Experimental manipulation of aquatic habitat in decommissioned aggregate pits and quarries to: a) determine the role of habitat in shaping fish communities, and b) identify effective options for reclaiming sites with fisheries potential

A collaborative research program between the
Management of Abandoned Aggregate Properties Program
And
Fisheries and Oceans Canada

Smokorowski, K.E., J.R.M. Kelso, and W.D. Geiling.

Abstract

A guiding principle in fisheries management is that the productive capacity of aquatic systems may be increased by the restoration or enhancement of fish habitats. The principles and assumptions for restoration and enhancement are based largely upon experience and a reasonable understanding of causes; the linkages between physical habitat and ecosystem or fish community performance are only partly understood and experimentation and documentation is limited. The objective of this study is to test the role of habitat in shaping fish communities and production in freshwater ecosystems. Four study systems (2 gravel pit ponds and 2 quarry ponds) were chosen for an experiment designed to last 6 years. All systems are small (<5.0 ha) and each has an established fish community. In three experimental systems we increased habitat diversity (2 in 2000, 1 in 2001) and will reference changes in fish community structure, biomass, production and growth to pre-manipulation conditions in each experimental system. Other aspects of the ecosystem, including invertebrates, plankton and water chemistry, are also being monitored. Three years pre-treatment data have been collected and we are currently in our 2nd year of post-treatment data for the systems manipulated in 2000. This presentation will describe the systems, habitat enhancements, monitoring program and preliminary results.

INTRODUCTION

In April 1998, Fisheries and Oceans Canada (DFO) entered into agreement with the Ontario Ministry of Natural Resources (OMNR), and the Management of Abandoned Aggregate Properties Program (MAAP). The goal of this collaboration is to utilize abandoned aggregate sites in an experimental manner to determine the role of aquatic habitat in shaping fish communities, and to identify effective options for reclaiming sites with fisheries potential.

This habitat manipulation experiment is designed to test the hypothesis that enhancement of physical habitat increases biological production. We propose to answer two key questions regarding the role of habitat in aquatic systems: 1) does any addition or increase (change) in physical habitat result in a change to fish biomass, fish growth, fish production or community structure i.e. the species and their abundance? and 2) is the effect mainly a redistribution of fish that are there?

SITE SELECTION

In March 1998, DFO and MAAP personnel conducted site visits and selected Bayside Quarry, VanLimbeek Pit, and Stoney Creek Quarry for use in this experiment. A fourth system, Gibb Pit near Stratford, Ontario was added in September of 1998. All selected systems had established fish communities. The area and perimeter of each system were obtained from Ontario Base Maps and randomly placed transects (minimum of 5) were established around each system to serve as permanent spatial reference points. Three of the systems were chosen to receive a different aquatic habitat addition, each considered as important to fishes and suitable to the system, while the fourth system remained unaltered as a control site.

VanLimbeek Pit, York Region, Queensville

VanLimbeek Pit has a surface area of 0.71 ha and a maximum depth of 5.4 m. It has a dissolved oxygen deficiency each summer in waters greater than 3.5m deep. Other than a short section of

shoreline at the northern end of the water body (approximately 15 m long) the sides were steeply sloped. The littoral zone, here defined as the area of the water body where 1% of incident light can penetrate to the bottom, is largely restricted to the north end of the pond.

A 50 m length of shoreline was excavated up to 20 m into the land surrounding the north-eastern end of the pit in November 2000. Excavation started approximately 2 to 3 m offshore (in 0.5 to 0.75 m depth of water) and worked inland at a 5% slope for approximately 16 m. The inland extent of excavation was more steeply-sloped, connecting the top of the newly excavated area to the toe of the existing grade. Eight channels, typically 0.6 m wide, were excavated to a depth of 40 cm below the newly graded slope. Topsoil and fill removed from the excavation were replaced in shallow berms (maximum height 0.5 m) between the channels, and planted (fall 2000, supplemented in June 2001) with aquatic and wetland plants that are native to the area. The excavation was intended to diversify habitat by adding a gently-sloped littoral area, and the new plants would sequester some of the excess nutrients in the system. The landowner also increased the amount of fencing around the pond to restrict livestock access (horses).

Bayside Quarry, Hastings County, Sidney Township

Bayside Quarry has a surface area of 0.35 ha and a maximum depth of 2.5 m. Much of the pond is gently sloped and is less than 2.0 m in depth. The entire pond would be considered to be littoral, and seasonal oxygen depletions have not been recorded.

An irregularly-shaped rock-rubble reef was constructed (November 2000) along the western edge of the 2.0 m depth contour. This reef is roughly 20 m in length along its major axis. Approximately 60 tonnes of clean, angular, limestone was used, 2/3 of which exceeded 30 cm in diameter, and 1/3 was composed of materials between 10 and 30 cm. Randomly placed angular rock in these size ranges will ensure that interstitial spaces (gaps between adjacent rocks) are abundant.

The reef increased the total surface area of substrate in the system and could result in an increase in prey organisms for fishes. The reef will also provide more cover, especially for smaller fish that can seek shelter in the interstitial spaces.

Gibb Pit, Perth County, South Easthope Township

Gibb Pit has a surface area of 4.29 ha and a maximum depth of 5.0 m. The north end and southwest corner of the pond are gently-sloped, while the much longer eastern and western shorelines are very steeply sloped. Submerged aquatic plant growth throughout the pond indicates that the whole pond could be considered as littoral, but by late summer algal growth prevents light reaching beyond approximately 4.0 m.

Twelve tree bundles were installed along the west shore in December 2001. Six of the bundles were coniferous (white pine) and 6 were deciduous (maple and ash sp.). The order in which the bundles were placed was randomly generated. Thirty coniferous and thirty deciduous trees, averaging 4.5 m in length per tree, were cut from adjacent land, yielding six bundles of five trees of each type. The potential benefits of tree bundle additions to Gibb Pit are similar to those for the rock reef in Bayside Quarry.

Stoney Creek Quarry, 87 Acre Park, Hamilton-Wentworth Region

Stoney Creek Quarry has a surface area of 4.68 ha and a maximum depth of 1.4m. Most of the pond contains dense beds of Eurasian milfoil (a non-native aquatic plant nuisance species), and the entire quarry is littoral. Dissolved oxygen deficiencies occur at depths greater than 1.0 m deep in some summers. The death of all fish in a few overnight minnow trap sets, and a dramatic reduction in sunfish abundance over the winter of 2000-2001, indicate that oxygen deficiencies impact fish.

METHODS

The study was designed to monitor all systems for three years before and after the habitat additions. Summer 2003 will be the final monitoring year in the current study.

An ecosystem-based approach was used to monitor the systems, although the fish community is sampled more intensively than other

parameters. Temperature and dissolved oxygen are measured, and water chemistry, chlorophyll *a*, and zooplankton samples are taken, during the ice free period in each system in each year. Water samples are analyzed for concentrations of major ions, carbons, nutrients, and trace metals. Periphyton and benthic macroinvertebrates are evaluated annually (from 1999 to present) in the systems receiving habitat additions using artificial substrates.

Monitoring of fish communities includes annual mark-recapture abundance estimation for all species caught in sufficient numbers in each system. A variety of fishing gears are used, such that individuals of all species present could be captured. Samples are taken from a subset of the fish captured for age determination, facilitating the computation of growth, biomass, and production statistics. Catch per unit effort (CUE) statistics are derived annually for each gear type. Underwater video camera and visual distance sampling by snorkelers was used to assess the association of fish with different habitat types.

RESULTS

All systems have high pH, conductivity, and alkalinity (Table 1). Stoney Creek Quarry exhibits relatively high sodium and chlorine concentrations, indicative of salt loading. In all systems, copper and cadmium concentrations occasionally exceed Canadian Water Quality Guidelines for the Protection of Aquatic Life (Canadian Council of Ministers of the Environment, 1999), but these instances are neither constant nor extreme.

Algal productivity, as measured by chlorophyll *a* (Table 1), indicates that Bayside Quarry and Gibb Pit have medium productivity levels, Van Limbeek borders on high, and Stoney Creek borders on excessive productivity (Wetzel, 2001). Nutrient (total phosphorus) measures support these classifications.

Consistent trends are not apparent in zooplankton abundance or composition by taxonomic group. Dipterans (true flies) are the most abundant taxonomic group in benthic invertebrate samples, and the diversity of benthic invertebrates on the artificial substrates is remaining fairly constant.

Tables 2(a) through 2(d) provide the results of the annual June fish mark-recapture abundance estimations for each water body. Since mark-recapture methods require that fish are caught, marked, replaced in the system and subsequently recaptured, the absence of an estimate for a species means that the species is relatively rare. Fishing methods were adjusted to suit the system and species to maximize catch. Estimates of the contribution of these species to whole-system biomass and production were made to ensure all fish species were included.

Table 3 provides whole-system fish biomass and production estimates for the first four years of the study. One item of interest is the decline of biomass and production figures for Stoney Creek Quarry between 2000 and 2001. It is assumed that this is the result of a winter kill of sunfish, due to dissolved oxygen depletion, during the winter of 2000/01. The system appears to be rebounding from this event in 2002 (Table 2.b.).

A multi-factorial analysis of variance model was used to test whether habitat additions increased catch rates in minnow traps (small fish) and trap nets (large fish) relative to the control. There were significant Treatment by Time interactions for both minnow trap and trap net CUE (MTCUE $F_{1,1269} = 82.3$, $P < 0.001$; TNCUE $F_{1,79} = 8.2$, $P = 0.005$), indicating that patterns of fish catches between our control and treatment sites differed before and after the habitat additions. Both minnow trap and trap net CUE increased slightly in systems where habitat was enhanced, and decreased in Stoney Creek, our control system (Figure 1).

DISCUSSION

Overall, these pit and quarry systems are composed of diverse and prolific fish communities, given their small size and isolation from natural waterways. They are highly productive and in some cases would be considered overly productive to the detriment of water clarity and quality. Inter-annual variation in fish population abundance is a naturally occurring phenomenon, and would be expected in the absence of a human induced change to the system. Yet it is this variability that renders detecting a response to a human induced change difficult, particularly in a short timeframe.

Changes to populations of longer-lived (larger, generally predatory) species are likely to become detectable only on a generational time scale, when changes (if any) to the growth and survivorship of a species can be translated into changes in reproductive success. Thus, caution should be used when interpreting these preliminary results as any pattern presented here may not persist.

We did not find significant changes in the water chemistry or lower trophic levels (plankton, invertebrates) in the study systems. This will make it more likely that any changes in the fish community that are (or are not) detected can be linked to the change in habitat, and not to some other outside influence.

Abundances, relative abundances, biomass and production of fishes all fluctuate annually at levels that are comparable to highly-productive natural lakes (Downing and Plante, 1993; Kelso and Johnson, 1991). Yet, despite this variability, we were able to detect an increase in catch rates in minnow traps and trap nets in systems that received habitat additions compared to the control system. However, it is unclear if this is the result of a decrease in CUE in the control system (Stoney Creek, sunfish winter kill), or if it represents a real increase in CUE in the altered systems. Addition of data collected in 2003 to our analytical process will enhance the defensibility of our results and interpretations.

The field collection portion of the study will conclude in August 2003. Data analysis will continue through the winter of 2003/04, with a final report expected by early spring 2004. This final report will contain recommendations regarding whether the diversification of aquatic habitat in decommissioned pits and quarries provides added value to the fish community.

REFERENCES

Canadian Council of Ministers of the Environment, 1999. Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg.

Downing, J. A., and C. Plante. 1993. Production of fish populations in lakes. Can. J. Fish. Aquat. Sci.50: 110-120.

Kelso, J.R.M., and M.G. Johnson. 1991. Factors related to the biomass and production of fish communities in small, oligotrophic lakes vulnerable to acidification. Can. J. Fish. Aquat. Sci. 48:2523-2532.

Wetzel, R.G. 2001. Limnology. P283. Academic Press. San Diego, California, U.S.A.

Table 1. Range in average pH, conductivity, alkalinity, and chlorophyll *a* concentrations of water samples taken from the pits and quarries, 1998 through 2001.

Water body	pH	Conductivity (μmhos cm^{-1})	Alkalinity (μequ L^{-1})	Chlorophyll *a* (mg m^{-3})
Bayside Quarry	8.0 – 8.3	281 – 300	1526 – 1906	2.2 – 7.8
Gibb Pit	8.3 – 8.9	290 – 320	2088 – 2419	3.4 – 9.5
Stoney Creek Quarry	10.0 – 10.4	316 – 430	772 – 2080	5.2 – 30.0
Van Limbeek Pit	8.2 – 8.4	293 - 327	1943 – 2701	8.2 – 15.5

Table 2.a. Summary of fish abundance estimates, (95% confidence intervals), Schnabel method, June sampling, Bayside Quarry, 1998 - 2002. Total catch listed in italics is for species caught in a year, but for which an abundance estimate is not available.

Species	**Population Estimates**				
	Before habitat addition			After habitat addition	
	June 1998	**June 1999**	**June 2000**	**June 2001**	**June 2002**
Rock bass	1682 (1085, 2582)	933 (552, 1544)	1342 (995, 1805)	1758 (1237, 2490)	1103 (813, 1495)
Bluntnose minnow	*45*	926 (626, 1362)	1898 (1450, 2480)	2156 (1801, 2579)	2238 (1768, 2831)
Yellow perch	122 (54, 240)	*26*	141 (70, 264)	146 (78, 261)	80 (40, 149)
Brown bullhead	6 (2, 10)	*1*	22 (8, 43)	*6*	*6*
Banded killifish	20	*14*	52 (11, 54)	*17*	*5*
Pumpkinseed			4 (1, 7)	6 (2, 12)	*3*
Bluegill	*2*			9 (4, 18)	*70*
Longnose gar	*1*	*1*		*1*	*1*

Table 2.b. Summary of fish abundance estimates, (95% confidence intervals), Schnabel method, June sampling, Stoney Creek Quarry, 1998 - 2002. Total catch listed in italics is for species caught in a year, but for which an abundance estimate is not available.

Species	**Population Estimates**				
	June 1998	**June 1999**	**June 2000**	**June 2001**	**June 2002**
Sunfish *	100651 (85243, 118823)	204486 (170211, 245597)	103261 (87658, 121621)	1006 (555, 1758)	17538 (14719, 20892)
Brown bullhead	1319 (655, 2473)	1074 (437, 2148)	450 (162, 884)	4601 (3029, 6932)	609 (345, 1043)
Fathead minnow	*22*	*299*	*61*	2266 (1958, 2621)	4068 (3765, 4395)
Goldfish		*1*	*6*	2872 (1941, 4224)	1595 (648, 3190)
Iowa darter					91 (27, 159)
Yellow perch	*6*	*3*	*1*		
Banded killifish				*2*	*3*
Golden shiner				*1*	*4*
Blacknose shiner	*19*				
Central mudminnow	*2*			*2*	*2*
White sucker	*1*				
Brook stickleback				*3*	*16*

*Includes pumpkinseed and green sunfish, as well as hybrids of the two species

Table 2.c. Summary of fish abundance estimates, (95% confidence intervals), Schnabel method, June sampling, Van Limbeek Pit, 1998 - 2002. Total catch listed in italics is for species caught in a year, but for which an abundance estimate is not available.

Species	**Population Estimates**				
	Before habitat addition			After habitat addition	
	June 1998	**June 1999**	**June 2000**	**June 2001**	**June 2002**
Pumpkinseed	19724 (12251, 31309)	4973 (3828, 6454)	5942 (4363, 8026)	7265 (5967, 8843)	14863 (10946, 20137)
Blacknose shiner	*300*	34849 (22940, 52505)	4802 (2839, 7949)	6994 (4135, 11577)	*34*
Banded killifish	59 (18, 103)	154 (87, 264)	195 (104, 347)	*48*	*12*
Golden shiner	1646 (728, 3244)	1605 (949, 2656)	12762 (12015, 13555)	7452 (5110, 10809)	2772 (2166, 3545)
Northern pike	73 (26, 144)	106 (59, 185)	200 (72, 393)	41 (21, 75)	88 (39, 174)
Brown bullhead	*9*	57 (32, 97)	181 (94, 331)	394 (118, 686)	582 (210, 1144)
Rock bass	15 (4, 25)	13	370 (110, 644)	8102 (3293, 16203)	3062 (1952, 4750)
Fathead minnow	441 (296, 654)	629 (499, 791)	349 (291, 418)	214 (77, 420)	*5*
Yellow perch			*25*	23 (7, 39)	472 (141, 821)
Northern redbelly dace			12 (4, 24)		
Emerald shiner	*2*				
Brook stickleback			*7*		

Table 2.d. Summary of fish abundance estimates, (95% confidence intervals), Schnabel method, June sampling, Gibb Pit, 2000 - 2002. Total catch listed in italics is for species caught in a year, but for which an abundance estimate is not available.

Species	**Population Estimates**			
	Before habitat addition			After habitat addition
	June 1999	**June 2000**	**June 2001**	**June 2002**
Largemouth bass	*33*	408 (211, 747)	552 (304, 964)	454 (243, 810)
Yellow perch	*152*	5851 (2111, 11508)	1801 (894, 3376)	3931 (2170, 6870)
White sucker	*9*	*17*	*6*	*23*
Rock bass	*1*			*1*

Table 3. Pits and Quarries Fish Biomass and Production Summary, 1998 through 2001. Total biomass and production estimates for all species combined reported per unit area (hectare).

System	**Biomass ($kg \bullet ha^{-1}$)**					**Production ($kg \bullet yr^{-1} \bullet ha^{-1}$)**			
	1998	1999	2000	2001		1998	1999	2000	2001
Gibb		108.65	136.47	73.13			54.33	59.24	28.81
Stoney Creek	161.33	285.85	272.82	59.54		172.10	220.77	222.27	32.34
Bayside	167.85	80.79	144.38	127.03		67.59	33.48	65.52	53.15
Van Limbeek	207.05	238.41	407.93	329.57		112.68	65.38	123.47	239.24

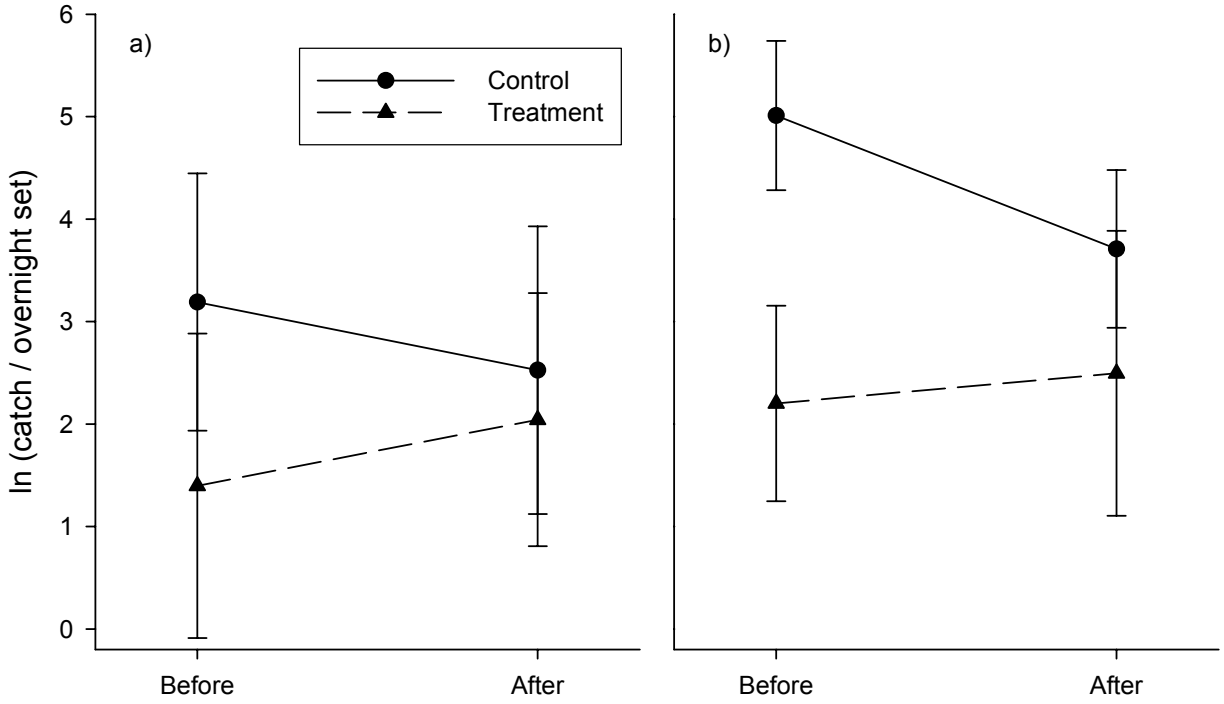

Figure 1. Mean catch-per-unit-effort (± standard deviation) of a) minnow traps and b) trap nets from unperturbed (control) and habitat-enhanced (treatment) systems before and after habitat additions.