. The unusual finding is that the abundance of piscine competitors and predators overwhelms the effects of other potentially important factors such as chemical fertility.

Reduction of walleye fingerling production in Minnesota's natural ponds may be the result of direct predation rather than competition for food resources. Fingerling size was positively correlated (Table 5) with the potential piscine predators and competitors (fathead minnow, bullhead, northern pike and yearling walleye). If competition with these other fish was operating, fingerling size would be negatively correlated (i.e., competition for food would cause walleye fingerlings to grow slower and be a smaller size at harvest). However, one possible process involving competition of walleye fry with fathead minnow could also be operating. High fathead minnow densities may deplete zooplankton food resources for walleye fry causing low survival due to starvation, cannibalism, or increased vulnerability to predation. Any surviving walleye fry that eventually grow large enough feed on fathead minnow would then potentially grow fast, and explain the positive correlation between walleye fingerling size and fathead minnow abundance. In any case, predation probably occurs on newly stocked walleye fry by fathead minnow and on fingerlings throughout the summer by bullhead, northern pike, and older walleye.

Interestingly, the highest correlation coefficient was calculated for fathead minnow. Fathead minnow can play a powerful role in structuring prairie pond ecosystems (Zimmer et al. 2000, 2001). Large standing stock biomasses are possible (Carlson and Berry 1990) with annual production of fathead minnow in South Dakota prairie ponds ranging from 15.6 lbs/acre (Payer and Scalet 1978) to 264 lbs/acre (Duffy 1998). Ponds with high densities of fathead minnow tend to have lower abundances of aquatic macroinvertebrates and zooplankton, higher turbidities, lower macrophyte densities, higher phosphorus concentrations, and higher phytoplankton densities (Zimmer et al. 2001). In addition to the negative effects that fathead minnow had on walleye fingerling production, they can also have detrimental effects on duck production (Cox et al. 1998). Fathead minnow colonization and recolonization rates are probably increasing due to stocking by a growing baitfish industry, and increased connections of ponds by the installation of ditches, culverts and drainage tile in Minnesota (Zimmer et al. 2000). Additionally, the capability of fathead minnow to survive under very low dissolved oxygen concentrations in the winter (Klinger et al. 1982) increases their ability to dominate shallow, natural ponds in northern latitudes.

Table 4. Pearson correlation coefficients with associated probabilities and sample sizes for factors affecting walleye fingerling pond production in Minnesota natural rearing ponds (variables transformed as described in methods).

	Area	Max-Depth	Mean-Depth	Totalk	Totp	Perc-for	Cattail	Bul-rush	Sub-merged	Amph	Blb	Nop	Fhm	Yrl-Prod	Fry-Dens	Num-Years
								Correlation Coefficients								
AREA	1.000															
MAXDEPTH	0.125	1.000														
ME-	0.203	0.659	1.000													
TOTALK	0.550	0.040	0.444	1.000												
TOTP	-0.140	0.180	0.245	0.557	1.000											
PERCFOR	-0.326	-0.013	-0.014	-0.748	-0.343	1.000										
CATTAIL	0.437	0.093	0.129	0.349	-0.070	-0.354	1.000									
BULRUSH	0.464	0.121	0.241	0.474	-0.087	-0.209	0.441	1.000								
SUB-	0.153	-0.149	0.006	0.309	-0.444	-0.104	0.249	0.250	1.000							
AMPH	0.046	0.017	-0.108	0.257	-0.087	-0.103	-0.081	0.207	0.213	1.000						
BLB	0.412	0.147	0.094	0.444	-0.275	-0.302	0.320	0.153	0.073	0.038	1.000					
NOP	0.294	-0.083	-0.100	0.145	0.012	-0.048	0.009	0.021	-0.040	0.040	0.260	1.000				
FHM	0.148	-0.087	0.068	0.220	0.398	-0.137	0.164	0.120	0.028	0.085	0.088	0.045	1.000			
YRLPROD	0.030	0.071	0.016	0.065	0.048	-0.138	0.070	0.077	0.001	0.225	-0.022	-0.037	-0.084	1.000		
FRYDENS	-0.065	0.029	-0.004	0.446	0.273	-0.271	0.081	0.154	0.038	0.134	-0.066	-0.153	-0.082	0.108	1.000	
NUMYEARS	-0.050	-0.024	-0.036	-0.119	-0.372	0.184	-0.146	0.023	0.138	0.164	-0.059	0.127	-0.102	0.052	-0.075	1.000
								Probabilities								
AREA	0.000															
MAXDEPTH	0.002	0.000														
ME-	0.000	0.000	0.000													
TOTALK	0.000	0.634	0.000	0.000												
TOTP	0.371	0.268	0.138	0.000	0.000											
PERCFOR	0.000	0.762	0.770	0.000	0.063	0.000										
CATTAIL	0.000	0.026	0.005	0.000	0.666	0.000	0.000									
BULRUSH	0.000	0.004	0.000	0.000	0.595	0.000	0.000	0.000								
SUB-	0.000	0.000	0.891	0.000	0.004	0.012	0.000	0.000	0.000							
AMPH	0.458	0.805	0.142	0.034	0.596	0.164	0.203	0.001	0.001	0.000						
BLB	0.000	0.001	0.054	0.000	0.082	0.000	0.000	0.000	0.080	0.542	0.000					
NOP	0.000	0.070	0.046	0.103	0.937	0.317	0.827	0.632	0.357	0.530	0.000	0.000				
FHM	0.001	0.058	0.181	0.018	0.010	0.004	0.000	0.006	0.516	0.180	0.044	0.306	0.000			
YRLPROD	0.392	0.078	0.713	0.431	0.758	0.000	0.065	0.044	0.971	0.000	0.590	0.380	0.049	0.000		
FRYDENS	0.069	0.472	0.934	0.000	0.076	0.000	0.036	0.000	0.319	0.031	0.111	0.000	0.056	0.002	0.000	
NUMYEARS	0.179	0.568	0.429	0.151	0.015	0.000	0.000	0.562	0.000	0.008	0.153	0.003	0.018	0.161	0.045	0.000

Table 4. Continued

	Area	Max-Depth	Mean-Depth	Totalk	Totp	Perc-for	Cattail	Bul-rush	Sub-merged	Amph	Blb	Nop	Fhm	Yrl-Prod	Fry-Dens	Num-Years
								Sample Sizes								
AREA	798															
MAXDEPTH	607	607														
ME-	506	506	506													
TOTALK	148	141	100	148												
TOTP	43	40	38	43	43											
PERCFOR	640	535	438	134	30	640										
CATTAIL	687	569	473	143	40	580	687									
BULRUSH	679	563	467	142	40	578	679	679								
SUB-	683	568	472	143	40	577	682	675	683							
AMPH	267	203	186	68	39	183	251	249	250	267						
BLB	599	500	418	123	41	478	573	565	571	256	599					
NOP	559	479	398	127	42	442	535	528	534	254	551	559				
FHM	547	470	389	116	41	433	528	522	528	252	530	528	547			
YRLPROD	798	607	506	148	43	640	687	679	683	267	599	559	547	798		
FRYDENS	790	600	499	146	43	634	679	671	675	260	591	551	539	790	790	
NUMYEARS	732	574	473	147	42	598	645	637	641	264	589	556	542	732	724	732

AREA – area
MAXDEPTH – maximum depth
ME- – mean depth
TOTALK – total alkalinity
TOTP – total phosphorus
PERCFOR – percent of watershed forested
CATTAIL – cattail abundance
BULRUSH – bulrush abundance
SUB- – submersed abundance
AMPH – amphipod abundance
BLB – bullhead abundance
NOP – northern pike abundance
FHM – fathead minnow abundance
YRLPROD – yearling production
FRYDENS – fry stocking density
NUMYEARS – number of years pond had been used

Table 5. Ranked Pearson correlation coefficients for variables affecting walleye fingerling size ($\log_e$) in Minnesota natural rearing ponds. Asterisks denote significance at the α=0.05 level after Bonferroni adjustment for multiple comparisons (α=0.003).

Variable	Transformation	*r*	*P*		*N*
Fingerling production	$\log_e$+1	-0.188	<0.001	*	483
Fathead minnow abundance	none	0.201	<0.001	*	348
Cattail abundance	none	0.254	<0.001	*	419
Bulrush abundance	none	0.163	0.001	*	414
Number of years used	none	-0.156	0.001	*	458
Mean depth	$\log_e$	0.182	0.001	*	311
Maximum depth	$\log_e$	0.121	0.019	*	377
Area	$\log_e$	0.086	0.060		483
Percent of watershed forested	none	-0.093	0.066		396
Yearling production	$\log_e$+1	0.079	0.084		483
Submersed vegetation abundance	none	0.076	0.122		418
Bullhead abundance	none	0.064	0.215		373
Total phosphorus	sqrt	-0.155	0.431		28
Amphipod abundance	none	0.024	0.754		177
Total alkalinity	sqrt	0.028	0.765		114
Fry stocking density	$\log_e$	-0.010	0.831		481
Northern pike abundance	none	0.009	0.865		362

Fathead minnow, northern pike, black bullhead, and the previous years' production of walleye are probably not the only fish that impact production of walleye fingerlings in natural rearing ponds. MNDNR pond managers identified 30 other species of fish in the 466 ponds used during the 3 years of the study (Table 6). Many of these species are potentially piscivorous on walleye at some life stage. Even the species listed as occasionally piscivorous in Table 6 (including the many insectivorous cyprinids) have the potential to prey on newly stocked walleye fry. For example, northern redbelly dace *Phoxinus eos* have been observed to eat smallmouth bass *Micropterus dolomieu* fry in the hatchery (Scott and Crossman 1973). Anecdotes from pond managers suggest that northern redbelly dace is a walleye fry predator (high dace populations have been frequently associated with pond failures). Daily (1996) also noted that dace and stickleback *Culea spp.* can reduce fry survival. Although no abundance measures of the species other than fathead minnow, northern pike, and black bullhead were attempted for this analysis, high abundances of any of these species have the potential to reduce walleye fingerling production in natural ponds.

The lack of large effects of chemical fertility on walleye fingerling production was surprising. However, the relatively weak relationship between the common measure of aquatic productivity, total alkalinity, and walleye fingerling production ($r=0.067$, $P=0.421$, $N=148$) was also observed by Moyle (1945, 1947), and Smith and Moyle (1945). Moyle (1947) suggested that the relationship between total alkalinity and walleye fingerling production would be best characterized as a threshold effect, and further suggested that total alkalinities <40 ppm could potentially limit pond production, and that production in ponds with total alkalinities >40 ppm was not correlated with total alkalinity. Moyle (1947) also suggested a similar threshold effect for phosphorus at 50 μg/l. Total phosphorus was not significantly related to fingerling production in the current study (although the number of ponds with total phosphorus data was small). As Moyle (1945) suggested, chemical fertility of a pond probably sets an overall yield potential, but many

Table 6. List of species reported by fisheries managers as occurring in natural ponds used for rearing fingerling walleye in Minnesota. Level of piscivory as suggested by Eddy and Underhill (1974) and Becker (1983) and names from American Fisheries Society (1991).

Common Name	Scientific Name	Piscivory
Bowfin	*Amia calva*	high
Northern pike	*Esox lucius*	high
Muskellunge	*Esox masquinongy*	high
Channel catfish	*Ictaluris punctatus*	high
Largemouth bass	*Micropterus salmoides*	high
Black bullhead	*Ameiurus melas*	moderate
Brown bullhead	*Ameiurus nebulosus*	moderate
Green sunfish	*Lepomis cyanellus*	moderate
Hybrid sunfish	*Lepomis sp.*	moderate
Yellow perch	*Perca flavescens*	moderate
White crappie	*Pomoxis annularis*	moderate
Black crappie	*Pomoxis nigromaculatus*	moderate
White sucker	*Catostomus commersoni*	occasional
Brook stickleback	*Culea inconstans*	occasional
Common carp	*Cyprinus carpio*	occasional
Iowa darter	*Etheostoma exile*	occasional
Pumpkinseed	*Lepomis gibbosus*	occasional
Orangespotted sunfish	*Lepomis humilis*	occasional
Bluegill	*Lepomis machrochirus*	occasional
Common shiner	*Luxilus cornutus*	occasional
Golden shiner	*Notemigonus crysoleucas*	occasional
Emerald shiner	*Notropis atherinoides*	occasional
Blacknose shiner	*Notropis heterolepis*	occasional
Spottail shiner	*Notropis hudonius*	occasional
Northern redbelly dace	*Phoxinus eos*	occasional
Finescale dace	*Phoxinus neogaeus*	occasional
Fathead minnow	*Pimephales promelas*	occasional
Creek chub	*Semotilus atromaculatus*	occasional
Pearl dace	*Semotilus margarita*	occasional
Central mudminnow	*Umbra limi*	occasional

other factors (e.g. presence of piscine competitors and predators) have a larger influence on the actual yield of the pond. Other productivity related variables such as amphipod abundance and percent of watershed forested did not significantly affect walleye fingerling pond production.

The previous history of production within a pond (as measured by number of years used) appeared to affect walleye fingerling growth more than survival (significant r in Table 5, but not in Table 2). Apparently, repeated use reduces the productive capacity of a pond through a depletion of walleye fingerling food production. The productive capacity may rebound after ponds are left fallow. Although it was not possible to calculate an optimal fallow/production cycle with the current data, such a calculation might be possible, as more years of data are made available.

Two pond morphometry variables (area and mean depth) significantly affected walleye fingerling production. Moyle (1945) also measured a significant negative relationship between pond size and walleye fingerling production, and suggested that smaller ponds are more completely harvested than larger ponds. Although harvesting now occurs with trap nets, rather than seining as used in Moyle's day, the increased efficiency of harvesting smaller ponds is probably still operating. The relationship could also be explained by the collinearity between area and other fish species - the larger the pond the greater the abundance of bullhead, northern pike, and

Table 7. Production of walleye fingerlings from 17 chemically rehabilitated natural rearing ponds in Minnesota, with associated project costs (chemical, labor, equipment, gas, miscellaneous).

Pond	County	Acres	Production Year	Lbs	Production Lbs/acre	Rehab Cost
Maple Marsh	Washington	35	1999	1,304	37.3	$3,238
Cole	Dakota	10	1999	248	24.8	$2,467
Horseshoe	Isanti	119	2000	0	0.0	$14,500
Lizard	Crow Wing	140	2000	8,486	60.6	$22,517
Horseleg	Isanti	95	2000	0	0.0	$13,000
Monson	Kandiyohi	42	2000	1,100	26.2	$7,994
Green Acres	Washington	13	2000	723	55.6	$3,554
Anderson	Washington	21	2000	1,208	57.5	$4,847
Carey	Cottonwood	117	2001	6,053	51.7	$7,598
Clear	Murray	105	2001	0	0.0	$16,268
Round	Martin	41	2001	2,276	55.5	$3,283
Bachelor	Brown	120	2001	1,963	16.4	$16,383
Juni	Brown	65	2001	5	0.1	$9,953
North Deaner	Washington	14	2001	1,404	100.3	$3,984
Wariakois	Washington	17	2001	1,310	77.1	$3,025
Frank	Swift	135	2001	680	5.0	$18,000
Mud	Washington	62	2002	3	0.0	$9,261
Totals and weighted means		1,151		26,763	23.3	$159,871

fathead minnow (Table 4). Although the relationship between mean depth and fish production is usually negative (Ryder 1965), the positive regression coefficient measured in this study probably represents a depth-summerkill relationship. As Daily (1996) noted, summer mortality of walleye in rearing ponds can occur in very shallow ponds during hot, calm portions of the summer.

Although the low level of variation explained by the variables in the final regression model ($r^2 = 0.228$) could be due to the many subjective estimates of abundances in predictor variables, other unmeasured factors might play important roles in determining walleye fingerling production in natural rearing ponds. Some of these variables could include factors that affect walleye fry survival at the time of stocking. Poor initial survival apparently occurs frequently even when potential predator populations are low. For example, even when fathead minnow and bullhead abundances were noted as low or none, and yearling walleye production was <1.0 lbs/acre, survival failures still occurred 37% of the time (walleye fingerling productions <1.0 lbs/acre occurred in 108 pond/year combinations out of a total of 292 combinations). Environmental factors such as zooplankton densities at the time of fry stocking could potentially have a large impact on fry survival. Although, the environmental factors that determine spring zooplankton populations may be complex, a simple plankton sampling methodology at the time of walleye fry stocking might provide useful data for future analyses of walleye fingerling production. Additionally, the variation in mortality from handling and stocking stresses (e.g. changes in temperature, oxygen, pH) should be investigated.

Management Recommendations

The strong effect that piscine predators have on walleye fry survival in natural rearing ponds suggests that techniques to eliminate fish in rearing ponds could prove useful. Several fish removing techniques are currently being evaluated in Minnesota. They include inducement of winterkill by mechanical agitation, and removal by chemical application. Another alternative would be to protect the walleye through the initial stages of life in a drainable pond or an enclosure, and to harvest and stock when they are large enough to escape predation. The important aspects of any of these alternatives are biological and cost effectiveness.

Winterkill may by induced by mechanical circulation of water under the ice with long, angled shaft outboards motors designed for marshes, or with air bubbler systems operated late in the winter when dissolved oxygen levels are naturally low. The hope is that high biological oxygen demand within bottom sediments will reduce dissolved oxygen concentrations to lethal levels, and that potential refugia will be eliminated by mixing of the pond. Unfortunately, fathead minnow may prove especially difficult to eliminate with winterkill inducement techniques because of their physiology that allows them to function with an anaerobic metabolism system at very low oxygen levels (Klinger et al. 1982)). Black bullhead are also especially winterkill tolerant (Becker 1983). Residual walleye should be easier to eliminate than fathead minnow and bullhead. In any case, the cost, practicality, and biological effectiveness of this technique are being examined.

Chemical removal of existing fish in natural ponds is another option that could increase walleye fingerling production. Walleye fingerling production in the chemically treated ponds was significantly higher, with a mean (weighted by pond size) of 23.2 lbs per acre (compared to the statewide weighted mean of 5.9 lbs per acre). Six of the chemical removal projects were deemed failures because they resulted in a production less than the statewide mean and 11 were deemed successful (65% success rate). When an existing fish population was successfully eliminated, production averaged 45.7 lbs per acre. These levels of production are similar to those observed in the very first years of natural pond walleye fingerling production in Minnesota: a mean of 38.1 lbs per acre in the unfertilized ponds of Moyle (1945).

The cost of chemical removal of residual fish was an average of $5.97 per pound of walleye fingerlings produced (Table 7). Assuming increases in mean production of 17.4 lbs/acre (23.3 lbs/acre minus the statewide average of 5.9 lbs/acre), a chemical removal adds $8.10 per pound to the mean cost of walleye fingerling production (hatchery and pond rearing costs including labor) of $9.97 per pound (statewide mean from 1991 through 2001). The cost of chemical removal can be amortized over several years because the beneficial effects of a chemical removal generally last from two to five years (before other species of fish become reestablished). This amortization of the chemical removal costs, coupled with the increased efficiencies in harvesting fingerlings from a pond with large production (higher catch rates in trap nets), probably makes chemical removal a viable economic option for increasing the production of walleye fingerlings in natural ponds.

Protection of initial life stages could be obtained by *in situ* enclosure culture of fry to a larger size (Te Brugge and McQueen 1991). The fry would be released from the enclosures after some weeks of growth and allowed to grow to full fall fingerling size throughout the pond. Another technique would be to raise small (e.g. early summer) fingerlings in hatchery drainable ponds, and then move them to natural ponds for further rearing to fall fingerling size. These protection techniques might be more suited for ponds with gape-limited predators such as fathead minnow rather than predators capable of ingesting larger fingerlings, such as black bullhead and carryover walleye. Cost effectiveness of these techniques will be a key issue.

Unfortunately, the more intensive nature of any these techniques adds to the artificiality of the fingerling product. The genetic effects of the increased artificiality, mediated through unnatural selection at many stages in the culture process, are only beginning to be understood (Hindar et al. 1991). The relative inefficiencies (lower fry survival) of a more extensive natural pond culture system may actually have some inadvertent genetic benefits - selection pressures operating in a natural pond with predators probably produce a higher quality fingerling (apart from the important issue of stock transfer). Because walleye fingerlings are still being stocked into some lakes in Minnesota with natural reproduction, the genetic ramifications of an increasingly intensive walleye culture program are important and need to be identified.

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