Experimental manipulation of aquatic habitat 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,
Aggregate Producers' Association of Ontario
And
Fisheries and Oceans Canada

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1 OVERVIEW

In April 1998, Fisheries and Oceans Canada (DFO) entered into agreement with the Ontario Ministry of Natural Resources (OMNR), and the Aggregate Producers' Association of Ontario (APAO, Management of Abandoned Aggregate Properties Program, MAAP). The goal of this collaboration was 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 completion report provides our methods used to collect data, analysis of the data collected, and discussion of the results from these analyses for the six year project (1998 through 2003). The report also provides a brief discussion of the possible value of adding to this research, including areas where the analyses of the effects of habitat addition could be strengthened as well as expected limitations in the interpretation of these analyses.

2 INTRODUCTION

For decades, aquatic resource managers have used a wide range of fish habitat rehabilitation, enhancement, and creation techniques as a tool for ecological restoration. In aquatic habitats, support for these decisions arises from observations that fish species diversity tends to increase with habitat heterogeneity (Eadie and Keast 1984), and that within systems, habitat type can influence localized fish assemblages (Weaver et al. 1997; Pratt and Smokorowski 2003). For example, aquatic macrophytes are believed to provide cover from predators (Savino and Stein 1982), and increased invertebrate densities (Crowder and Cooper 1982), while rocky habitats contain unique assemblages (Pratt and Smokorowski 2003).

To make decisions regarding development proposals involving aquatic habitat, Fisheries and Oceans Canada uses the Policy for the Management of Fish Habitat (DFO 1986), in which the guiding principle is to achieve no net loss of the productive capacity of fish habitats. Under the *Fisheries Act*, any activity that could result in a harmful alteration, disruption or destruction (HADD) of fish habitat is prohibited, unless authorized at the discretion of DFO with the necessary inclusion of habitat compensation to meet policy objectives. The policy assumes that restoration, enhancement or creation of fish habitat increases the productive capacity of the system, and will therefore compensate for loss from development activities. However, the benefits of habitat restoration efforts have received little assessment (Kelso and Wooley 1996; Smokorowski et al. 1998), and evidence that enhancement of physical fish habitat increases fish production is often anecdotal, circumstantial and inadequate (Bohnsack 1989).

This habitat manipulation experiment is designed to test the hypotheses that enhancement of physical habitat increases biological production. Abandoned aggregate ponds contain a minimum amount of what is traditionally considered desirable heterogeneous fish habitat, thus, by studying a suite of systems both before and after enhancing structural habitat, we propose to address a long standing question 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, or is the effect mainly a redistribution of fish that are there?

3 HABITAT MODIFICATIONS

Work on baseline data collection commenced in three systems in June 1998. The systems were Van Limbeek Pit (Queensville, York region, 44° 10’ N, 79°22’ W), Bayside Quarry

(Sidney Township, Hastings County, 44° 08’ N, 77° 31’ W), and Stoney Creek Quarry (City of Stoney Creek, 43° 11’ N, 79° 40’ W). A fourth system, Gibb Pit (Stratford, Perth County, 43°19’ N, 80° 57’ W), was added to the experiment in June 1999. Each of Bayside Quarry, Van Limbeek Pit, and Gibb Pit received a different habitat modification. Stoney Creek Quarry was left undisturbed to serve as a control system.

3.1 BAYSIDE QUARRY

Bayside Quarry has a surface area of 0.35 ha and a maximum depth of 2.5 m. Much of the quarry (est. 30-40%) is gently sloped with substrate composed primarily of boulder combinations on bedrock covered with a layer of flock/muck. This flock is partially organic matter, and partially calcium based precipitates, or marl. Vegetation is sparse and mostly emergent, growing along edges where the muck accumulated to a greater depth.

A single rock-rubble reef was constructed (November 2000) along the western edge of the 2.0 m depth contour. This irregularly-shaped reef is approximately 20 m in length along its major axis. It was intended that the reef would be roughly triangular in cross-section, averaging 0.6 m high at center. Approximately 60 tonnes of clean, angular, limestone was placed. Approximately 2/3 of the rock added exceeded 30 cm in length, while the remaining 1/3 was composed of materials between 10 cm and 30 cm in length. Angular rock in these size ranges, randomly placed along the reef structure, ensured that interstitial spaces were abundant.

Depth contours were re-measured in October 2001 using a combined depth sounding and differential Geographic Positioning System (GPS) unit. The intention was to use these data, along with the original depth sounding data, to create before and after manipulation maps using Geographic Information System (GIS) software. GIS software would enable calculation of the total volume of rock added. Unfortunately, the pond and reef were too small for the GPS unit to provide a reliable picture of the system. The data collected were inconsistent, with depth measurements rarely the same at locations (intersections of boat-based transects) identified as identical by the GPS unit. As an alternative, depths in the area of the reef were manually measured in July 2002. A rope grid, with 3 m by 3 m individual cells, was laid over the reef area, and nine depth measurements were recorded within each cell of the grid. The data were used to manually produce a post manipulation map of the quarry (Appendix A).

There are two hypothesized mechanisms by which the reef could enhance the fishery. The reef has increased the total surface area of substrate in the system and could result in greater primary and secondary production (increased invertebrate abundance in response to increased epilithic algae production). Fish production could therefore increase in response to the greater availability of prey organisms. The reef will also provide more cover, especially for smaller fish that can seek shelter in the interstitial spaces of the rock. This could result in increased survival of small fish species and young of the larger species.

3.2 VAN LIMBEEK PIT

Van Limbeek has a surface area of 0.76 ha and a maximum depth, as measured in a limited series of depth soundings, of 5.4 m. Other than an area at the north end where the dock and swimming platform are located, the slope of the pond sides are steep. The shore around most of the Van Limbeek Pit is primarily composed of sand, with some clay, gravel, and rubble. Macrophytes (vascular aquatic plants) were found in the southwest and northwest corners.

A 50 m length of shoreline, originally steeply-sloping in the water, was excavated up to 20 m into the land surrounding the pit at the Northeast corner in November 2000. The excavated area is more gently sloped than the original shoreline. Excavation started approximately 2 to 3 m offshore (in 0.5 to 1.0 m depth of water) and worked inland at a 5% slope for approximately 16

m. The inland-most 4 m were 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 have been replaced in shallow berms (maximum height 0.5 m) between the channels and have been planted (fall 2000, supplemented in June 2001) with aquatic and wetland plants that are native to the area. Waterfowl subsequently removed much of the planted vegetation, but we fully expect colonization to continue via seeding from remaining and local vegetation. Vegetation was observed to be better established in June 2003, both along shore and in the channels, than it had been in previous years. Native trees and shrubs have been planted inland from the waters edge to improve slope stability and to provide shade and leaf litter. A snow fence was installed immediately after the planting of trees and shrubs to preclude horses from trampling the new plants. The landowner has since replaced the snow fence with a permanent wood rail fence.

The wetland habitat enhancement was hypothesized to improve ecosystem function in a variety of ways. The newly created wetland may bind some of the often excessive nutrients present in the pit into plant growth. The aquatic vegetation will serve as food and cover for invertebrates, and cover for small fish. Dead aquatic vegetation will serve as an additional food source for organisms that break down organic matter, improving conditions for the invertebrates that feed on these organisms. The channels will increase water supply to the planted berms under lower water conditions, and will increase spawning habitat availability for species that use shallow weedy areas (e.g. northern pike, brown bullhead).

Over time, it is anticipated that a wetland will evolve in the excavated area. In a natural setting, wetland areas are dynamic, with plant assemblages changing in response to rising and falling water levels. The varied slope of the excavated area will allow for these changes. Depth contours in the excavated area were measured manually, and referenced to GPS waypoints, in June 2001. These data were used to produce before and after manipulation depth contour maps using GIS software. These maps have been simplified, in part to adjust issues of scaling of the electronic data, and are presented in Appendix A. Using these simplified before and after manipulation maps, the total surface area of the pond has been estimated to have increased by 452 m^2, an increase of 6.4%. The area of the pond less than or equal to 1.0 m in depth is now estimated be 20% (previously 15%) of the total surface area, an increase from 1076 m^2 to 1528 m^2.

3.3 GIBB PIT

Gibb Pit has a surface area of 4.3 ha and a maximum depth of 4.7 m. Nearly 60% of the Gibb Pit is greater than 2 m in depth. The substrate of the Gibb pit is similar to Van Limbeek, with mainly gravel and sand along the edges, and muck accumulated at the northwest and southwest corners. Almost the entire pit is covered with aquatic vegetation, primarily Potamogeton spp.

Twelve wood bundles were installed along the length of the west shore of the Gibb Pit in December 2001 (Appendix A). 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. Five of the bundles were installed at underwater video recording sites, while the other seven were installed not less than 10 m away from underwater video sites. Underwater video recording of fish movement occurred at each site in the summer of 2001, with video footage recorded at these same locations in 2002 and 2003. All trees were cut from the Gibb family property, just prior to installation. Thirty white pine and a total of 30 maple and ash, averaging 4.5 metres in length per tree, were cut, yielding twelve bundles of five trees each.

Installation involved the driving of a metal T-bar into the ground approximately 25cm upslope from the high water mark of the pond. A metal cable attached this T-bar to a central cable that was tied around the entire bundle. Five other T-bars were driven in among the trees in each bundle. Metal cables connected each individual tree to these five T-bars. Each completed tree bundle fanned out as the bundle protruded offshore. This design allowed for slight movement of the trees with wind and current, and yet resulted in a stable structure that remained in place for the duration of the experiment.

The same potential benefits of the rock-rubble reef addition in Bayside Quarry were hypothesized to result with the placement of tree bundles in the Gibb Pit, namely an increase in surface area for food production and increased cover. In addition, the organisms that slowly decompose the trees may increase the food supply for invertebrates. Also, the most abundant fish species in Gibb Pit is yellow perch. Yellow perch lay their eggs in gelatinous strings, often attached to submerged branches and aquatic plants. The substantial increase in submerged branches could result in greater reproductive success of yellow perch.

3.4 STONEY CREEK QUARRY

Stoney Creek Quarry, the control site for this experiment, has a surface area of 4.68 ha and a maximum depth of 1.4 m (Appendix A). Stoney Creek Quarry is entirely covered with Eurasian milfoil. Fish community, zooplankton, and water chemistry assessments were carried out here in a manner similar to the other systems, but quarry habitat was not altered.

4 METHODS

4.1 CHEMICAL LIMNOLOGY

Water chemistry samples were collected to provide an ongoing qualitative picture of system conditions. While samples were analysed using up to date methods and technology, the sampling regime was not designed to quantitatively identify subtle changes in chemical composition. The intentions of sampling were threefold: 1) to provide a broad-based understanding of the conditions within which the biotic communities exist, 2) to be able to identify or discount contaminant issues as limiting or influencing the biotic communities, and 3) to be able to detect larger-scale changes that might unexpectedly result from the habitat additions.

Water chemistry samples were collected by taking a grab sample just below the water surface (Bayside Quarry and Stoney Creek Quarry), or by using a 5 meter composite tube (Gibb Pit and Van Limbeek Pit), to represent epilimnetic conditions. Water samples were taken in June, July and August of each year. At the deepest part of each system 1-2L bottle of water was collected, returned to the laboratory and processed and analysed for pH, conductivity, and alkalinity. The rest of the sample was spilt using standardized methods and sent to the Great Lakes Forestry Centre (Sault Ste. Marie) where they were analysed for nutrients, carbons, major ions, and trace metals. Temperature and dissolved oxygen profiles were also taken at each system using a YSI dissolved oxygen/temperature meter.

4.2 BIOLOGICAL LIMNOLOGY

4.2.1 Phytoplankton

Concentration of chlorophyll *a* (a photosynthetic plant pigment) within the water column indicates the level of algal productivity within a system. Chlorophyll *a* samples were collected in

June, July, and August of each year. At the deepest part of each system 3-1L bottles of water were collected by taking a grab sample just below the surface of the water (Bayside Quarry and Stoney Creek Quarry), or by using a 5 meter composite tube (Gibb Pit and Van Limbeek Pit) and returned to the laboratory for processing. Using a glass millipore filtering system, each 1-L bottle was poured into a 1000 mL graduated cylinder and then filtered through a glass fibre filter (Whatman GF/C, 42.5 mm). The filters were sealed in labelled plastic bags and frozen prior to chlorophyll *a* analysis (American Public Health Association 1985).

4.2.2 Periphyton

Periphytic algae, or algae that grows attached to surfaces, contribute significantly to the productivity of a system. Periphyton was sampled annually using artificial substrates left in situ for approximately 4 weeks in July and August. Each artificial substrate consists of a "T" shaped metal post that was inserted in the substrate, from which 2 components are suspended just off the bottom. The algae/periphyton colonization component consisted of a single 10 cm X 15 cm Plexiglas plate that hangs vertically from one end of the "T". The other end was occupied by benthic macro invertebrate colonization component (see section 4.2.4). A total of 10 artificial substrates were installed in the littoral zone of each system except Stoney Creek, which was excluded due to installation and retrieval difficulties resulting from the bedrock substrate and extremely dense submerged macrophytes. The biofilm that adheres to the artificial substrate is a combination of organic matter (e.g. bacteria, protozoa, algae) and inorganic matter (e.g. sand, clay). Measuring the chlorophyll *a* content provides a measure of the algal content of this biofilm; combusting the sample at very high temperatures eliminates all organic matter (ash weight), providing a measure of accumulated inorganic matter (ash free dry weight).

4.2.3 Zooplankton

Zooplankton samples were collected using a Wisconsin Zooplankton net (17.5 diameter, 60 µm mesh net) at the deepest part of each system. The net was slowly lowered into the water until 0.5 m above the substrate. The net was held in place for 30 seconds then hauled up at a constant speed of 0.5 $m \cdot s^{-1}$. Filtered water was used to wash down plankton adhered to the net sides into the collection bucket. The bucket was carefully unscrewed and drained of most water. The sample was then rinsed into a 100 mL glass sample jar with 95% ethanol. Three replicates were taken at each sampling effort (June, July, and August). Zooplankton samples were identified to family or genus level and enumerated under a dissecting microscope using a standardized sub-sampling method. Subsample counts were extrapolated to the sample and divided by volume of water filtered to generate an estimate of $No \cdot L^{-1}$. Zooplankton taxa were grouped into categories of cladocerans, immature copepods and adult copepods, and their densities plotted over time in each system.

4.2.4 Benthic Invertebrates

Artificial substrates were used to acquire a relative measure of the abundance and diversity of benthic invertebrates in the pit and quarry systems. Invertebrates on artificial tiles may not colonize in similar proportion and abundance as natural substrates, and thus results are only relative among systems and years and are not necessarily representative of actual aerial abundance of invertebrates on and in the substrate.

In July of each of 1999 through 2003, 10 stacks, consisting of 4 horizontally oriented rectangular vinyl plates (each 10 cm by 15 cm, total surface area of 4 plates =1200 cm^2) spaced along a single, central vertical post hanging off of one end of the “T”, were installed in the littoral zone of the manipulation systems (Bayside Quarry, Van Limbeek Pit, and Gibb Pit). Benthos stacks were left in the systems for approximately 4 weeks to allow colonization. Collected tiles were scraped and washed, and the resulting matter was concentrated and preserved in 70% ethanol. Samples were sorted under a dissecting microscope, and benthic invertebrates were identified and enumerated (for taxonomic groupings, see Appendix C). Note that benthic invertebrate groupings are at different taxonomic levels, which were chosen on the basis of accuracy and efficiency of identification.

4.2.4.1 Invertebrate Diversity

Benthic community diversity was examined using three measures: species richness, heterogeneity, and evenness. Note that the taxonomic distinctions utilized in enumerating benthic organisms also served to divide the organisms into "species" to calculate diversity measures (Appendix C). Species richness (S) is the number of species in the community. In this study, species richness was calculated as the total number of taxonomic groups represented on artificial substrate tiles. The Shannon-Wiener function (H') is a popular measure of the heterogeneity of a community; this index considers both the number of species and the number of individuals within each species. H' values increase with some combination of greater species diversity and balance of abundances among species, hence increasing H' values are interpreted as a positive sign for benthic communities. A measure of evenness (J), or equitability, compares the community to a hypothetical community in which all species are equally abundant. Evenness scales a measure of heterogeneity to its maximal value. The evenness measure is higher when the abundance of individuals by species are similar.

4.3 FISH

4.3.1 Abundance, Biomass and Production

A variety of gear was used to capture fish including trap nets (2 m deep, mesh size 3.8 cm stretched measure), gill nets (six panels ranging from 3.8 cm to 10.2 cm stretched measure mono/multifilament mesh) (Gibb Pit, Van Limbeek Pit, and Bayside Quarry), minnow traps (6 mm mesh), Plexiglas minnow traps, hoop nets, beach seine, and angling (Gibb Pit only). Using a variety of gear in the sampling program increases the probability of sampling a diverse array of fish species, size, and life stages (Weaver and Magnuson, 1993; Jackson and Harvey, 1997). Each fish captured was marked with a year-specific fin clip; some larger individuals received an individually numbered Floy tag. Large individuals were measured for length and weight in the field, and a scale sample was removed for subsequent age determination. A subsample of small individuals was preserved and processed for length-weight-scale data in the laboratory. Schnabel mark-recapture techniques (Ricker, 1975) were used to generate estimates of abundance for all species where capture-recapture rates were adequate (usual number of recaptures is four or more).

Catch-per-unit-effort (CUE) was calculated for each gear type based on a standard unit per gear type (trap nets, TN = overnight net set; gill nets, GN = 0.5 hr set; minnow traps, MT = overnight net set; hoop net, HN = overnight net set). For each combination of species and gear type, the overall annual CUE was calculated as the ratio of the sum of the catch for that species over the total effort involved for that year as follows:

Annual $CPUE_{g,s} = (\Sigma c_{g,s} / \Sigma e_g)$,

Where c = catch, e = units of effort according to gear type, g = gear type, and s = species. Behaviour of fish of different species will vary throughout a year in response to changes in water temperatures, dissolved oxygen supply, and other factors. These changes in behaviour can result in changes to a species' susceptibility to capture. Calculating CUE values for the same time of year, each year, yields data that are more meaningfully comparable between years.

Biomass of individual age classes were summed to obtain whole-lake biomass for that species ($B_x = \Sigma B_i$). Ages, proportion of species abundance within age classes, and mean weight at age were used to calculate instantaneous population growth rate (G_x; Ricker, 1975). Annual production of each species was estimated by $P_x = B_x \times G_x$. Total fish community biomass was estimated by summing the total biomass of each species in the lake ($B_c = \Sigma B_x$). When all species were represented, total community production was estimated by summing species' production ($P_c = \Sigma P_x$). T

These estimates use age-class based calculation methods, with the exception of brown bullheads. Fish age information has been determined from scale samples taken from captured fish, and since brown bullhead is a scaleless species, ageing can only be done by sectioning of hard fin rays or otoliths (ear bone). The former method requires removal of a pectoral fin completely, such that fin regeneration is not possible, while the latter requires sacrificing the fish. In 2002, hard fin rays were cut from brown bullheads as close as possible to their insertion point in the body of the fish. The fin rays were subsequently sectioned in the lab and annuli counted under a microscope, however the resulting age data were unreliable, probably because the most basal portion of the fin ray was left inside the body of the fish. A surrogate method of age class determination was thus used for brown bullhead biomass and production calculations. Sampled fish were subdivided into length class cohorts, based upon length frequency distributions. Total abundance was allocated to cohorts based upon the proportion of sampled fish that fell within each cohort length range. Abundance by length class cohort was then used to calculate biomass and production, rather than abundance by age class.

4.3.1.1 Fish Species Analysis

The individual fish species attributes evaluated are biomass and condition factor by species. Biomass is used instead of abundance estimates as it is more meaningful, and necessarily incorporates abundance in its calculation. For example, declines in the abundance of a species may be offset by an increase in mean size of the animals remaining, such that the contribution of that species to biomass of a system remains unchanged. Condition factor (Fulton's K, see Fisheries Techniques, Second Edition) is a mathematical comparison of the weight of an individual to its length, with higher values interpreted positively. Given two fish of the same species and of equal length, the one that weighs more would have the higher condition factor.

Fulton's K

$$K = (W/L^3) \times 100{,}000$$

Where W= weight (g), L=Length (mm). The constants 100,000 used in the equation are simply scaling constants to convert small decimals to mixed numbers so that the numbers can be more easily comprehended.

4.3.2 Fish Distribution and Aquatic Habitat

Sampling locations for every set of all gear types were recorded on maps during the 1998 through 2000 field seasons, and by hand-held geographic positioning system units (GPS) in 2001 and 2002. These data were originally collected to reference capture rates to habitat survey information, but the small size of the systems may obviate gear-catch-habitat relationships. That a fish is captured in a gear left in place overnight (i.e. trap and hoop nets, minnow traps) may simply mean that the fish passed through that area sometime within a 24 hour period. Gill net captures are also difficult to interpret, as the nets are long in relation to the systems, each set can cover a range of depths and habitat types (where aquatic habitat is not homogenous), and catches can be influenced by the time of day that the net was set. Net location was therefore not used in any subsequent analysis, and instead alternate fish distribution assessment methods were added to the study to determine site-specific fish habitat use.

To get an indication of the propensity of fish to remain within certain areas of a pit or quarry pond, we modified our fish sampling methods in Bayside Quarry in 2002. Rather than a single fin clip being used to mark fish during the annual June sampling period, coloured dye injections were used. The quarry was subdivided into 4 sections, each with somewhat different characteristics (the new reef was one such section). Fish captured in each section were marked with a dye injection of a colour specific to that section. The Bayside Secondary School Ecobound class assisted in the recapture period in the fall of 2002. In early November the quarry was resampled using 3 minnow traps and one hoop net in each of the 4 sections, along with a trap net in its traditional location. Fish captured in each section were processed separately, with the colour of the dye injections from June noted when present.

4.3.3 Underwater Visual Methods

We used direct underwater observation methods, from both video and snorkelling, to assess changes in the distribution of fishes in Bayside Quarry and Gibb Pit pre-and post-habitat addition. These assessments, in combination with the system-wide fish production estimates, allowed us to evaluate the attraction-production question in these systems. We also used the underwater snorkelling observations to determine the habitat selection of fishes within Bayside Quarry.

4.3.3.1 Underwater Visual Camera

We filmed fish with a Fisheye (Techsonic Industries, Inc.) underwater video camera in Bayside Quarry and Gibb Pit to quantify fish distribution and species use of habitat classes in habitat types designed to provide standard habitat measurements and mimic natural littoral zone habitats. Three habitats were filmed in each system. Two habitat types were common to both Bayside Quarry and Gibb Pit: 1) open (OPEN), areas that were at least 2 m x 2 m and had no vertical physical structure; and 2) natural vegetation (VEG), areas where there was at least 0.5 m^2 with more than five plants of emergent aquatic vegetation. The Gibb Pit habitat additions resulted in a third habitat in that system, woody habitat (LOG), which consisted of fallen trees with a diameter between 10 and 65 cm, anchored at or above the water line and extending into the water. A fourth habitat type, rocky substrate (ROCK), was predominantly composed of rubble and small boulders and occurred naturally in, and was intentionally added during reef construction to, Bayside Quarry.

The placement of the habitat additions and difference in size between the two study systems necessitated a contrasting experimental design. In Bayside Quarry, where the rubble reef was added to one previously featureless section of the quarry, 5 sites were selected for filming in each habitat, while an additional 8 OPEN sites were filmed in and around the area of reef construction. The small size of the quarry meant that the reef influenced habitat on both sides of the system. In contrast, the brush bundles added to the larger Gibb Pit were all located on the same side, and these structures did not influence habitat on the opposite side of the pit. Five sites for each habitat type were consequently filmed on both the untreated and addition sides, with up to 10 additional sites filmed where the brush bundles were added. We filmed in Bayside Quarry in July 2000-2002 and Gibb Pit in July 2001-2003, which meant that we filmed one pre- and two post-habitat manipulation years in both systems. Recording difficulties meant that some sites were missed each year, but at least 27 and 34 sites were filmed in Bayside Quarry and Gibb Pit, respectively. Site selection was randomized, but once selected a site remained constant through the three filming years.

Our filming protocol was as follows. A filming order was randomly selected, and at each site we recorded 5 min of video footage with a Fisheye black and white video camera. The camera has an 85.6° field of view and we relied on natural illumination. All sites were filmed between 0900 and 1700 hrs and concurrent weather conditions were recorded. To reduce the degradation of image quality due to increased water turbidity and to protect the onshore electronics, filming did not occur during rainfall. We set the camera underwater at the shoreline facing offshore, and started the 5 min filming episode 0.5 hrs after deployment of the camera. The 0.5 hr acclimation period was chosen after five randomly chosen sites per system were filmed for 0.5 hr episodes immediately after deployment to investigate fish behaviour in relation to the camera, after which we judged that 0.5 hr was sufficiently long for fish to acclimate. A barrier was constructed and placed 1 m from the camera to ensure a constant area was censused.

We split each 5-min video recording into 60 5-sec period captured video clips (640 x 480 pixel resolution) using a video capture card (All-in-Wonder Pro, ATI Technologies, Inc). For analysis, we examined the video recording at each site by using three freeze frame counts taken at 0, 2, and 4 seconds in 10 randomly selected 5-sec periods, and summing the counts for a total of 30 frames per site. Due to a high number of video freeze frame counts with zero fish observed, we divided our fish abundance observations into four abundance classes: zero, one, two, or three or more fish. We felt that this approach was necessary as the high number of frames with zero fish would bias a parametric average of the number of fish per site. The subsequent video observation analyses use the weighted number of fish in each habitat type per lake and per time period, calculated as the total number of freeze frame counts in each abundance class summed over the number of sites times the value of the abundance class category (i.e., 0, 1, 2 , 3+).

A minnow trap, baited with cat food, was set for 0.5 hr at each site immediately following each filming. We expected that the number of fish captured by the minnow trap would help validate the site-specific fish numbers observed by the camera.

4.3.3.2 Distance Sampling

Distance sampling abundance estimates were made in both Bayside Quarry and Gibb Pit in July 2001-2003, though the motive for sampling each system differed. We used Bayside Quarry to assess the utility the visual sampling method and assign habitat preferences to fishes, as before/after habitat addition comparisons were not available. Since we had before and after habitat addition data from Gibb Pit, we used abundance estimates to determine whether species shifted their use from one side of the pit to the other with the addition of brush bundles.

We snorkelled over line transects and used distance sampling to estimate habitat-specific species abundances from 3 habitats (OPEN, ROCK, VEG) in Bayside Quarry and two sides (BRUSH BUNDLE, CONTROL) of Gibb Pit. The method involves laying a 15 or 30 m lead-line transect, with 4 m cross pieces located every 2.5 m, that were set perpendicular to shore in Bayside Quarry and parallel to shore in Gibb Pit. The transect was marked at 1 m intervals along its length to allow estimates of habitat area, and the cross-pieces were marked at 5 cm intervals to ensure accurate perpendicular sighting distances. Transects were snorkelled by swimming slowly over the center of the transect, with habitat type, fish species, life stage and perpendicular distance (in relation to the centre transect line) noted on wrist slates for each fish sighting. When fish were aggregated (which they commonly were), habitat type, aggregation size and composition, and the perpendicular distance of the centre of the aggregation were noted. The snorkelling distance sampling method has advantages over the underwater camera method as it can identify fish to species, meaning that species-specific habitat preferences can be tested.

4.3.4 Data Analysis

The fisheries portion of the study was based upon a Before-After Control-Impact (BACI) design, with one control site (unaltered) and three treatment sites (habitat additions in this case). Similar amounts of effort were expended in all systems for a period of time before and after treatments were affected. Fish community attributes before and after treatment are then to be compared against a control system to separate out changes due to the treatments from broader scale environmentally-induced changes. For example, if the pre-treatment years were cool and wet, but post-treatment years were warm and dry, then some changes to the fish communities may have occurred even in the absence of the treatments.

When appropriate, the multiple before-after control-impact (MBACI) mixed-model ANOVA developed by Keough and Quinn (2000) was used to analyze for change. The MBACI model tests the effect of change, in this case habitat manipulation, by examining whether multiple control and treatment locations diverge over time. Our model consists of five factors: Waterbody (random); Treatment (fixed); Time (fixed); Year (nested in Time, fixed); and Site (nested in Waterbody, random). The model examines for change by testing $MS_{(Treatment * Time)}$ /

MS $_{(Site[Treatment] * Time)}$. Natural log plus one transformed weighted fish numbers were used in the analysis to meet the assumptions necessary for the use of parametric statistics.

The use of the MBACI model assumes that the biological variables of interest respond similarly to abiotic change. Stoney Creek Quarry was similar in morphometry to the experimental quarry, contained similar fish species as two experimental systems, and was located in a similar climate region. The purpose of the control system is to document ecological response to regional climate in the absence of any known alteration to prevailing conditions, such as a major habitat addition, and ideally multiple control systems are used to improve confidence in achieving that objective. When the unit of study is an entire system, however, constraints on design often preclude the use of multiple controls. When it appeared that this essential criterion was not met with Stoney Creek, the MBACI model was not used in analysis, and instead within system changes were assessed using two-tailed Students t-tests, testing for differences before and after the treatment, with an effective probability level of $\alpha = 0.05$. Because the probability of obtaining a significant result increases with the number of tests even with randomly generated data, to maintain this probability and ensure no increase in Type I error, Bonferroni corrections were applied (new $\alpha = 0.05/\#$ tests) which reduces the level at which you consider a result significant, dependent on the number of tests.

4.3.4.1 Fish Diversity

Diversity values for the fish communities in the systems were calculated and compared from before to after treatment. Diversity is of interest as a measure of community resilience and stability. For example, the higher the diversity value, the less influence that disease, or other factors that negatively influence a subset of the species present, will have on community attributes as a whole. For this study, Hurlbert's PIE (Hurlbert 1971; probability of an interspecific encounter) index was calculated, using total June catches and biomass estimates by species, for each system in each year using Ecosim software (Gotelli and Entsminger 2004). This index yields the probability that two randomly sampled individuals, or units of biomass, represent two different species. As the index value is a probability (e.g. ranges between zero and one), higher values represent a lesser probability that the two sample units are the same, or a greater balance of total numbers or biomass within the community.

$$PIE = \left(\frac{N}{N-1}\right)\left(1 - \sum_{i=1}^{S} p_i^2\right)$$

where N = the total number of species in the assemblage, and p(i) = proportion of the entire sample represented by species i.

4.3.4.2 Assessment of Fish Habitat Use

We investigated whether our underwater video protocol was useful for documenting fish habitat-associations by testing for differences in fish habitat use among habitat types using nested ANOVA's, with each unique site nested within habitat type. Manipulation sites, where habitat features were either added or removed during the course of the study, were not included in the analysis. For this and all subsequent analyses, data were natural log plus 1 transformed as needed to meet normality requirements. Subsampling, or repeated observations on the same experimental unit, is analogous to nested factor ANOVA designs except the appropriate F statistic for treatment effects uses the experimental error mean square in the test statistic denominator (Neter et al. 1990). For this and all subsequent analyses, Bonferroni corrections were applied to ensure that the experiment-wise probability remained at 0.05.

The full five minute video trials were examined to determine whether there were among-habitat differences in length of time individual fish remained in view of the camera, hereafter called residency time, and the number of times individual fish were recorded feeding in a given habitat type. These data, available only from underwater observation, could provide additional insight on the importance of habitat types to fish, as refuge from predators and prey availability are critical for understanding habitat use and importance. Only an average time per aggregation, resulting in a single data point, was used in the residency analysis when fish aggregations were observed.

We determined habitat preferences for species in Bayside Quarry only using the snorkelling data, as the depth and morphometry of Gibb Pit precluded its use in that system. Fish use of three habitats, OPEN, VEG and ROCK were examined by species and preferences calculated using an electivity index (Ivlev 1961):

$$E = (r-n)/(r+n)$$

where E = Ivlev's electivity measure, r = percentage of population using a particular habitat, and n = percentage of habitat available. Electivity then becomes a value between -1 and 1, with values around zero indicating no preference, -1 meaning total avoidance and 1 indicating complete preference.

4.3.4.3 Assessment of Fish Distribution

Potential site-level changes in the distribution of fish were examined against system-wide population trends to determine whether our habitat manipulations simply re-distributed fish or noticeably changed system-wide productivity. Mean system biomass, calculated by multiplying the average weight of captured individuals with abundance estimates for each species, was calculated for two pre and two post manipulation years. Two-factor ANOVA's, with System and Time (before or after manipulation) as factors, were used to test for changes in biomass in Bayside and Gibb. System-wide production, as measured by the habitat productivity index (HPI) (Randall & Minns 2000), was examined for change post-manipulation using the same ANOVA models. The HPI estimates production per unit biomass (*P/B*) ratios by summing the product system-wide biomass and the associated *P/B* ratio for each species from each habitat type (Randall & Minns 2000).

5 RESULTS

5.1 CHEMICAL LIMNOLOGY

5.1.1 Temperature and Dissolved Oxygen

Water temperature and dissolved oxygen profiles for all systems are provided in Appendix B. The differences in water temperature between the surface and bottom were relatively small in Bayside Quarry, Gibb Pit, and Stoney Creek Quarry, with the exception of June 2001 in Stoney Creek Quarry that was likely the result of the temperature sensor being immediately atop a groundwater input. Van Limbeek Pit exhibited decreases in temperature from surface to bottom in all years since this system was of adequate depth to thermally stratify. A dissolved oxygen concentration of 4 $mg \cdot L^{-1}$ can be used as a rule of thumb minimum for supporting a diverse aquatic community. Only Bayside Quarry met or exceeded this minimum in all cases. Stoney Creek Quarry (three occurrences) and Gibb Pit (two occurrences) had dissolved oxygen concentrations below 4 mg·L-1, but in each case this was at the deepest point of measurement only. From 1998 through 2001 Van Limbeek Pit had a dissolved oxygen deficiency in the summer months in all water deeper than 3.5m to 4.0m. August 2002 was the first time this deficiency did not occur, but subsequent measures to confirm improved conditions in deeper water were prevented by equipment malfunctions.

5.1.2 pH, Conductivity, and Alkalinity

The average pH, conductivity, and alkalinity of water samples collected in 1998 through 2003 are reported in Table 1.

Table 1: Average pH, conductivity (μmhos·cm^{-1}), and alkalinity (μequ·L^{-1}), with standard errors, of water samples from the pits and quarries, 1998 through 2003. Also shown is the pH range suggested as a target by *The Canadian Water Quality Guidelines for the Protection of Aquatic Life* (CWQG) (Canadian Council of Ministers of the Environment, 1999).

		Bayside Quarry					
	CWQG	1998	1999	2000	2001	2002	2003
pH	6.5 - 9.0	8.3 ± 0.1	8.0 ± 0.4	8.2 ± 0.0	8.3 ± 0.1	8.4 ± 0.2	8.3 ± 0.0
Conductivity		289 ± 5	288 ± 6	281 ± 15	300 ± 4	317 ± 4	267 ± 23
Alkalinity		1773 ± 26	1526 ± 14	1674 ± 88	1906 ± 84	1621 ± 128	1480 ± 85
		Van Limbeek Pit					
		1998	1999	2000	2001	2002	2003
pH	6.5 - 9.0	8.4 ± 0.1	8.2 ± 0.0	8.3 ± 0.2	8.4 ± 0.2	8.7 ± 0.2	8.6 ± 0.1
Conductivity		327 ± 5	293 ± 9	315 ± 16	294 ± 21	258 ± 27	243 ± 14
Alkalinity		2533 ± 51	2523 ± 45	2701 ± 120	1943 ± 316	1923 ± 316	1927 ± 172
		Gibb Pit					
		1998	1999	2000	2001	2002	2003
pH	6.5 - 9.0	8.3 (na)	8.6 ± 0.1	8.6 ± 0.1	8.9 ± 0.1	9.1 ± 0.7	9.0 ± 0.2
Conductivity		295 (na)	290 ± 13	320 ± 12	315 ± 10	314 ± 56	282 ± 30
Alkalinity		2088 (na)	2419 ± 84	2393 ± 111	2289 ± 121	2183 ± 557	2174 ± 411
		Stoney Creek Quarry					
		1998	1999	2000	2001	2002	2003
pH	6.5 - 9.0	10.1 (na)	10.0 ± 0.2	10.4 ± 0.0	10.1 (na)	9.3 (na)	9.2 (na)
Conductivity		430 (na)	416 ± 24	316 ± 25	350 (na)	410 (na)	410 (na)
Alkalinity		1924 (na)	2080 ± 32	1833 ± 44	772 (na)	1858 (na)	1732 (na)

(na) - not available

The waters of all pits and quarries are mildly to moderately basic (pH range = 8.0 - 10.4). The alkalinity values indicate that all systems have substantial capacity to neutralize acidic inputs. Conductivity values are in the range that would be classified as hard water.

5.1.3 Major Ions

Table 2 contains the average concentrations of major ions in the pit and quarry systems from water samples collected in 1998 through 2003.

Table 2: Average major ion concentrations (mg·L^{-1}), with standard errors, of water samples from the pits and quarries, 1998 through 2003.

Ion	**Bayside Quarry**					
	1998	1999	2000	2001	2002	2003
Ca	33.70 ± 1.85	39.10 ± 4.13	38.78 ± 1.50	36.75 ± 1.84	39.47 ± 3.07	33.89 ± 1.01
Mg	12.24 ± 0.02	14.23 ± 0.22	13.67 ± 0.41	15.45 ± 0.64	15.14 ± 0.30	12.08 ± 0.47
K	2.13 ± 0.12	2.37 ± 0.06	1.91 ± 0.02	2.40 ± 0.19	2.62 ± 0.22	1.81 ± 0.05
Na	5.27 ± 0.13	6.15 ± 0.14	4.32 ± 0.10	5.99 ± 0.45	5.07 ± 0.27	3.89 ± 0.16
SO_4	61.35 ± 0.02	82.66 ± 0.46	78.84 ± 3.48	75.92 ± 2.57	83.49 ± 3.59	75.77 ± 1.46
Cl	2.07 ± 0.07	2.51 ± 0.10	1.87 ± 0.09	2.66 ± 0.18	2.18 ± 0.09	2.26 ± 0.05
SiO_2	3.98 ± 1.94	2.99 ± 1.86	3.26 ± 0.94	2.89 ± 0.89	4.27 ± 1.89	3.34 ± 1.24
	Van Limbeek Pit					
	1998	1999	2000	2001	2002	2003
Ca	29.26 ± 1.49	30.40 ± 1.96	41.67 ± 3.09	38.25 ± 5.67	30.65 ± 5.74	29.16 ± 3.04
Mg	15.30 ± 0.12	15.87 ± 0.23	10.91 ± 0.89	10.18 ± 0.07	9.67 ± 0.11	8.69 ± 0.19
K	1.69 ± 0.08	2.12 ± 0.06	2.95 ± 0.15	3.72 ± 0.06	3.57 ± 0.10	3.65 ± 0.06
Na	13.09 ± 0.10	13.26 ± 0.28	9.92 ± 0.51	10.12 ± 0.09	9.75 ± 0.13	9.67 ± 0.20
SO_4	14.72 ± 0.29	14.75 ± 0.14	14.35 ± 1.41	14.25 ± 0.04	14.90 ± 0.19	13.60 ± 0.19
Cl	20.05 ± 1.70	21.12 ± 0.78	17.55 ± 1.02	22.81 ± 1.45	20.87 ± 0.77	20.87 ± 0.52
SiO_2	0.89 ± 0.47	1.57 ± 0.61	2.59 ± 1.01	1.80 ± 0.34	1.08 ± 0.30	1.10 ± 0.32
	Gibb Pit					
	1998	1999	2000	2001	2002	2003
Ca	35.55 (na)	30.11 ± 2.49	31.25 ± 2.39	25.83 ± 2.93	24.62 ± 6.12	25.17 ± 5.82
Mg	18.78 (na)	18.36 ± 0.19	18.60 ± 0.37	20.05 ± 0.31	19.86 ± 0.26	17.22 ± 0.24
K	1.38 (na)	1.03 ± 0.13	1.07 ± 0.13	1.29 ± 0.17	1.04 ± 0.18	0.99 ± 0.11
Na	8.08 (na)	8.13 ± 0.25	9.30 ± 0.38	10.18 ± 0.21	10.88 ± 0.19	10.57 ± 0.16
SO_4	12.43 (na)	14.69 ± 0.79	15.32 ± 0.29	17.49 ± 0.68	16.95 ± 0.51	16.49 ± 0.29
Cl	19.85 (na)	20.88 ± 1.10	20.80 ± 3.77	27.24 ± 0.34	26.67 ± 0.57	26.08 ± 0.62
SiO_2	1.93 (na)	0.63 ± 0.31	1.00 ± 0.34	0.69 ± 0.17	0.80 ± 0.37	0.48 ± 0.18
	Stoney Creek Quarry					
	1998	1999	2000	2001	2002	2003
Ca	18.85 (na)	21.73 ± 1.73	19.41 ± 4.23	19.24 (na)	23.04 (na)	20.51 (na)
Mg	19.74 (na)	23.25 ± 0.07	20.80 ± 0.71	21.75 (na)	23.67 (na)	21.19 (na)
K	1.37 (na)	2.59 ± 0.02	1.66 ± 0.17	0.98 (na)	2.79 (na)	2.15 (na)
Na	22.60 (na)	28.90 ± 1.85	21.65 ± 1.11	25.76 (na)	25.84 (na)	28.10 (na)
SO_4	22.08 (na)	27.39 ± 2.10	31.85 ± 1.72	35.70 (na)	40.59 (na)	48.67 (na)
Cl	46.36 (na)	36.95 ± 20.72	46.17 ± 1.09	51.51 (na)	59.15 (na)	60.73 (na)
SiO_2	2.62 (na)	3.21 ± 0.49	1.33 ± 0.20	0.87 (na)	0.21 (na)	0.26 (na)

(na) - not available, results from single sample

Total measured ion concentrations in the two quarries are roughly 50% greater than in the two pits. Total ion concentrations in Bayside Quarry, Van Limbeek Pit, and Gibb Pit have remained fairly stable over the six years of the study. Total ion concentrations in Stoney Creek Quarry have increased over this time, driven largely by increases in sulphate and chloride concentrations.

5.1.4 Carbons and Nutrients

Carbon and nutrient concentrations from ater samples are presented in Table 3.

Table 3: Average carbon and nutrient concentrations ($mg \cdot L^{-1}$), with standard errors, of water samples from the pits and quarries, 1998 through 2003.

	Bayside Quarry					
	1998	1999	2000	2001	2002	2003
T.O.C.	5.01 ± 0.90	8.49 ± 1.26	5.94 ± 1.46	5.41 ± 0.79	6.85 ± 2.40	5.15 ± 0.20
T.I.C.	19.27 ± 0.90	20.04 ± 2.40	18.35 ± 0.99	14.56 ± 2.84	19.56 ± 0.80	16.70 ± 0.52
T.P.	0.008 ± 0.000	0.012 ± 0.001	0.009 ± 0.001	0.010 ± 0.001	0.012 ± 0.002	0.009 ± 0.001
T.N.	0.539 ± 0.057	0.602 ± 0.028	0.491 ± 0.053	0.527 ± 0.100	0.505 ± 0.017	0.421 ± 0.017
NO_2+NO_3	0.023 ± 0.003	0.023 ± 0.004	0.015 ± 0.004	0.275 ± 0.050	0.137 ± 0.098	0.017 ± 0.007
NH_4	0.059 ± 0.041	0.305 ± 0.134	0.057 ± 0.013	0.025 ± 0.011	0.031 ± 0.010	0.016 ± 0.004
	Van Limbeek Pit					
	1998	1999	2000	2001	2002	2003
T.O.C.	7.81 ± 1.14	8.55 ± 0.85	10.26 ± 1.07	9.86 ± 0.96	9.62 ± 1.48	10.14 ± 1.10
T.I.C.	25.19 ± 3.33	28.33 ± 0.56	29.56 ± 1.20	18.23 ± 5.16	20.93 ± 2.75	21.94 ± 1.84
T.P.	0.025 ± 0.003	0.029 ± 0.003	0.036 ± 0.007	0.036 ± 0.013	0.019 ± 0.002	0.021 ± 0.002
T.N.	0.727 ± 0.060	0.941 ± 0.041	0.926 ± 0.086	0.855 ± 0.068	0.748 ± 0.066	0.745 ± 0.046
NO_2+NO_3	0.012 ± 0.001	0.017 ± 0.003	0.027 ± 0.019	0.121 ± 0.094	0.047 ± 0.037	0.008 ± 0.002
NH_4	0.050 ± 0.036	0.048 ± 0.012	0.072 ± 0.033	0.020 ± 0.008	0.015 ± 0.001	0.218 ± 0.189
	Gibb Pit					
	1998	1999	2000	2001	2002	2003
T.O.C.	4.31 (na)	4.63 ± 0.86	4.52 ± 0.28	4.49 ± 0.61	5.97 ± 2.60	4.73 ± 0.39
T.I.C.	39.27 (na)	27.42 ± 0.83	27.08 ± 1.21	15.55 ± 3.47	22.63 ± 3.81	24.94 ± 2.46
T.P.	0.014 (na)	0.016 ± 0.002	0.021 ± 0.004	0.018 ± 0.004	0.013 ± 0.001	0.010 ± 0.001
T.N.	0.860 (na)	0.993 ± 0.173	1.755 ± 0.395	2.033 ± 0.215	1.711 ± 0.192	0.679 ± 0.134
NO_2+NO_3	0.186 (na)	0.385 ± 0.150	1.215 ± 0.325	2.028 ± 0.424	1.407 ± 0.264	0.298 ± 0.175
NH_4	0.154 (na)	0.121 ± 0.100	0.067 ± 0.016	0.074 ± 0.040	0.024 ± 0.011	0.009 ± 0.003
	Stoney Creek Quarry					
	1998	1999	2000	2001	2002	2003
T.O.C.	12.37 (na)	20.50 ± 1.20	15.42 ± 0.05	7.75 (na)	9.05 (na)	13.22 (na)
T.I.C.	16.27 (na)	17.80 ± 0.96	14.47 ± 1.93	11.51 (na)	17.16 (na)	17.77 (na)
T.P.	0.050 (na)	0.087 ± 0.006	0.042 ± 0.001	0.032 (na)	0.040 (na)	0.060 (na)
T.N.	1.156 (na)	1.401 ± 0.004	1.052 ± 0.024	0.805 (na)	0.840 (na)	1.085 (na)
NO_2+NO_3	0.013 (na)	0.016 ± 0.001	0.011 ± 0.004	0.073 (na)	0.001 (na)	0.020 (na)
NH_4	0.020 (na)	0.082 ± 0.029	0.030 ± 0.011	0.024 (na)	0.013 (na)	0.014 (na)

(na) - not available

Eutrophy can be defined as a state of high nutrient supply, such that a eutrophic system would have the potential for excessive biotic productivity. Based upon total phosphorus (TP) concentrations exceeding 0.020 mg·L^{-1}, Stoney Creek Quarry and Van Limbeek Pit would be considered to be eutrophic. Phosphorus levels in Van Limbeek Pit in 2002 and 2003 were, however, lower than in previous years (0.019·mg L^{-1} and 0.021 mg·L^{-1}, respectively).

5.1.5 Trace Metals

The toxicity of metals to aquatic organisms generally increases as the acidity of the water increases (i.e. as pH declines from 7 toward 0). Canadian Water Quality Guideline concentrations in Table 4 are thus expressed as a range. Lower guideline concentrations for metals are given when the acid buffering capacity of the water (expressed as the concentration of CaCO3) is low. While CaCO3 concentrations are not directly measured in the study systems, their range in pH, relatively high alkalinity values (see Table 1), and presence of limestone (quarries) indicates that the pits and quarries have substantial acid buffering capacity. Metal concentrations should thus be compared against the high end of the CWQG range provided in Table 4. Measured copper and cadmium concentrations did exceed guideline concentrations in some instances between 1998 and 2000, although there were no instances of copper or cadmium exceeding water quality guidelines from 2001 forward. The other metals were undetectable, or measured at concentrations below the guidelines in all cases.

Table 4: Maximum trace metal concentrations (mg·L^{-1}) found in water samples from the pits and quarries, 1998 through 2003. Values proceeded by "<" indicate that the maximum sample concentration was less than the detection limits of the analytical equipment used; the detection limit is the number provided after "<". Also shown are selected maximum concentrations suggested by *The Canadian Water Quality Guidelines for the Protection of Aquatic Life* (CWQG) (Canadian Council of Ministers of the Environment, 1999).

		Bayside Quarry					
	CWQG	1998	1999	2000	2001	2002	2003
Al	0.100	0.0066	0.0253	0.0136	0.0100	0.0201	0.0346
Fe	0.300	0.0092	0.2118	0.0078	0.0123	0.0169	0.0214

Mn		0.0058	0.0125	0.0048	0.0027	0.0033	0.0050
Zn	0.030	<0.005	0.0097	<0.005	0.0250	<0.005	<0.005
Pb	0.001-0.007[a]	<0.02	<0.02	<0.02	<0.002	<0.002	<0.002
Ni	0.025-0.150[a]	0.0188	0.0047	0.0134	0.0045	0.0066	0.0052
Cd	0.000017	0.0046	<0.002	0.0028	<0.001	<0.001	<0.001
Cu	0.002-0.004[a]	0.0054	0.0040	0.0070	<0.002	<0.002	0.0022
		Van Limbeek Pit					
		1998	1999	2000	2001	2002	2003
Al	0.100	0.0641	0.0184	0.0887	0.0404	0.0240	0.0222
Fe	0.300	0.1210	0.0361	0.2019	0.0735	0.0374	0.0729
Mn		0.0207	0.0098	0.0597	0.0391	0.0121	0.0445
Zn	0.030	<0.005	0.0102	<0.005	<0.005	0.0050	<0.005
Pb	0.001-0.007[a]	<0.02	<0.02	<0.02	<0.002	<0.002	<0.002
Ni	0.025-0.150[a]	0.0212	0.0168	0.0102	<0.002	<0.002	0.0021
Cd	0.000017	0.0051	0.0026	0.0025	<0.001	<0.001	<0.001
Cu	0.002-0.004[a]	0.0052	0.0054	0.0076	<0.002	<0.002	0.0023
		Gibb Pit					
		1998	1999	2000	2001	2002	2003
Al	0.100	0.0124	0.0354	0.0262	0.0090	0.0128	0.0115
Fe	0.300	0.0251	0.0359	0.0351	0.1642	0.0151	0.0127
Mn		0.0115	0.0147	0.0085	0.1241	0.0042	0.0034
Zn	0.030	<0.005	0.0087	<0.005	<0.005	0.0050	<0.005
Pb	0.001-0.007[a]	<0.02	<0.02	<0.02	<0.002	<0.002	<0.002
Ni	0.025-0.150[a]	0.0119	0.0148	0.0167	<0.002	<0.002	<0.002
Cd	0.000017	<0.002	0.0026	0.0037	<0.001	<0.001	<0.001
Cu	0.002-0.004[a]	0.0051	0.0061	0.0077	<0.002	0.0022	<0.002
		Stoney Creek Quarry					
		1998	1999	2000	2001	2002	2003
Al	0.100	-	0.0089	0.0526	0.0099	0.0309	0.0709
Fe	0.300	-	0.0406	0.0731	0.0107	0.0463	0.1064
Mn		-	<0.002	0.0337	0.0024	0.0195	0.0409
Zn	0.030	-	<0.005	<0.005	<0.005	<0.005	<0.005
Pb	0.001-0.007[a]	-	<0.02	<0.02	<0.002	<0.002	<0.002
Ni	0.025-0.150[a]	-	<0.002	0.0204	<0.002	<0.002	<0.002
Cd	0.000017	-	<0.002	0.0037	<0.001	<0.001	<0.001
Cu	0.002-0.004[a]	-	<0.002	0.0054	<0.002	<0.002	0.0022

[a] target maxima increase with increasing $CaCO_3$ concentrations in the water (low end of range when $CaCO_3$ <60 mg•L^{-1}, high end of range when $CaCO_3$ >180 mg•L^{-1})

5.2 BIOLOGICAL LIMNOLOGY

5.2.1 Phytoplankton

A system with low productivity, or an oligotrophic system, would have a mean chlorophyll *a* concentration of around 2 μg·L^{-1}; a medium productivity, or mesotrophic system, would have chlorophyll *a* of around 5 $\mu g \cdot L^{-1}$; and a highly productive, or eutrophic system, would have a chlorophyll *a* of around 14 $\mu g \cdot L^{-1}$ (Wetzel 2001). The concentrations in Bayside Quarry and Gibb Pit (Table 5) indicate mesotrophic status. Van Limbeek Pit chlorophyll *a* concentrations ranged between mesotrophic and eutrophic prior to habitat manipulation, while they have remained within the mesotrophic range since 2001. Stoney Creek Quarry would generally be defined as eutrophic.

Table 5: Average concentration of Chlorophyll *a* ($mg \cdot m^{-3}$ ± standard error, SE) in water from each system, across the sampling season, 1998 through 2003.

System	1998	1999	2000	2001	2002	2003
Bayside Quarry	3.1	7.8	2.2	2.5	3.1	3.0
	(± 1.1)	(± 2.6)	(± 1.1)	(± 0.2)	(± 0.3)	(± 0.1)
Van Limbeek Pit	9.6	8.8	15.5	8.2	5.7	6.4
	(± 2.5)	(± 3.3)	(± 17.6)	(± 2.3)	(± 0.4)	(± 0.7)
Gibb Pit	3.4	6.2	5.4	9.5	2.9	11.5
	(--)	(± 1.9)	(± 1.5)	(± 2.6)	(± 0.4)	(± 2.0)
Stoney Creek Quarry	10.5	30.0	19.8	5.2	15.4	19.3
	(± 1.1)	(± 12.4)	(± 12.5)	(± 0.4)	(± 0.5)	(± 1.5)

5.2.2 Periphyton

The chlorophyll *a* values, along with the dry weight, ash weight and ash free dry weight for Bayside Quarry, Van Limbeek Pit, and Gibb Pit samples for 1998 through 2002 are shown in Tables 6, 7, and 8 respectively. Total biofilm mass was greater on average in VanLimbeek than in the other systems, but much of that mass was inorganic matter (sand etc., ash weight) which decreased in the latter years of the study. No trend is apparent in Bayside Quarry or Gibb Pit.

Table 6: Average (±SE) dry weight (mg), ash weight (mg), ash-free dry weight (mg) and chlorophyll a ($\mu g \cdot m^2$) of periphyton collected from artificial substrates in Bayside Quarry, summers of 1998 through 2003.

	1998 July 22 – Aug 13	1999 July 7 – Aug 9	2000 July 17 – Aug 15	2001 July 16 - Aug 15	2002 July 16 – Aug 14	2003 July 7 – Aug 12
# samples	9	9	8	8	10	7
Dry Weight	28.2 (±6.6)	156.7 (±23.7)	82.8 (±15.1)	108.8 (±52.8)	299.3 (±105.3)	89.2 (±44.4)
Ash Weight	12.9 (±2.9)	94.2 (±16.9)	47.8 (±9.2)	80.6 (±40.8)	240.2 (±101.4)	59.4 (±28.4)
AFDW	15.3 (±4.2)	62.6 (±7.6)	35.0 (±6.1)	28.1 (±12.3)	59.8 (±15.5)	29.8 (±16.0)
Chlorophyll *a*	661.0 (±198.1)	2978.0 (±262.0)	625.0 (±121.3)	806.6 (±316.3)	2833.5 (±769.1)	688.7 (±239.6)

Table 7: Average (±SE) dry weight (mg), ash weight (mg), ash-free dry weight (mg) and chlorophyll a ($\mu g \cdot m^2$) of periphyton collected from artificial substrates in Van Limbeek Pit, summers of 1998 through 2003.

	1998 July 22 – Aug 13	1999 July 7 – Aug 9	2000 July 17 – Aug 15	2001 July 16 - Aug 15	2002 July 17 – Aug 14	2003 July 7 – Aug 12
# samples	9	2*	10	5*	10	7
Dry Weight	224.3 (±26.3)	502.6 (±269.5)	606.8 (±134.7)	604.6 (±256.7)	173.2 (±39.6)	311.0 (±75.7)
Ash Weight	184.2 (±23.8)	445.7 (±255.4)	442.2 (±100.7)	429.0 (±223.9)	131.5 (±33.7)	207.2 (±73.1)
AFDW	40.1 (±6.3)	56.9 (±14.62)	164.7 (±35.5)	141.3 (±43.5)	45.8 (±9.7)	103.7 (±34.4)
Chlorophyll a	1121.3 (±128.1)	3380.7 (±1394.8)	1372.5 (±267.2)	1518.8 (±461.2)	1600.0 (±267.4)	819.1 (±152.4)

* A number of samples were rendered invalid due to a dramatic drop in water levels after installation of the tiles

Table 8: Average (±SE) dry weight (mg), ash weight (mg), ash-free dry weight (mg) and Chlorophyll a ($\mu g \cdot m^2$) of periphyton collected from artificial substrates in Gibb Pit, summers of 1999 through 2003.

	1999 July 8 – Aug. 10	2000 July 18 – Aug 14	2001 July 17 – Aug 14	2002 July 16 – Aug 13	2003 July 7 – Aug 11
# samples	8	9	10	4*	9
Dry Weight	392.9 (±72.3)	80.1 (±21.6)	28.4 (±10.5)	21.4 (±15.8)	51.3 (±24.0)
Ash Weight	272.3 (±65.5)	45.4 (±12.5)	17.9 (±8.3)	13.5 (±10.8)	25.8 (±11.6)
AFDW	120.6 (±10.6)	34.7 (±12.9)	10.4 (±3.1)	7.9 (±5.2)	25.5 (±14.0)

Chlorophyll a	5339.5 (±641.5)	357.4 (±56.1)	149.1 (±19.4)	171.2 (±94.9)	114.4 (±30.3)

* data from tiles that had aquatic grasses attached are ignored

5.2.3 Zooplankton

Zooplankton abundance appeared to increase over the summer months in Gibb Pit (Fig. 3), while consistent trends in zooplankton abundance in the other system were not apparent. In 2001 through 2003, zooplankton densities were relatively low in all systems compared to previous years. The densities of zooplankton reported are the mean values of the three samples from each day (Figs. 1 – 4).

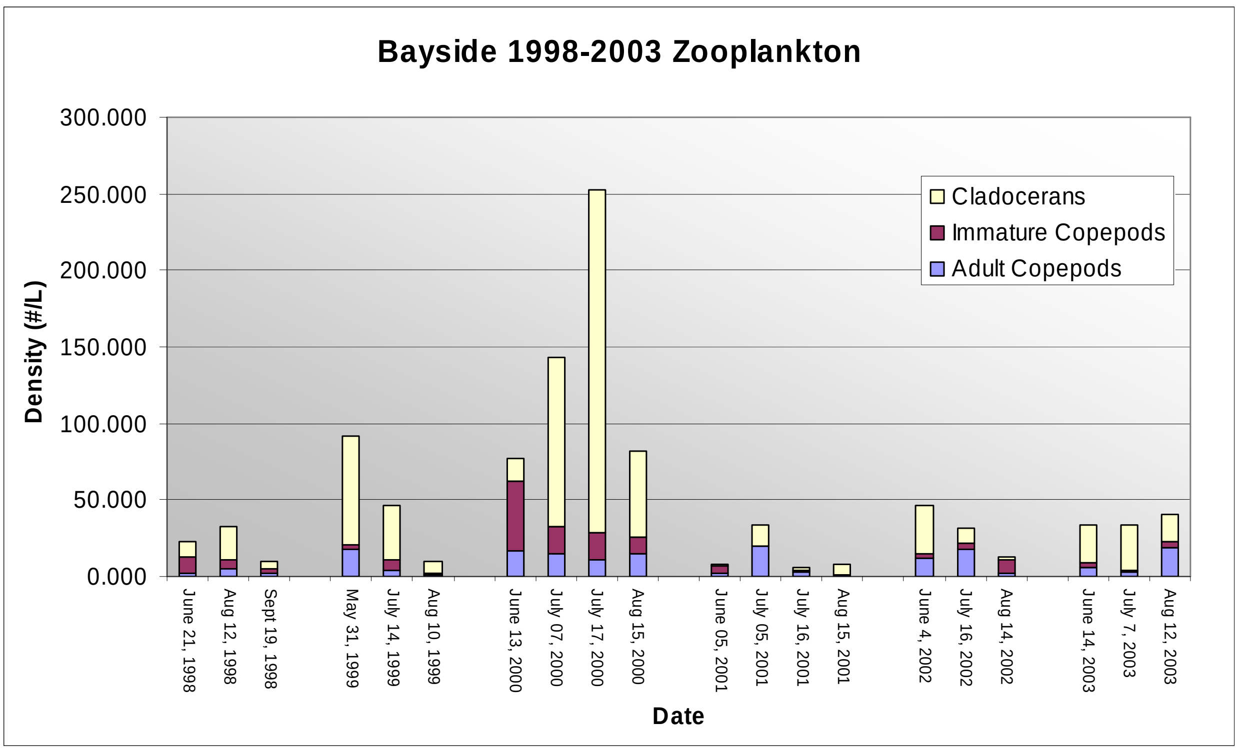

Figure 1: Zooplankton abundance, in individuals per litre of adult copepods, immature copepods and cladocerans, Bayside Quarry, Bayside, ON, 1998 - 2003.

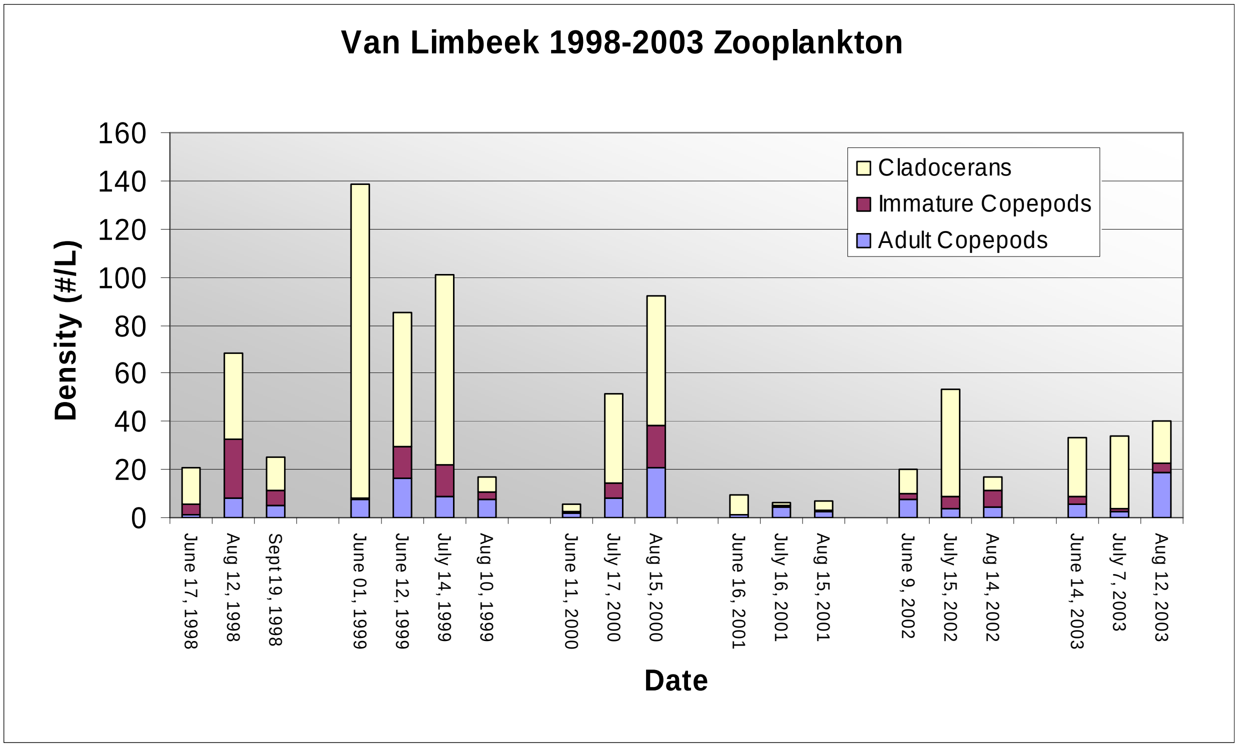

Figure 2: Zooplankton abundance, in individuals per litre of adult copepods, immature copepods and cladocerans, Van Limbeek Pit, Newmarket, ON, 1998 - 2003.

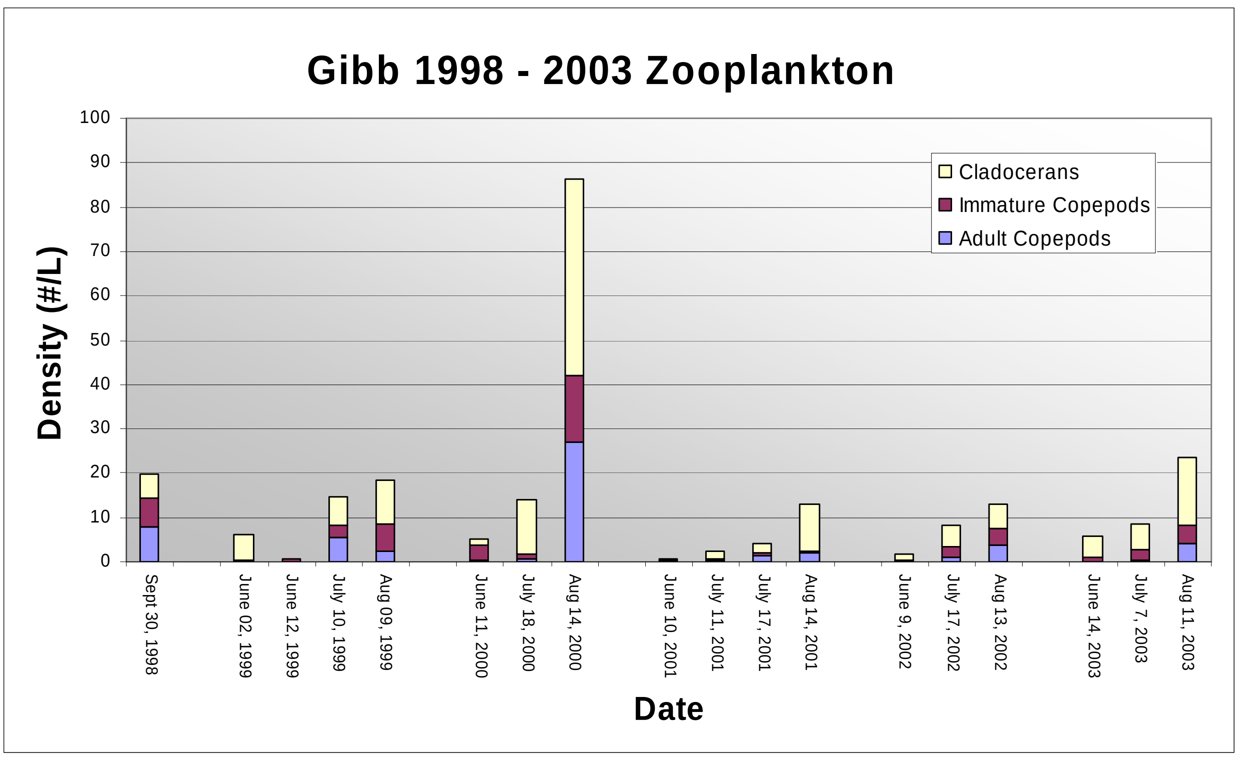

Figure 3: Zooplankton abundance, in individuals per liter of adult copepods, immature copepods and cladocerans, Gibb Pit, Stratford, ON, 1998 - 2003.

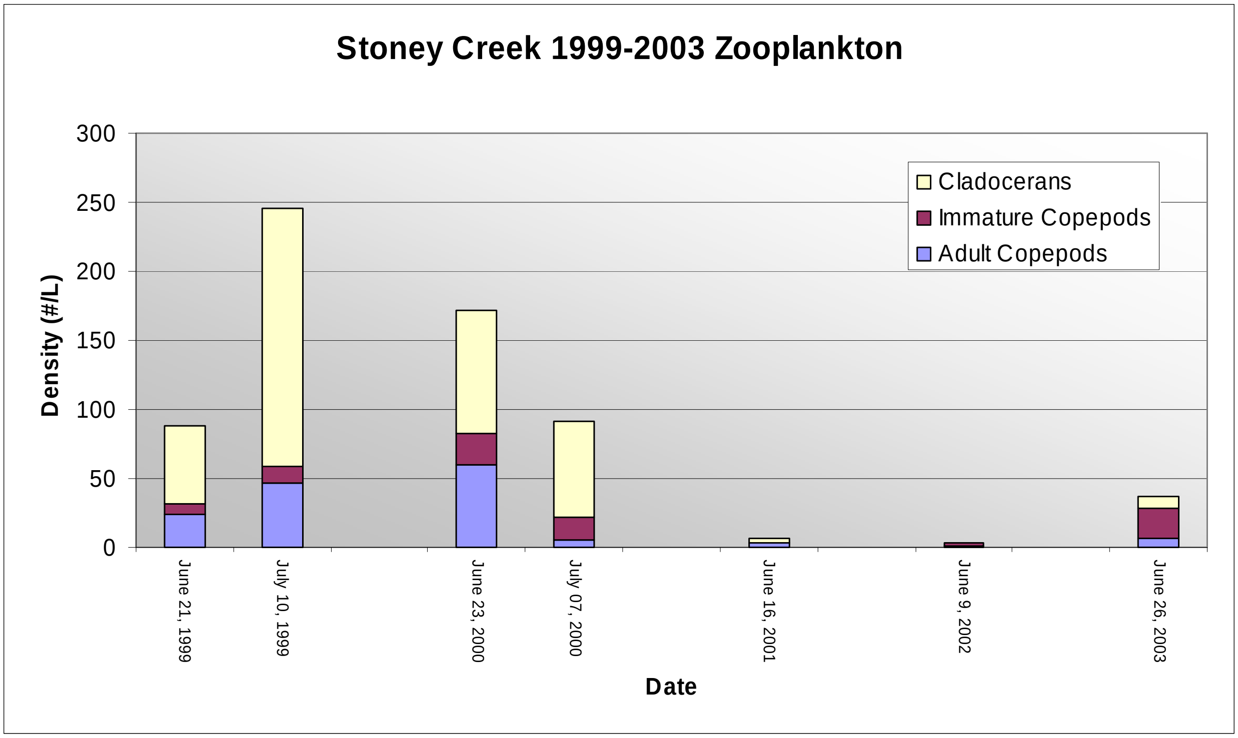

Figure 4: Zooplankton abundance, in individuals per litre of adult copepods, immature copepods and cladocerans, Stoney Creek Quarry, Stoney Creek, ON, 1999 - 2003.

5.2.4 Benthic Invertebrates

5.2.4.1 Abundance

Average abundance of various benthic invertebrate groups that colonized the artificial substrates in 1999 through 2003, at Bayside Quarry, Van Limbeek Pit, and Gibb Pit, are provided in Figures 5, 6, and 7 (note: scales are not the same for all figures).

In Bayside Quarry and Van Limbeek Pit, dipterans (true flies) were the dominant group on the artificial substrates in terms of abundance. Dipterans accounted for 66% to 96% of all benthic invertebrate organisms in Bayside Quarry in the years 1999 through 2003. Dipterans accounted for 77% to 82% of all organisms in Van Limbeek Pit samples over these same years. Dipterans were also the most abundant taxonomic group in Gibb Pit artificial substrate samples in 1999, 2000, and 2003. Gastropods (snails) were the most abundant taxon in 2001 and 2002.

The total number of benthic invertebrates on artificial substrates in all systems varies from year to year. No trends in invertebrate abundance are evident in any of the systems.

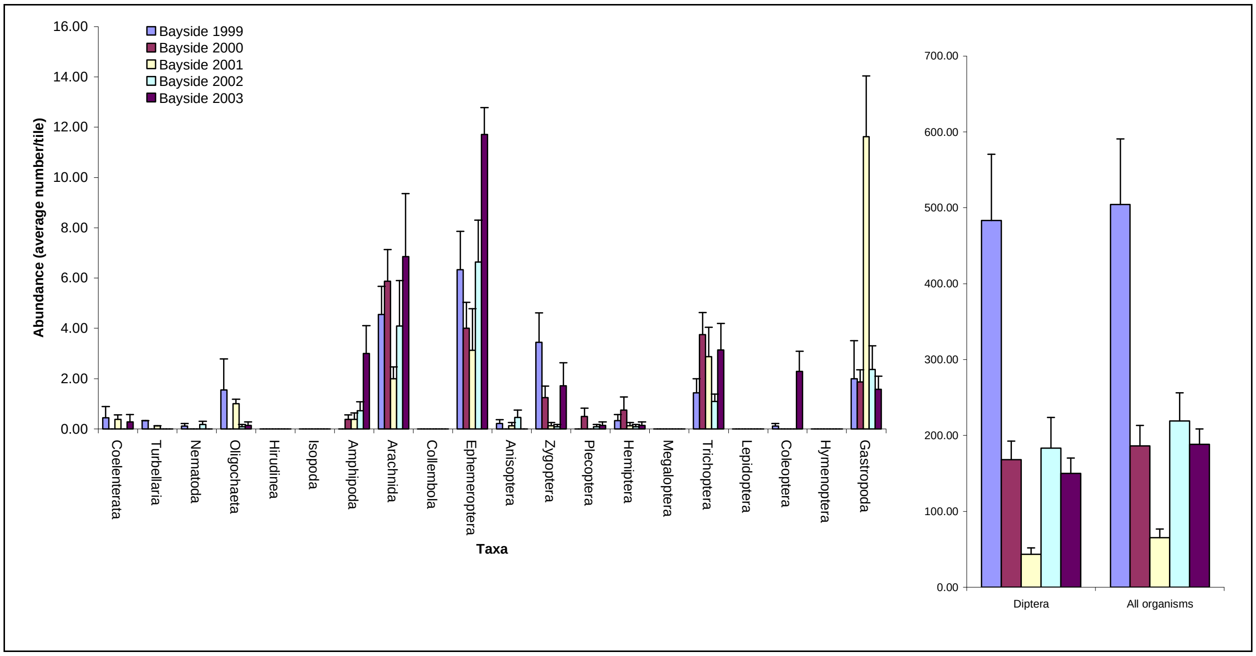

Figure 5. Abundance (average number of organisms/artificial substrate), with standard errors, of benthic invertebrate groups found on artificial substrates in Bayside Quarry, 1999 - 2003.

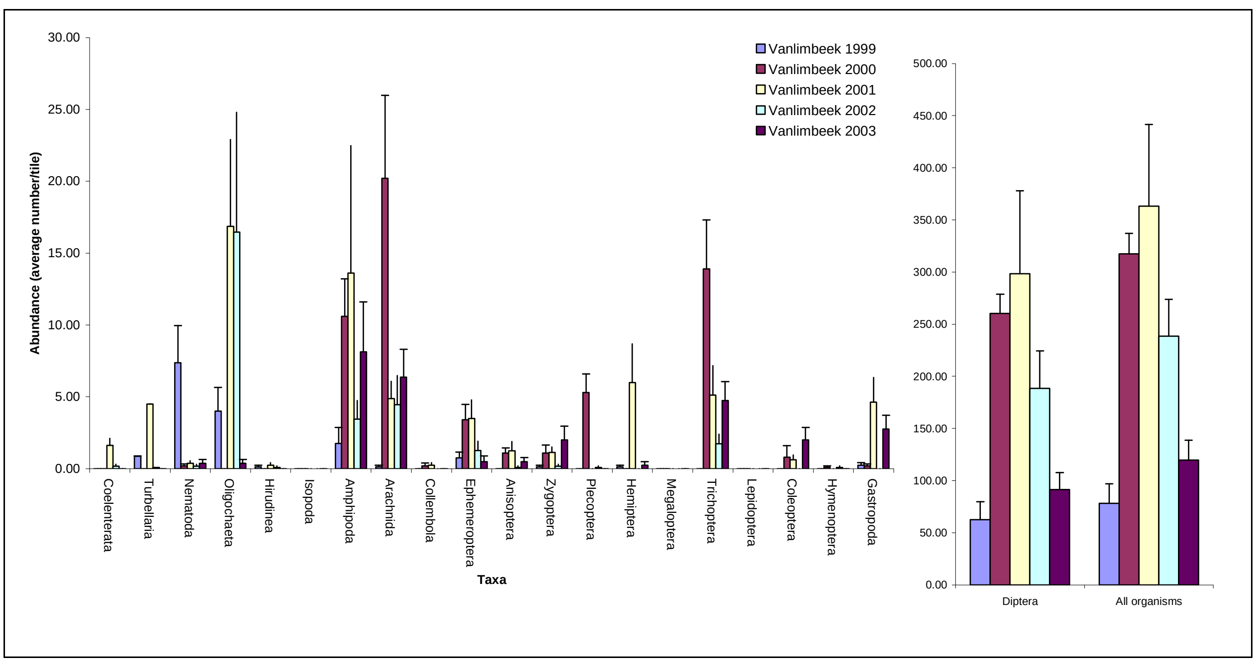

Figure 6. Abundance (average number of organisms/artificial substrate), with standard errors, of benthic invertebrate groups found on artificial substrates in Van Limbeek Pit, 1999 - 2003.

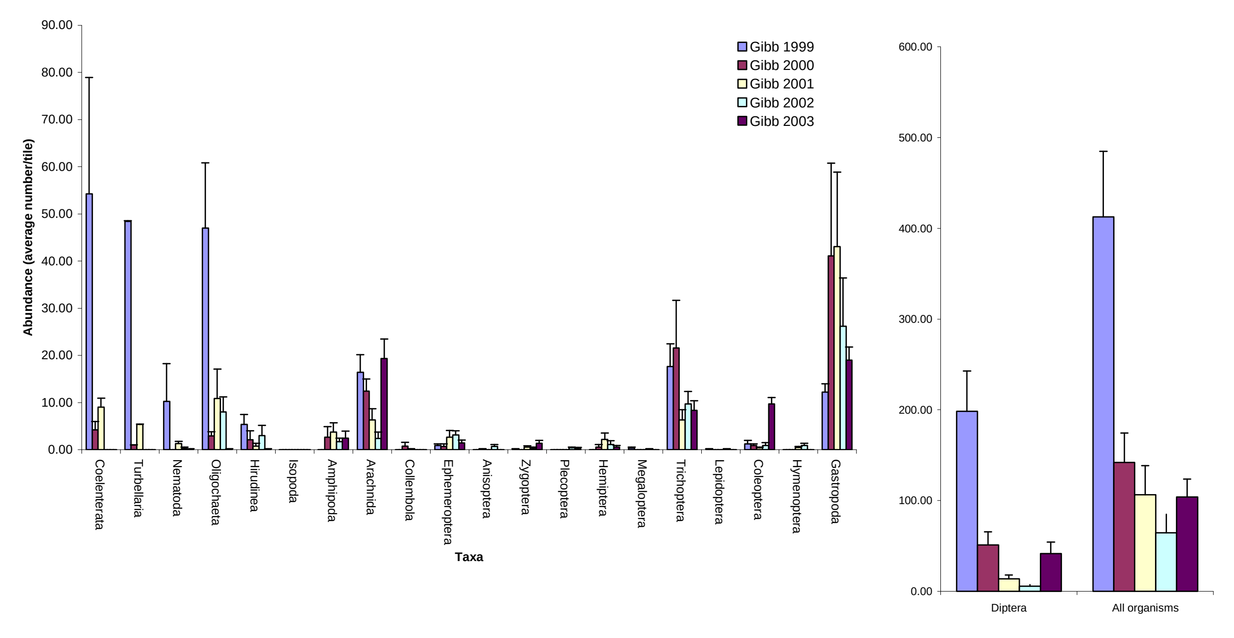

Figure 7. Abundance (average number of organisms/artificial substrate), with standard errors, of benthic invertebrate groups found on artificial substrates in Gibb Pit, 1999 - 2003.

5.2.4.2 Diversity

Species richness, heterogeneity, and evenness values for the benthic invertebrate communities in Bayside Quarry, Van Limbeek Pit, and Gibb Pit are provided in Table 9. The diversity measures of benthic invertebrates on artificial tiles are similar for all years in Van Limbeek Pit and Gibb Pit. Note that even though community shifts were observed in Van Limbeek Pit and Gibb Pit between years, the measures of diversity remained similar. The diversity measures of benthic invertebrates on artificial tiles in Bayside Quarry are more variable than the other two systems, but a trend in values is not apparent.

Table 9: Numbers of taxa and Diversity Indices of the benthic invertebrate community on artificial substrates in the pit and quarry systems, 1999 - 2003.

Diversity Index	Bayside Quarry				
	1999	2000	2001	2002	2003
Species richness (S)	13	9	12	12	12
Shannon – Wiener index (H’)	0.25	0.50	1.14	0.41	0.76

Evenness (J)	0.10	0.23	0.46	0.16	0.31
	Van Limbeek Pit				
	1999	2000	2001	2002	2003
Species richness (S)	11	13	16	14	12
Shannon – Wiener index (H')	0.79	0.78	0.86	0.56	0.99
Evenness (J)	0.33	0.30	0.31	0.21	0.40
	Gibb Pit				
	1999	2000	2001	2002	2003
Species richness (S)	14	14	16	17	13
Shannon – Wiener index (H')	1.67	1.69	2.01	1.97	1.68
Evenness (J)	0.63	0.64	0.72	0.70	0.65

5.3 FISH

5.3.1 Fish Abundance, Biomass and Production

A breakdown of the fishing effort invested in each system in 1998–2003 is presented in Tables 10-13. A suite of fishing methods has been tailored to each system that is effective for capturing all species present, and is efficient given the biotic and abiotic characteristics of each system.

Table 10: Summary of fishing effort, Bayside Quarry, June 20 – 24, September 19 – 22, 1998; June 1 – 4, July 13 – 14, 1999; June 13 – 17, 2000; June 4 - 8, 2001; June 4 – 9, 2002; and June 17 – 23, 2003.

Gear type	Total effort						Units of effort and comments
	1998	1999	2000	2001	2002	2003	
Plexiglas minnow trap	12	4					Trap-days - traps checked 1 or 2 times per 24 hours
Small mesh hoop net		4	8	8	9	12	Net-days - nets checked 1 or 2 times per 24 hours
Wire minnow trap	91	42	48	58	58	69	Trap-days - traps checked 1 or 2 times per 24 hours
Beach seine	1	3					Hauls – one end of 20' net stationary
Trap net (4' box)	7	3	4	4	5	6	Trap-days - trap left ~ 24 hrs. between checks
Gill net	525 (14)	749 (12)	616 (13)	248 (8)	487 (11)	1069 (20)	Total netting time in minutes (# of sets)
Visual fish survey	1	1					Count of marked and unmarked fish by diver(s)

Video Camera			28	28	28		Total number of 5 minute filming events
Snorkelling				10	24	20	Total number of transects swam.

Table 11: Summary of fishing effort, Van Limbeek Pit, June 15 – 19, September 14 – 19, 1998; June 12 - 16, July 14 - 16, 1999; June 11 – 17, 2000; June 10 - 16, 2001; June 9 – 15, 2002; and June 14 – 20, 2003.

Gear type	Total effort						Units of effort and comments
	1998	1999	2000	2001	2002	2003	
Plexiglas minnow trap	22	4					Trap-days - traps checked 1 or 2 times per 24 hours
Small mesh hoop net		9	11	11	10	10	Net-days - nets checked 1 or 2 times per 24 hours
Wire minnow trap	96	73	60	71	58	62	Trap-days - traps checked 1 or 2 times per 24 hours
Beach seine	5						Hauls – one end of 20' net stationary
Trap net (4' box)	9	4	6	6	6	5	Trap-days - trap left ~ 24 hrs. between checks
Gill net	2184 (60)	444 (9)	1909 (32)	1549 (36)	1673 (30)	1578 (27)	Total netting time in minutes (# of sets)

Table 12: Summary of fishing effort, Gibb Pit, September 29 – October 1, 1998; June 7 – 12, July 8 – 10, 1999; June 5 – 11, 2000; June 5 - 10, 2001; June 3 – 9, 2002; and June 8 – 14, 2003.

Gear type	Total effort						Units of effort and comments
	1998	1999	2000	2001	2002	2003	
Plexiglass minnow trap	1	10					Trap-days - traps checked 1 or 2 times per 24 hours
Small mesh hoop net		12	12	10	9	10	Net-days - nets checked 1 or 2 times per 24 hours
Wire minnow trap	24	93	72	60	65	60	Trap-days - traps checked 1 or 2 times per 24 hours
Beach seine		3					Hauls – one end of 20' net stationary
Trap net (4' box)	2	5	5	5	6	6	Trap-days - trap left ~ 24 hrs. between checks
Gill net	125 (2)	1238 (23)	1849 (25)	576 (12)	873 (14)	1018 (18)	Total netting time in minutes (# of sets)
Angling		14.2	14.9	17.3	18.0	18.3	Rod-hours
Video Camera				38	35	36	Total number of 5 minute filming events
Snorkelling				25	35	34	Total number of transects swam.

Table 13: Summary of fishing effort, Stoney Creek Quarry, June 24 – 29, September 23 – 29, 1998; June 16 – 21, July 10 – 12, 1999; June 17 – 23, 2000; June 16 - 22, 2001; June 9 – 15, 2002, and June 20 – 26, 2003.

Gear type	Total effort						Units of effort and comments
	1998	1999	2000	2001	2002	2003	
Plexiglas minnow trap	16						Trap-days - traps checked 1 or 2 times per 24 hours
Small mesh hoop net		12	12	11	10	11	Net-days - nets checked 1 or 2 times per 24 hours
Wire minnow trap	232	122	116	109	110	111	Trap-days - traps checked 1 or 2 times per 24 hours
Trap net (4' box)	10	5	6	6	6	6	Trap-days - trap left ~ 24 hrs. between checks
Beach seine	1						Hauls – one end of 20' net stationary

The level of fishing effort does not influence catch-per-unit-effort. Effort does have an influence on confidence levels in abundance estimates because abundance estimates depend on total fish caught (C), marked (M) and recaptured (R) (the higher the numbers the lower the bias in the estimate). The amount of fishing effort needed to obtain reliable estimates is dependent on the system size and fish catchability and thus is different in each system. Abundance estimates are calculated on a daily basis while conducting the effort and fishing only stops when the estimates remain relatively consistent (or in some cases when increased effort is not appreciably increasing C, M or R).

A summary of all fish captured in 1998-2003 in the pits and quarries program is presented in Tables 14-17 (see Appendix D for scientific names). Tables 14-17 are not provided as a basis for comparison between years, since effort varied from year to year. Fish captures from additional sampling in the fall (1998) and summer (1999) are included in this table, while the 2000 through 2003 efforts were concentrated on the June sampling period only. Fishing data from Bayside Quarry from October/November of 2000 to 2002 are not included as a) not all gear types were employed, and b) cool to very cold water temperatures changed the catchability of some species.

Table 14: Summary of all fish caught in 1998 through 2003, Bayside Quarry.

Species	Bayside Quarry					
	1998	1999	2000	2001	2002	2003
Sunfish *	4		7	23	73	899
Rock bass	495	242	400	400	345	304
Yellow perch	92	29	57	61	42	86
Brown bullhead	22	2	17	6	6	24
Banded killifish	92	14	13	17	5	10
Bluntnose minnow	454	348	572	888	655	442
Fallfish					1	
Longnose gar	1	1		1	1	1

* includes pumpkinseed and bluegill sunfish, along with hybrids of these two species

Table 15: Summary of all fish caught in 1998 through 2003, Van Limbeek Pit.

Species	Van Limbeek Pit					
	1998	1999	2000	2001	2002	2003
Pumpkinseed	1356	961	767	1355	1196	530
Rock bass	18	17	42	283	392	1
Northern pike	54	19	40	31	34	39
Yellow perch	3	108	25	12	49	2
Brown bullhead	80	142	62	47	71	34
Banded killifish	20	73	68	48	12	13
Fathead minnow	242	370	354	45	5	5
Emerald shiner	2					
Nor. redbelly dace			10			
Golden shiner	303	414	6041	722	675	449
Blacknose shiner	302	1716	410	503	34	19
Brook stickleback			7			

Table 16: Summary of all fish caught in 1998 through 2003, Gibb Pit.

Species	Gibb Pit					
	1998	1999	2000	2001	2002	2003
Largemouth bass	9	62	93	116	100	112
Rock bass		1			1	
Yellow perch	55	346	208	176	312	148
White sucker		9	17	6	23	17

Table 17: Summary of all fish caught in 1998 through 2003, Stoney Creek Quarry.

Species	Stoney Creek Quarry					
	1998	1999	2000	2001	2002	2003
Sunfish spp. *	11176	9263	6045	165	2382	1247
Yellow perch	11	3	1			
Brown bullhead	451	118	59	497	134	899
Banded killifish				2	3	
Fathead minnow	22	436	61	1063	2714	8
Golden shiner		1		1	4	1
Blacknose shiner	27					
Cent'l mudminnow	2			2	2	1
Goldfish		1	6	420	128	45
White sucker	1					
Iowa darter				3	22	1
Brook stickleback				3	16	1
Channel catfish						2

* includes pumpkinseed and green sunfish, along with hybrids of these two species.

Abundance estimates by system by fish species are provided in Tables 18-21. Absence of an estimate for a species in a given year does not necessarily mean that the species was not present, but that marked fish of that species were not recaptured in that year. Usually this only happens in the case of relatively rare species. Note that the capture of fish in Gibb Pit, using conventional sampling gears, was too low in 1999 to generate reliable abundance estimates. Estimates were generated in 2000 and subsequent years, once a substantial increase in angling effort was added to the use of conventional sampling gears.

In general, the abundance estimates illustrate that fish communities do not exist in a static state, but rather vary from year to year in response to factors both within (e.g. competition, predation, food supply) and outside (e.g. temperature, water replenishment) the systems. The most obvious change in fish community structure occurred in Stoney Creek Quarry between 2000 and 2001 (Table 21, see also Table 17). The dramatic decline in fish abundance, in combination with the eutrophic status indicated by water chemistry results and the observed dense macrophytes growth, strongly indicate that a winter kill of fish occurred during the winter of 2000/2001.

Table 18: Summary of fish species abundance estimates, Schnabel method, (95% confidence intervals), June sampling period, Bayside Quarry, 1998 through 2003.

Species	**Abundance Estimates**					
	June 1998	**June 1999**	**June 2000**	**June 2001**	**June 2002**	**June 2003**
Rock bass	1682 (1085, 2582)	933 (552, 1544)	1342 (995, 1805)	1758 (1237, 2490)	1103 (813, 1495)	1117 (798, 1558)
Bluntnose minnow		926 (626, 1362)	1898 (1450, 2480)	2156 (1801, 2579)	2238 (1768, 2831)	1983 (1386, 2823)
Yellow perch	122 (54, 240)		141 (70, 264)	146 (78, 261)	80 (40, 149)	90 (61, 130)
Brown bullhead	6 (2, 10)		22 (8, 43)			16 (9, 27)
Banded killifish			52 (11, 54)			
Sunfish *			4 (1, 7)	18 (9, 33)		5575 (4121, 7527)

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

Table 19: Summary of fish species abundance estimates, Schnabel method, (95% confidence intervals), June sampling period, Van Limbeek Pit, 1998 through 2003.

Species	**Abundance Estimates**					
	June 1998	**June 1999**	**June 2000**	**June 2001**	**June 2002**	**June 2003**
Pumpkinseed	19724 (12251, 31309)	4973 (3828, 6454)	5942 (4363, 8026)	7265 (5967, 8843)	14863 (10946, 20137)	1683 (1323, 2140)
Blacknose shiner		34849 (22940, 52505)	4802 (2839, 7949)	6994 (4135, 11577)		
Banded killifish	59 (18, 103)	154 (87, 264)	195 (104, 347)			31 (9, 54)
Golden shiner	1646 (728, 3244)	1605 (949, 2656)	12762 (12015, 13555)	7452 (5110, 10809)	2772 (2166, 3545)	3020 (2007, 4512)
Northern pike	73 (26, 144)	106 (59, 185)	200 (72, 393)	41 (21, 75)	88 (39, 174)	88 (42, 169)
Brown bullhead		57 (32, 97)	181 (94, 331)	394 (118, 686)	582 (210, 1144)	102 (41, 204)
Rock bass	15 (4, 25)		370 (110, 644)	8102 (3293, 16203)	3062 (1952, 4750)	
Fathead minnow	441 (296, 654)	629 (499, 791)	349 (291, 418)	214 (77, 420)		
Northern redbelly dace			12 (4, 24)			
Yellow perch				23 (7, 39)	472 (141, 821)	

Table 20: Summary of fish species abundance estimates, Schnabel method, (95% confidence intervals), June sampling period, Gibb Pit, 2000 through 2003.

Species	**Abundance Estimates**			
	June 2000	**June 2001**	**June 2002**	**June 2003**
Largemouth bass	408 (211, 747)	552 (304, 964)	454 (243, 810)	477 (270, 817)
Yellow perch	5851 (2111, 11508)	1801 (894, 3376)	3931 (2170, 6870)	1180 (586, 2212)

Table 21: Summary of fish species abundance estimates, Schnabel method, (95% confidence intervals), June sampling period, Stoney Creek Quarry, 1998 through 2003.

Species	**Abundance Estimates**					
	June 1998	**June 1999**	**June 2000**	**June 2001**	**June 2002**	**June 2003**
Sunfish *	100651 (85243, 118823)	204486 (170211, 245597)	103261 (87658, 121621)	1006 (555, 1758)	17538 (14719, 20892)	11092 (8497, 14462)
Brown bullhead	1319 (655, 2473)	1074 (437, 2148)	450 (162, 884)	4601 (3029, 6932)	609 (345, 1043)	1326 (1161, 1515)
Fathead minnow				2266 (1958, 2621)	4068 (3765, 4395)	
Goldfish				2872 (1941, 4224)	1595 (648, 3190)	
Iowa darter					91 (27, 159)	

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

Fish biomass and production estimates for each system are provided both as a total for the entire system by species, and on a per-hectare basis combining species to facilitate among-system comparisons (Tables 22 and 23). Fish biomass and production in Bayside quarry remained relatively stable across the years until a large increase was observed in 2003, largely driven by the sunfish population. Fish biomass and production peaked in Van Limbeek in 2002 resulting from a peak in a number of species, but 2003 saw a return to previous levels. Stoney Creek fish biomass and production reflected the dramatic decline in sunfish abundance which occurred in 2001.

Appendix E provides catch-per-unit-effort (CUE) information for all fishing methods for all systems in all years. The total effort reported in these tables will, in some cases, be less than reported in Tables 10-13 above, since CUE data have been calculated for the annual June sampling efforts only.

Table 22. Pits and Quarries Fish Biomass and Production Summary, 1998 through 2003. Total biomass and production estimates by species by system. Darkened vertical lines separate data from before and after habitat additions.

System & Species	Biomass (kg)						Production (kg•yr^{-1})					
Bayside	1998	1999	2000	2001	2002	2003	1998	1999	2000	2001	2002	2003
Rock bass	50.69	20.78	36.34	39.97	18.02	19.24	21.26	8.80	18.16	16.86	11.11	13.13
Bluntnose minnow	0.35	2.63	6.05	7.12	7.74	3.65		1.23	2.29	4.32	3.80	2.19
Yellow perch	4.98	3.41	4.89	3.89	1.84	3.15	2.24	1.61	2.33	1.55	0.65	1.30
Brown bullhead	0.94	0.10	1.77	0.94	0.71	1.15			0.40			0.32
Banded killifish	0.04	0.03	0.01	0.01	0.01	0.03						
Sunfish	0.31		0.32	1.03	0.75	72.39				0.67	0.95	95.00
Longnose gar	1.05	1.14	0.79	0.79	1.25	1.90						
Fallfish					0.29							
Total	*58.36*	*28.09*	*50.17*	*53.75*	*30.61*	*101.51*	*23.50*	*11.64*	*23.18*	*23.40*	*16.51*	*111.94*
Van Limbeek												
Pumpkinseed	82.41	30.69	38.17	16.71	73.04	7.95	62.14	9.40	28.09	19.22	68.52	7.18
Blacknose shiner	7.05	47.86	8.43	11.15	0.97	0.02	2.90	17.30	2.07	6.34	0.18	
Banded killifish	0.13	0.35	0.33	0.46	0.01	0.01		0.13				
Golden shiner	6.22	9.14	43.40	46.43	47.27	35.89	3.67	5.02	19.10	41.38	41.61	20.45
Northern pike	45.76	69.56	166.79	35.11	89.98	64.08	9.92	10.27	28.20	4.59	11.56	11.53
Brown bullhead	1.04	6.22	22.34	36.04	63.79	11.90		2.56	9.53	14.72	32.42	4.53
Rock bass	3.90	4.39	8.85	91.71	168.76	0.01	1.14	1.35	0.28	83.83	199.51	
Fathead minnow	0.65	1.25	0.76	0.54	0.01	0.01	0.32	0.44	0.25			
Nor. redbelly dace			0.02									
Yellow perch			0.86	0.79	12.52	0.05			0.24	0.58	12.25	
Emerald shiner	0.01											
Brook stickleback			0.01									
Total	*147.17*	*169.46*	*289.96*	*238.94*	*456.35*	*119.92*	*80.09*	*46.47*	*87.76*	*170.66*	*366.05*	*43.69*

System & Species	Biomass (kg)						Production (kg•yr^{-1})					
Gibb	1998	1999	2000	2001	2002	2003	1998	1999	2000	2001	2002	2003
Largemouth bass		174.74	170.51	217.59	229.33	220.93		78.96	73.47	78.89	73.28	75.00

Yellow perch		284.50	399.64	145.52	364.43	106.19			152.51	176.63	68.11	146.01	33.98
White sucker		6.40	15.32	4.98	9.92	13.19			2.59	5.02	2.05	7.43	8.83
Rock bass		0.48			0.62								
Total		*466.12*	*585.47*	*368.09*	*604.30*	*340.31*			*233.06*	*254.12*	*149.05*	*226.72*	*117.81*
Stoney Creek													
Sunfish	679.67	1270.74	1236.23	13.12	152.71	192.50		754.97	987.49	1019.12	9.12	113.40	155.47
Brown bullhead	74.41	62.89	39.81	254.67	42.06	60.68		51.17	44.73	21.82	142.39	25.24	42.33
Fathead minnow	0.30	5.19	1.04	7.46	7.60	0.01		0.13	2.11	0.39		3.05	
Goldfish		0.12	0.86	3.67	17.91	4.64						23.36	3.06
Yellow perch	0.29	0.27	0.23										
Banded killifish				0.01	0.01								
Golden shiner		0.01		0.01	0.02	0.01							
Blacknose shiner	0.03												
Cent'l mudminnow	0.01			0.01	0.01	0.01							
White sucker	1.12												
Iowa Darter				0.01	0.09	0.01							
Brook stickleback				0.01	0.02	0.01							
Channel catfish						0.64							
Total	*755.83*	*1339.22*	*1278.17*	*278.97*	*220.42*	*258.51*		*806.27*	*1034.33*	*1041.33*	*151.51*	*165.05*	*200.86*

Table 23. Pits and Quarries Fish Biomass and Production Summary, 1998 through 2003. Total biomass and production estimates for all species combined reported per unit area (hectare). Darkened vertical lines separate data from before and after habitat additions.

System	**Biomass (kg•ha^{-1})**							**Production (kg•yr^{-1}•ha^{-1})**					
	1998	1999	2000	2001	2002	2003		1998	1999	2000	2001	2002	2003
Bayside	167.85	80.79	144.29	154.59	88.04	291.95		67.59	33.48	66.67	67.30	47.48	321.94
Van Limbeek	207.05	238.41	407.93	316.06	603.64	158.62		112.68	65.38	123.47	225.74	484.19	57.79
Gibb		108.65	136.47	85.80	140.86	79.33			54.33	59.24	34.74	52.85	27.46
Stoney Creek	161.33	285.85	272.82	59.54	47.05	55.18		172.10	220.77	222.27	32.34	35.23	42.87

Figures 8-15 provide a summary of the annual biomass and production estimates for the systems for all species combined, and for the dominant centrarchid component (sunfish, rock bass) of the estimates. In the case of Van Limbeek Pit, the relatively high biomass and production values in 2002 were followed, in 2003, by the lowest values detected for these community attributes in the six years of study. The increases in mean biomass and production values, from before to after treatment, have thus not been sustained. The pulse increase in Bayside Quarry occurred in 2003, but whether the increases in mean biomass and production values will be sustained here is not known.

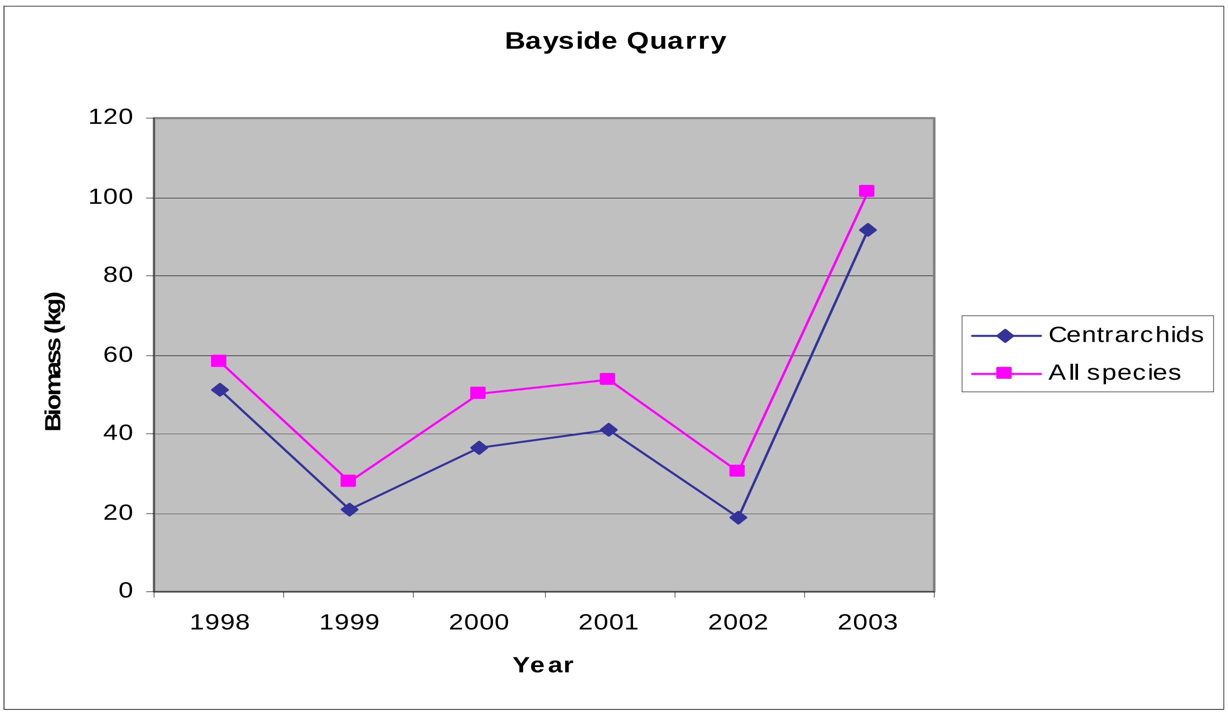

Figure 8: Annual biomass estimates for centrarchids (sunfish including pumpkinseed and bluegill, rock bass) and all fish species, Bayside Quarry, 1998 through 2003.

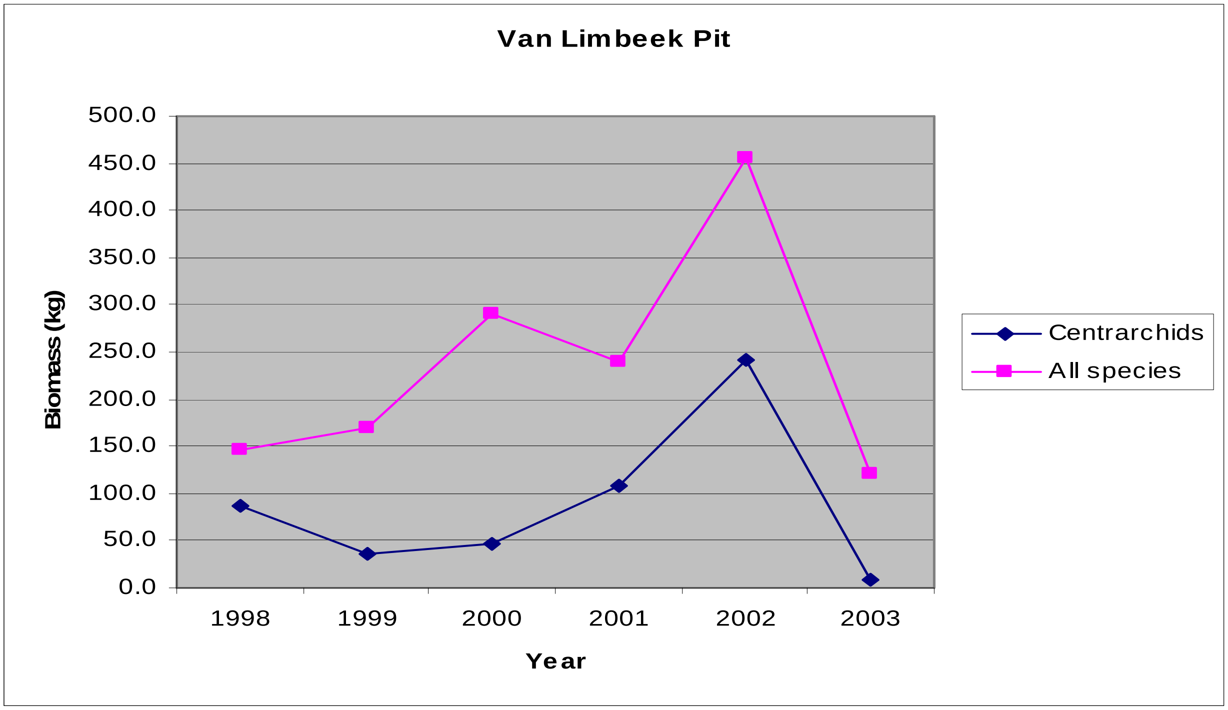

Figure 9: Annual biomass estimates for centrarchids (sunfish including pumpkinseed, rock bass) and all fish species, Van Limbeek Pit, 1998 through 2003.

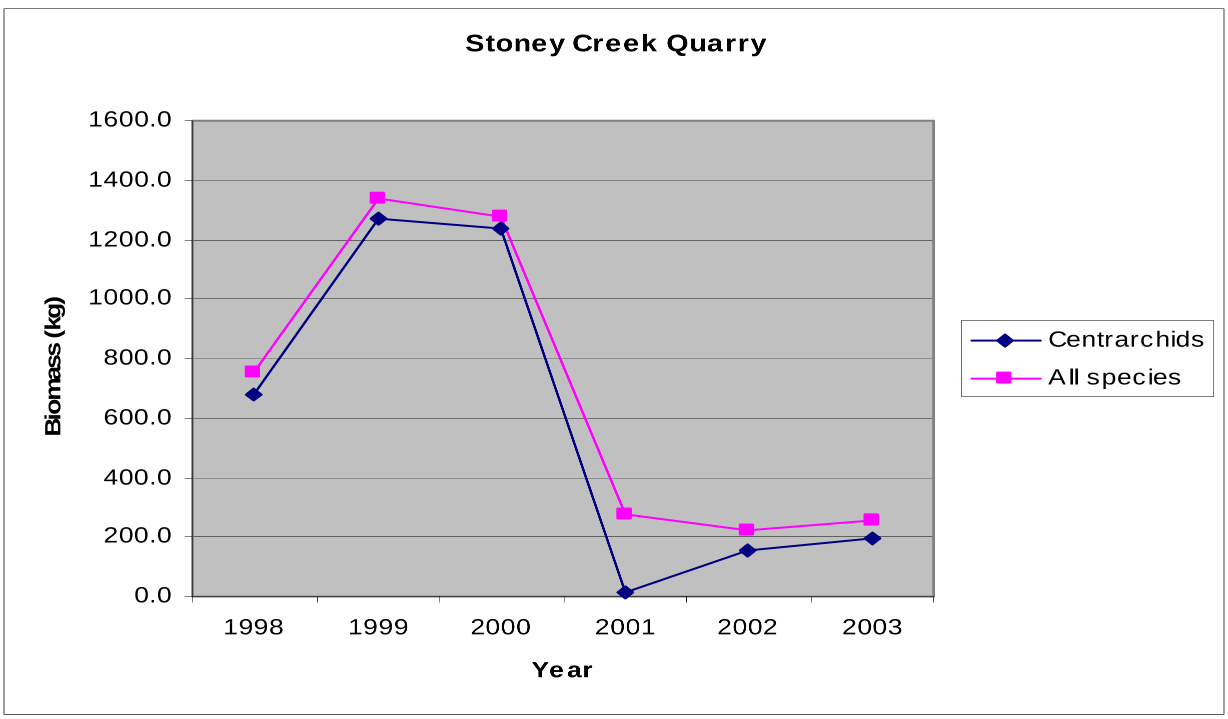

Figure 10: Annual biomass estimates for centrarchids (sunfish including pumpkinseed and green sunfish) and all fish species, Stoney Creek Quarry, 1998 through 2003.

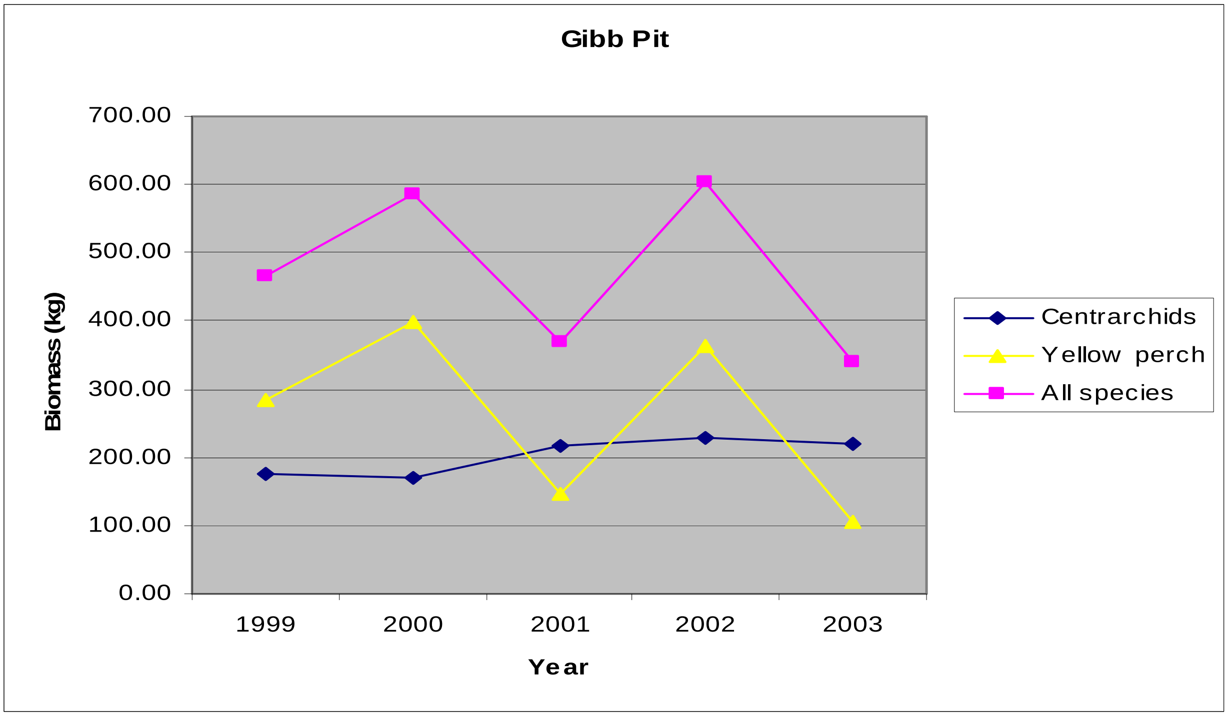

Figure 11: Annual biomass estimates for centrarchids (largemouth bass), yellow perch, and all fish species, Gibb Pit, 1999 through 2003.

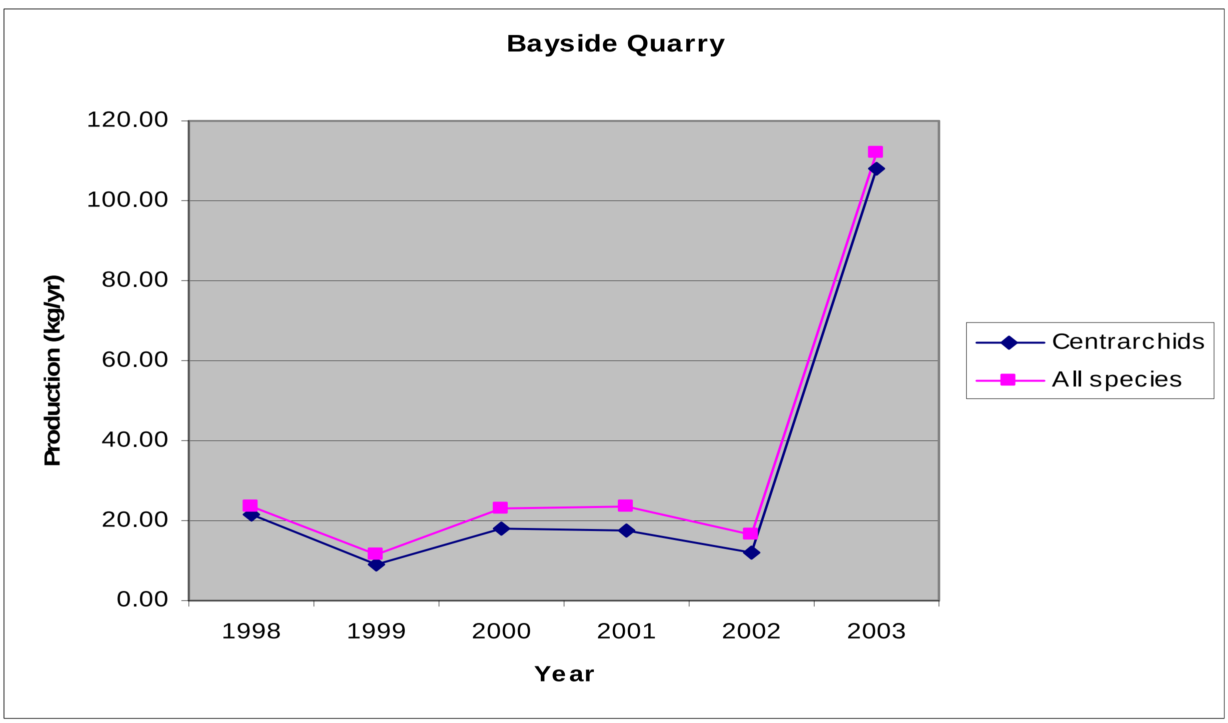

Figure 12: Annual production estimates for centrarchids (sunfish including pumpkinseed, bluegill and rock bass) and all fish species, Bayside Quarry, 1998 through 2003.

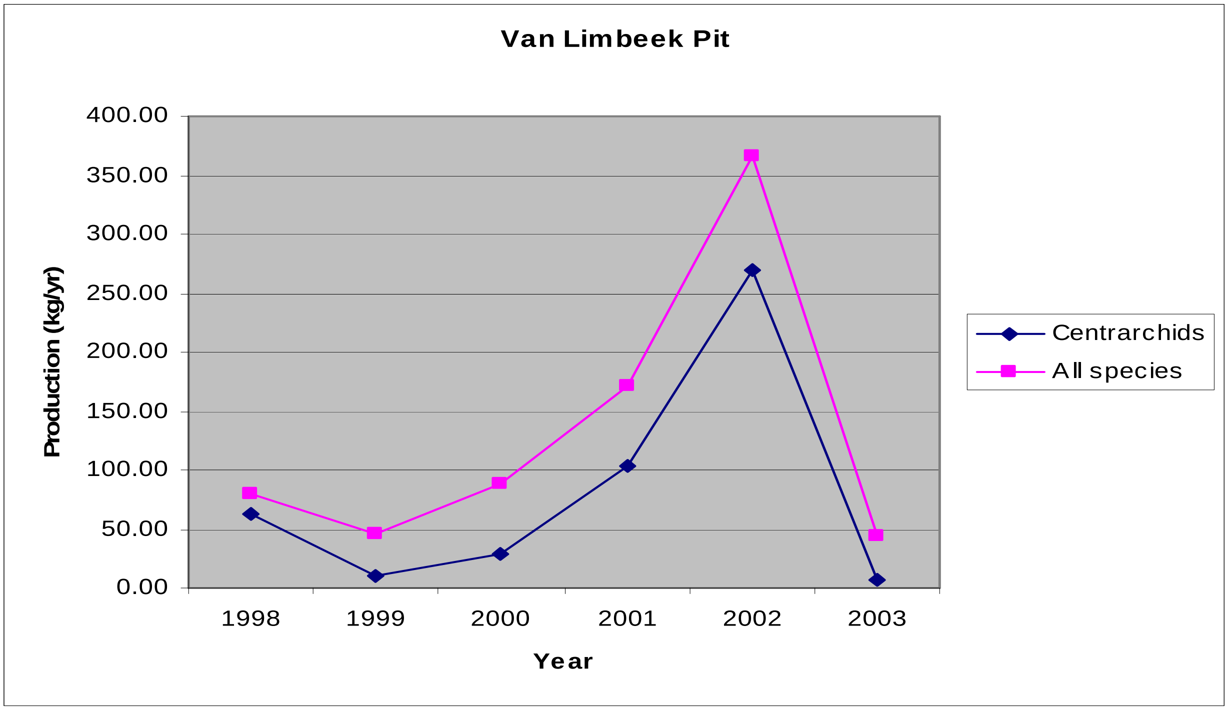

Figure 13: Annual production estimates for centrarchids (sunfish including pumpkinseed and rock bass) and all fish species, Van Limbeek Pit, 1998 through 2003.

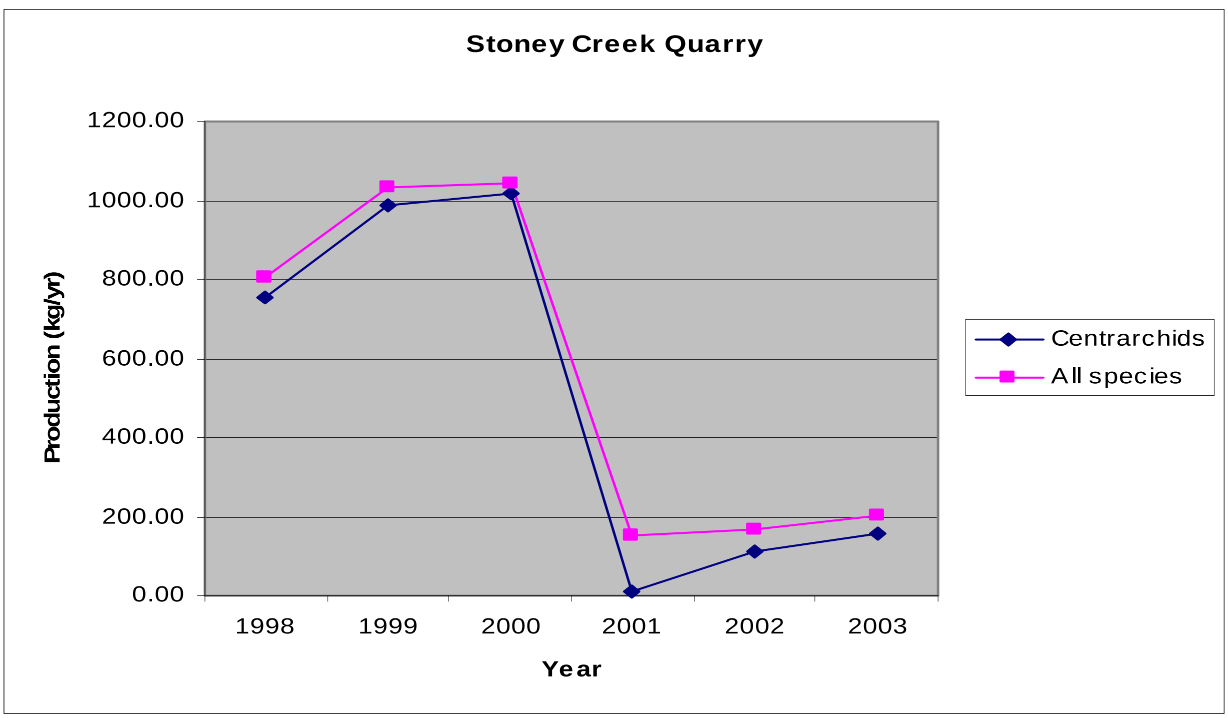

Figure 14: Annual production estimates for centrarchids (sunfish including pumpkinseed, bluegill and green sunfish) and all fish species, Stoney Creek Quarry, 1998 through 2003.

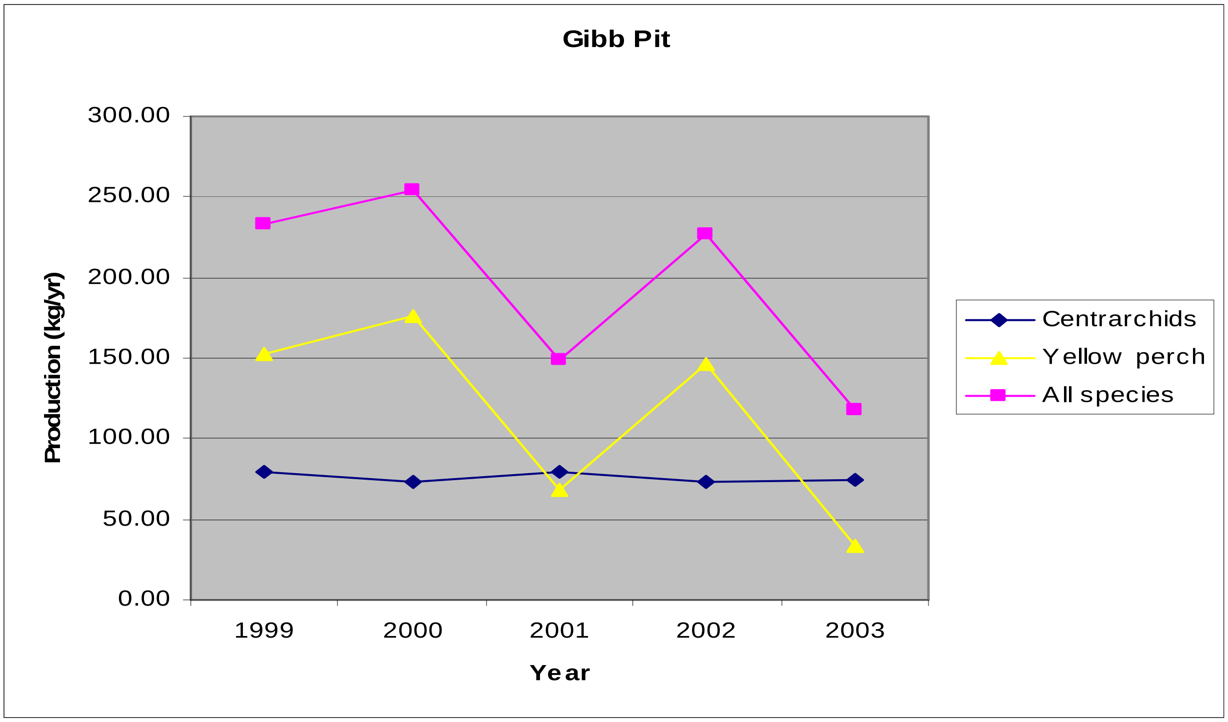

Figure 15: Annual production estimates for centrarchids (largemouth bass), yellow perch, and all fish species, Gibb Pit, 1999 through 2003.

While total fish biomass has not changed significantly in the systems, the apparent increase in post-treatment variability indicates that changes to the communities are occurring. As the pulse increases in Bayside Quarry and Van Limbeek Pit were in different years, although both had habitat treatments at the same time, it is assumed that the changes are not the result of broader-based environmental change.

There was no change in annual mean total fish biomass or production in Gibb Pit. The absence of change in Gibb Pit should be viewed a little more cautiously than in Bayside Quarry or Van Limbeek Pit. With only two years of post-treatment data, and a fish community consisting solely of longer-lived and longer to mature species, it is unlikely that the full effects of habitat addition, if any, will have fully manifested within the system. Unlike Bayside Quarry and Van Limbeek Pit, the changes in annual mean values are not driven by the centrarchid community (in this case largemouth bass), but are rather driven by changes to the yellow perch population (see Figures 8-15). Yellow perch have, so far, exhibited alternating years of relative strength and relative weakness in the pit, a pattern apparently independent of treatment.

Strongly significant changes (declines) did occur in mean annual total fish biomass and production between 1998 – 2000, and 2001 - 2003, in Stoney Creek Quarry. This system is also centrarchid-dominated (sunfish), which are sensitive to winterkill conditions (Fox and Keast 1991).

5.3.1.1 Fish Species Analysis

The following will concentrate on analyses of changes to individual species within the systems (mean biomass and condition factor by species), and how these changes relate to the whole system changes previously discussed.

Bayside Quarry:

Prior to habitat addition, sunfish (pumpkinseed and bluegill) accounted for approximately 0.5% of the mean annual total fish biomass in Bayside Quarry (Table 24). After habitat addition, the contribution of sunfish increased to approximately 40% of the mean annual total fish biomass. This increase in biomass was driven by the 2003 sunfish estimate of 72.39 kg, as compared to a maximum of 1.03 kg in any previous year (Table 22). Mean bluntnose minnow biomass doubled from before to after habitat addition, and mean annual total fish biomass also increased. Biomass of rock bass and yellow perch, that together represented over 88% of total fish biomass before habitat addition, declined and comprised only 46% of post-addition biomass. Despite the seemingly large magnitude of biomass changes within the system, none of these changes were statistically significant.

Table 24. Summary of mean biomass (kg) and condition factor by species, before (1998 – 2000) and after (2001 – 2003) habitat addition, Bayside Quarry. Bonferroni corrected α = 0.01.

	Before habitat addition	After habitat addition	t-test p value
Biomass (kg)			
All species	45.54	61.96	0.510
Rock bass	35.94	25.74	0.414
Yellow perch	4.43	2.96	0.136
Bluntnose minnow	3.01	6.17	0.205
Sunfish	0.21	24.72	0.362
Condition factor			
Rock bass	2.17	1.85	0.015
Yellow perch	1.25	1.04	0.018
Bluntnose minnow	1.18	1.25	0.377
Sunfish	3.01	2.01	0.033

There were nearly significant declines in condition factor from before to after habitat addition for rock bass and yellow perch (Table 24). Over the same period, the total mean annual abundance estimates for all species combined increased from 2376 to 5427 (p=0.160) (see Table 18). These figures indicate that Bayside Quarry has more individual fish than before the habitat addition, but that the centrarchids and perch in the system, that comprise in excess of 85% of total system biomass, are smaller by weight.

Mean condition factor for the small-bodied bluntnose minnow increased from before to after habitat addition, as did mean biomass, although neither increase was statistically significant. Abundance estimates also increased for this species.

<u>Van Limbeek Pit</u>

Changes in biomass of individual species in Van Limbeek Pit from before to after habitat addition are noticeable in all cases (minimum change of 33%), although none of the changes were statistically significant (Table 25). Total mean biomass increased for all species combined. Like Bayside Quarry, the increase in biomass is driven by the increase in a centrarchid species, in this case rock bass (Table 22), but as discussed earlier, this increase was not sustained.

Table 25. Summary of mean biomass (kg) and condition factor by species, before (1998 – 2000) and after (2001 – 2003) habitat addition, Van Limbeek Pit. Bonferroni corrected α = 0.007.

Van Limbeek Pit	Before habitat addition	After habitat addition	t-test p value
Biomass (kg)			
All species	202.20	271.74	0.555
Golden shiner	19.59	43.20	0.132
Northern pike	94.04	63.06	0.485
Pumpkinseed	50.42	32.57	0.530
Brown bullhead	9.87	37.24	0.168
Blacknose shiner	21.11	4.05	0.285
Rock bass	5.71	86.83	0.172
Condition factor			
Golden shiner	1.20	1.36	0.048
Northern pike	0.70	0.74	0.399
Pumpkinseed	1.92	1.98	0.695
Brown bullhead	1.49	1.56	0.534
Blacknose shiner	1.15	1.12	0.865
Rock bass	2.51	2.27	0.162

Figure 16 provides the percent contribution of two species groups to the total fish biomass in Van Limbeek Pit. The first group is comprised of the four species (pumpkinseed, golden shiner, northern pike, and brown bullhead) for which biomass estimates exceed 1.0 kg in every year. Prior to habitat addition, these species averaged 86.0% of total fish biomass per year, with values in excess of 92% in 1998 and 2000. After habitat addition, these four species averaged 64.8% of total fish biomass per year, with a high of 99.9% in 2003. The second group (rock bass, blacknose shiner) is comprised of those species that, in some years, contributed noticeably to total annual biomass. In neither case (BNS – 1999, RB – 2001, 2002) did these species sustain, to the end of the study period, an appreciable contribution to total fish biomass in Van Limbeek Pit.

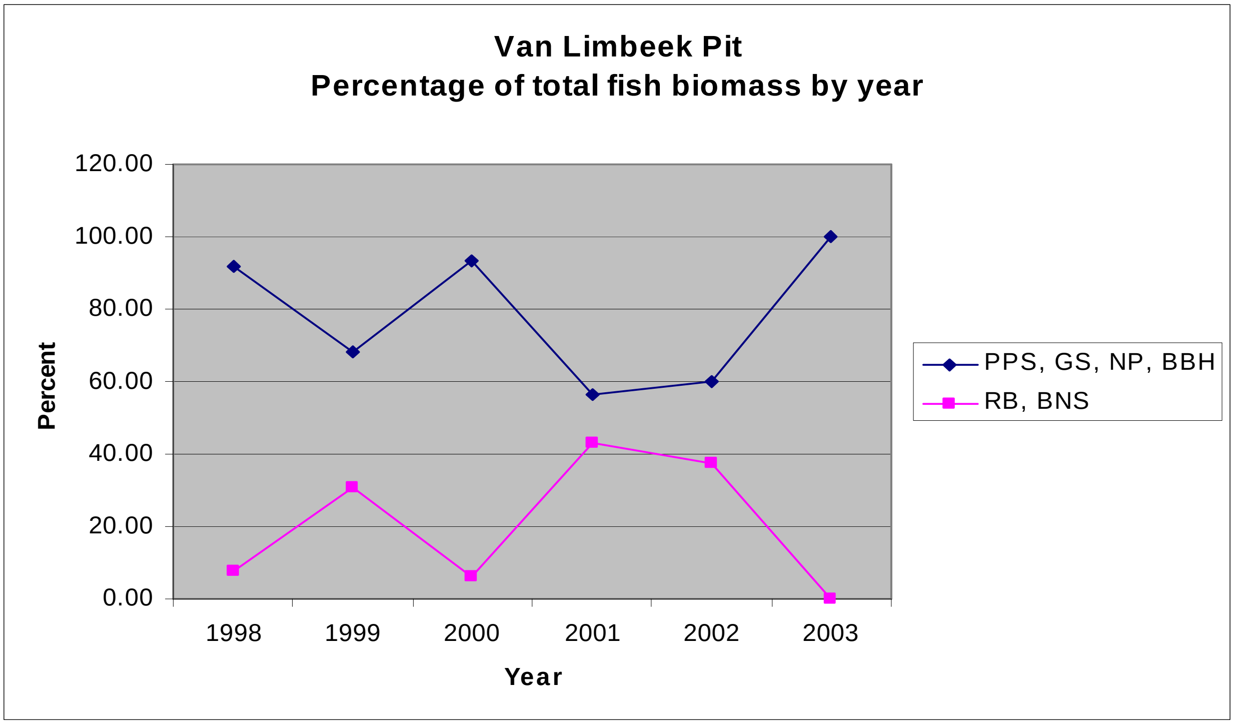

Figure 16. Percentage of total fish biomass in Van Limbeek Pit by year. The upper line combines pumpkinseed, golden shiner, northern pike, and brown bullhead biomass estimates. The lower line combines rock bass and blacknose shiner biomass.

Mean condition factor for each of the four main species increased from before to after habitat addition, although none were significant at the corrected significance level. Mean condition factor decreased for both rock bass and blacknose shiner.

Gibb Pit:

Total fish biomass in Gibb Pit remained unchanged from before to after habitat addition (Table 26). The decrease in mean yellow perch biomass was offset by the increase in largemouth bass biomass, although the changes in both species are not statistically significant. The condition factors of the species in Gibb Pit are unchanged from before to after habitat addition.

Table 26. Summary of mean biomass (kg) and condition factor by species, before (1999 – 2001) and after (2002 – 2003) habitat addition, Gibb Pit. Bonferroni corrected $\alpha = 0.01$.

	Before habitat addition	After habitat addition	t-test p value
Biomass (kg)			
All species	473.23	472.31	0.995
Largemouth bass	187.61	225.13	0.152
Yellow perch	276.55	235.31	0.780

White sucker	8.90	11.56	0.585
Condition factor			
Largemouth bass	1.42	1.46	0.599
Yellow perch	1.35	1.31	0.483
White sucker	1.50	1.54	0.780

Stoney Creek Quarry

The significant decline in sunfish biomass in Stoney Creek Quarry between June 2000 and June 2001, and the associated influence on total fish biomass in the system, are provided in Table 27. While brown bullhead and fathead minnow biomass increased, partially filling the void left by the sunfish decline, the increases are not statistically significant. The decrease in mean condition factor for brown bullhead and fathead minnow, despite the presumed reduction in competition for food supply, may suggest that the system is still under stress. The sunfish that remain in the system have exhibited a significant increase in condition factor.

Table 27. Summary of mean biomass (kg) and condition factor by species, before (1998 – 2000) and after (2001 – 2003) the presumed winterkill, Stoney Creek Quarry. Bonferroni corrected $\alpha = 0.01$.

	Before presumed winterkill	After presumed winterkill	t-test p value
Biomass (kg)			
All species	1124.41	252.63	0.009
Sunfish	1062.21	119.44	0.009
Brown bullhead	59.04	119.14	0.431
Fathead minnow	2.18	5.02	0.387
Condition factor			
Sunfish	2.04	2.33	0.005
Brown bullhead	1.20	1.13	0.427
Fathead minnow	1.74	1.55	0.250

5.3.2 Fish Diversity

Mean Hurlbert's PIE index values from before to after habitat treatment are presented in Table 28. Before and after mean values were compared using a two-tailed Students t-test to identify statistically significant changes in index value. In all cases, the mean index values increased from before to after treatment, although only the increase in the index value calculated from total catch for Stoney Creek Quarry was statistically significant.

Table 28. Mean Hurlbert's PIE index values, before and after habitat treatments, pits and quarries. Bonferroni corrections (adjusting significance level due to multiple tests) were applied to ensure that the experiment-wise probability remained at 0.05. Bonferroni corrected $\alpha = 0.006$.

System	Measure	Mean value (pre)	Mean value (post)	t-test p value
Bayside Quarry	Catch	0.525	0.572	0.420
	Biomass	0.372	0.484	0.249
Van Limbeek Pit	Catch	0.563	0.655	0.386
	Biomass	0.616	0.714	0.241
Gibb Pit	Catch	0.450	0.491	0.599
	Biomass	0.476	0.486	0.646
Stoney Creek Quarry	Catch	0.068	0.576	<0.001
	Biomass	0.128	0.343	0.091

5.3.3 Fish Distribution and Aquatic Habitat

Table 29 provides the marked fish in the quarry at the end of the June sampling period, by colour of the mark, and subsequent recapture data by section from November for bluntnose minnows.

Table 29. Summary of colour marks applied to bluntnose minnows in June 2002, Bayside Quarry, and location of their subsequent recapture in November 2002.

Mark Colour	Marks at Large (end June)	Bluntnose minnow recaptures, November 2002				
		Numbers by pond section where recaptured				
		Yellow	Red	Orange	Green	Total
Yellow	157	0	1	0	1	2
Red	105	2	3	1	1	7
Orange	169	2	1	15	7	25
Green	55	6	3	1	2	12
Total	486	10	8	17	11	46

The shaded cells in Table 29 highlight those fish, originally captured in June, that were recaptured in the same pond section in November. Of the 46 bluntnose minnows recaptured, 26 were recaptured in a different section of the pond than where they were originally marked. In the case of rock bass and yellow perch, 5 of the 6 recaptured fish were not caught in the same section in which they were originally marked. It appears that fish in Bayside Quarry move freely throughout the pond rather than stay in one area, indicating that the fish in this system captured at a particular location are transient, and not necessarily there as a result of a habitat preference. Thus, as expected, relating catches to the habitat present at the gear location is not a reliable measure of the preferential use of habitat types by fish.

5.3.4 Underwater Visual Methods

5.3.4.1 Examination of Snorkeling Method

As the combination of snorkelling with distance sampling methodology to provide population estimates for fish was a new addition to this study, we first wanted to assess whether the data outcomes appeared valid. To this end, we correlated Bayside Quarry abundance estimates provided by the mark-recapture surveys with the abundance estimates supplied by the snorkelling surveys. Abundance estimates from both techniques were natural log transformed prior to analyzing.

Abundance estimate data from mark-recapture and visual surveys were significantly positively correlated ($r=0.63$, $P=0.049$; Figure 17). Rock bass were consistently under-represented in the visual survey, while the remaining species had similar abundance estimates from both techniques. Removal of rock bass from the data set greatly improved the similarity of the estimates (no rock bass $r=0.92$, $P=0.003$).

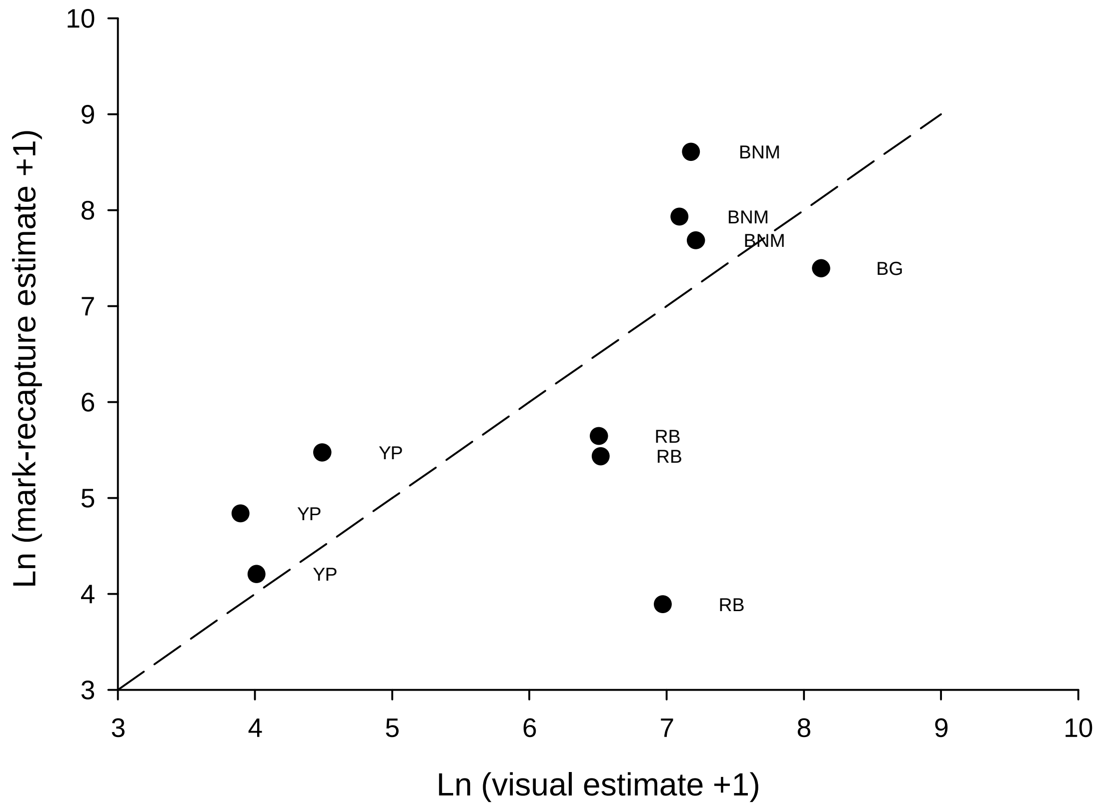

Figure 17. The relationship between mark-recapture and visual abundance estimates across three data collection years in Bayside Quarry. The dashed line represents the 1:1 line. Data points are labelled as follows: BG is bluegill, BNM is bluntnose minnow, RB is rock bass and YP is yellow perch.

5.3.4.2 Assessment of Fish Habitat Use

We tested for differences in fish habitat use with both the underwater camera and snorkelling data. We found no among-habitat differences in fish use of natural habitat types, as represented by weighted video observation averages, in either Bayside or Gibb (Table 30), although structurally complex habitats contained slightly more fish that open habitats in Bayside (Fig. 18). Overall, we found no clear patterns of fish distribution among habitat classes. Significant among-site differences were observed in the Gibb Pit and high coefficients of variation were observed in both systems (Table 30).

Table 30. The nested analysis of variance results and coefficients of variation (CV) from tests of fish-habitat use from natural, unmanipulated habitats in Bayside and Gibb using an underwater camera. Starred probabilities indicate significance after applying a Bonferroni correction.

Waterbody	Habitats Examined	Effect	$F_{(DF)}$	*P*	CV
Bayside Quarry	OPEN, VEG, ROCK	Habitat	1.0 $_{(2,17)}$	0.39	64.6
		Site (Habitat)	0.9 $_{(17,37)}$	0.56	
Gibb Pit	OPEN, VEG	Habitat	0.1 $_{(1,16)}$	0.90	159.4
		Site (Habitat)	3.0 $_{(16,31)}$	0.004*	

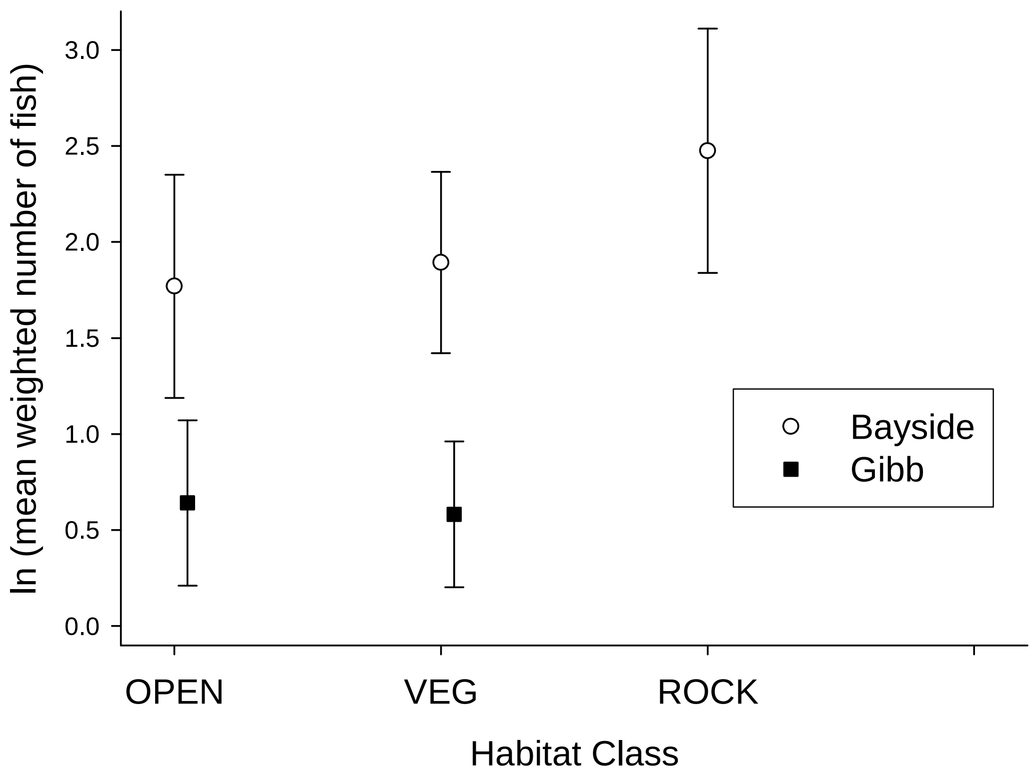

Figure 18. Fish relative abundance patterns by natural habitat type, as measured by underwater visual observation in Bayside Quarry and Gibb Pit.

No among-habitat differences were found in fish residency time, though significant among-site differences were detected in Bayside Quarry (Table 31). Fish spent less time in VEG habitats in Gibb Pit, but the most time in VEG habitats in Bayside Quarry (Fig.19). Coefficients of variation were similar, ranging between 35-45%, in both systems. No among-habitat differences were detected, and no among-site differences were detected (Table 31). VEG habitats had the lowest number of feeding attempts in all systems except Bayside Quarry (Fig. 19). The variability in feeding attempt data was high in all systems (Table 31).

Table 31. The nested analysis of variance results and coefficients of variation (CV) from tests that examined for differences in a) the length of time that an individual fish remained in the habitat patch (residency) and b) the number of feeding attempts that occurred over the five minute filming (feeding). Starred probabilities indicate significance after applying a Bonferroni correction.

a) Residency

Waterbody	Habitats Examined	Effect	$F_{(DF)}$	*P*	CV
Bayside Quarry	OPEN, VEG, ROCK	Habitat	$0.6_{(2,17)}$	0.54	43.1
		Site (Habitat)	$3.6_{(17,596)}$	<0.001*	
Gibb Pit	OPEN, VEG	Habitat	$2.5_{(1,13)}$	0.14	36.2
		Site (Habitat)	$1.2_{(13,62)}$	0.33	

b) Feeding

Waterbody	Habitats Examined	Effect	$F_{(DF)}$	*P*	CV
Bayside Quarry	OPEN, VEG, ROCK	Habitat	$1.8_{(2,17)}$	0.20	137.3
		Site (Habitat)	$0.6_{(17,37)}$	0.84	
Gibb Pit	OPEN, VEG	Habitat	$1.5_{(1,16)}$	0.23	486.1
		Site (Habitat)	$0.1_{(16,30)}$	0.72	

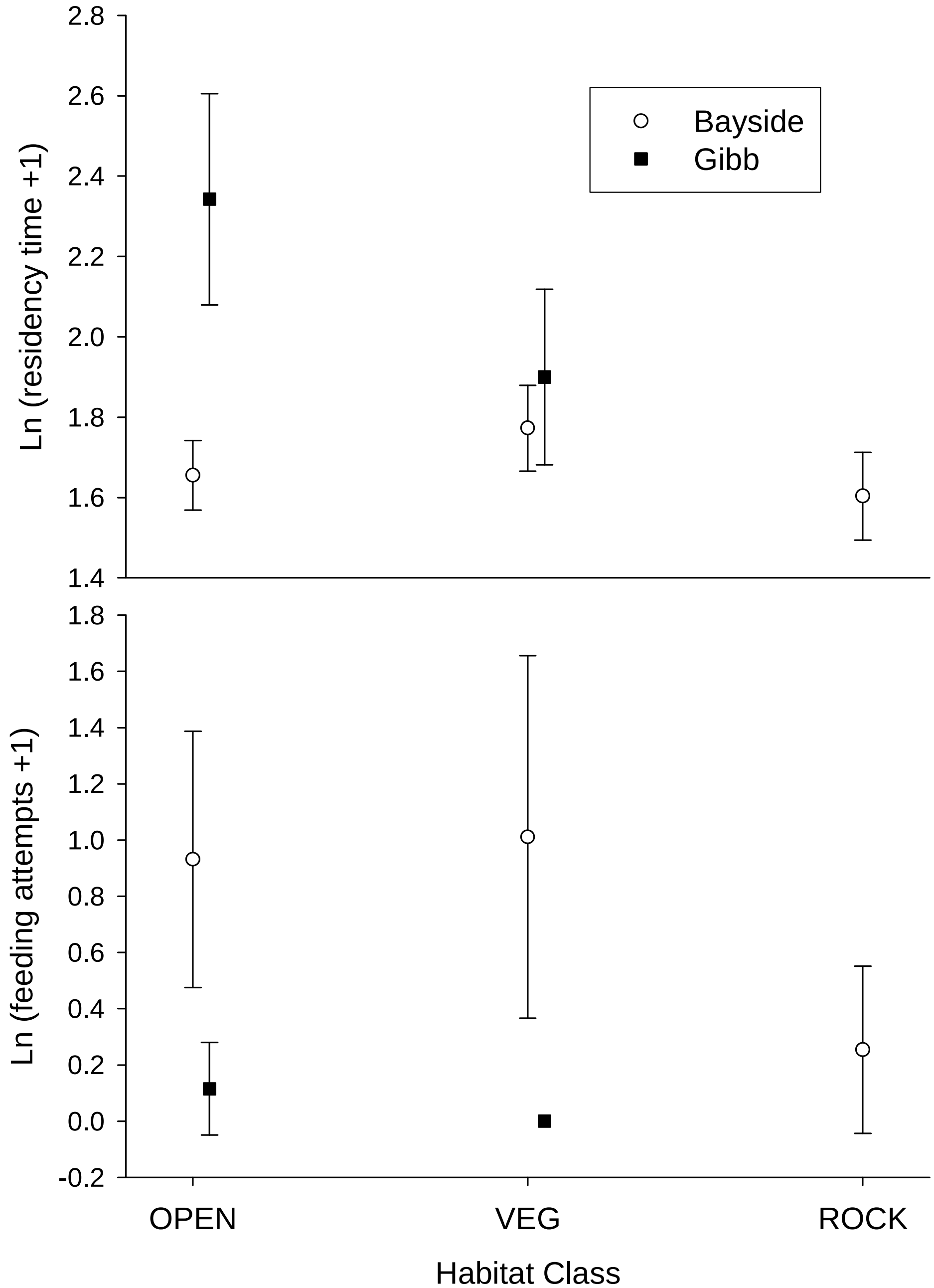

Figure 19. The mean length of time fish were present on-screen (top panel), and number of feeding attempts observed (lower panel), during the filming period. Error bars represent 95% confidence intervals.

Individual fish species showed strong habitat preference behaviour in Bayside Quarry. Bluntnose minnow and bluegill had the most general habitat use patterns, while banded killifish displayed the most habitat specificity (Figure 20). OPEN habitats were always used less in proportion to their availability, while vegetated habitats were always used more than expected. In general, structurally complex habitats were used preferentially.

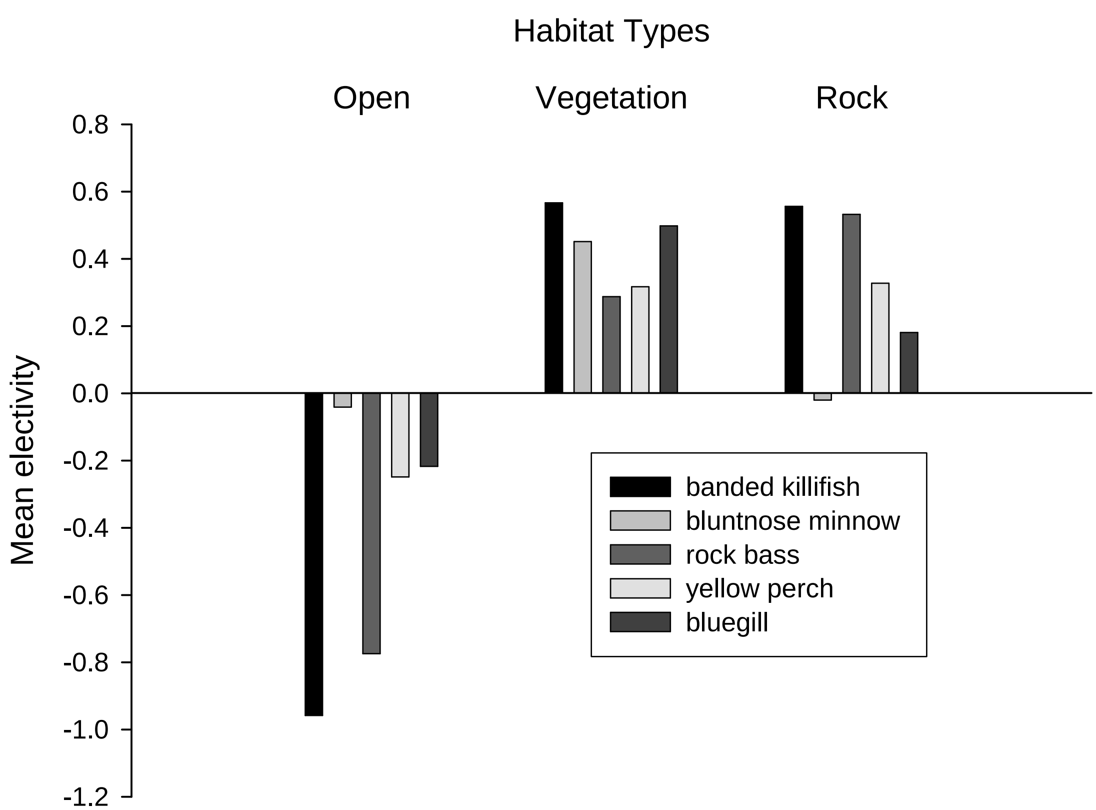

Figure 20. Mean electivity index (Ivlev) of fish species among three habitat types in Bayside Quarry.

5.3.4.3 Assessment of Fish Distribution

Side-specific distance sampling abundance estimates of yellow perch and largemouth bass available for the control and brush-bundle addition sides from Gibb Pit before and after the habitat addition showed a significant shift in distribution of the two fish species analyzed (Table 32). Yellow perch utilized the control side more after brush bundle addition, while largemouth bass were observed in significantly greater proportions on the brush bundle side after habitat addition.

Table 32. Fish use of control and brush-bundle addition sides of Gibb Pit by yellow perch and largemouth bass before (2001) and after (2002, 2003) brush-bundle addition. Before/after changes were tested for each species using log-linear analysis, and the resulting chi-square and p-value are presented below.

Year	Yellow perch			Largemouth bass		
	Wood bundles	Control	χ^2,*P*	Wood bundles	Control	χ^2,*P*
2001	138 (84-226)	9 (3-29)	χ^2=8.6, P=0.003	23 (8-64)	46 (11-189)	χ^2=7.6, P=0.006
2002	196 (136-284)	56 (22-141)		47 (27-81)	39 (19-80)	
2003	238 (146-386)	25 (8-80)		86 (51-145)	74 (39-142)	

Our MBACI analysis detected a significant site-level shift in habitat use in both Bayside Quarry and Gibb Pit (Table 33). In both systems, fish increased their use of sites where habitat was added, and reduced their use of control sites (Fig. 21, left-hand panel). There were no significant changes in system-wide biomass (Biomass Time $F_{1,4}$ = 0.03, *P* = 0.87) or productivity (HPI Time $F_{1,4}$ = 0.002, *P* = 0.96) before or after the habitat manipulations occurred. Biomass and productivity levels remained consistent from before to after treatment (Fig. 21, right-hand panel).

Table 33. Multiple before-after control-impact (MBACI) analysis of variance results from Bayside Quarry and Gibb Pit. The key test of the BACI model is the Treatment * Time interaction. Starred probabilities indicate significance after applying a Bonferroni correction.

	Source of variation	*SS*	df	*MS*	Test	*F*	*P*
	Treatment	0.01	1	0.01	$MS_{Treatment}$ / $MS_{Site\ [Treatment]}$	<0.001	0.99
	Time	0.20	1	0.20	MS_{Time} / $MS_{Time\ *\ Site\ [Treatment]}$	0.15	0.70
	Treatment * Time	8.82	1	8.82	$MS_{Treatment\ *\ Time}$ / $MS_{Time\ *\ Site\ [Treatment]}$	6.51	0.02*
	Year [Time]	0.15	1	0.15	$MS_{Year\ [Time]}$ / MS_{Error}	0.08	0.78
	Site [Treatment]	62.7	26	2.41	$MS_{Site\ [Treatment]}$ / MS_{Error}	1.37	0.22
	Treatment * Year [Time]	0.18	1	0.18	$MS_{Treatment\ *\ Year\ [Time]}$ / MS_{Error}	0.10	0.76
	Time * Site [Treatment]	31.16	23	1.36	$MS_{Time\ *\ Site\ [Treatment]}$ / MS_{Error}	0.77	0.74
	Error	42.39	24	1.77			

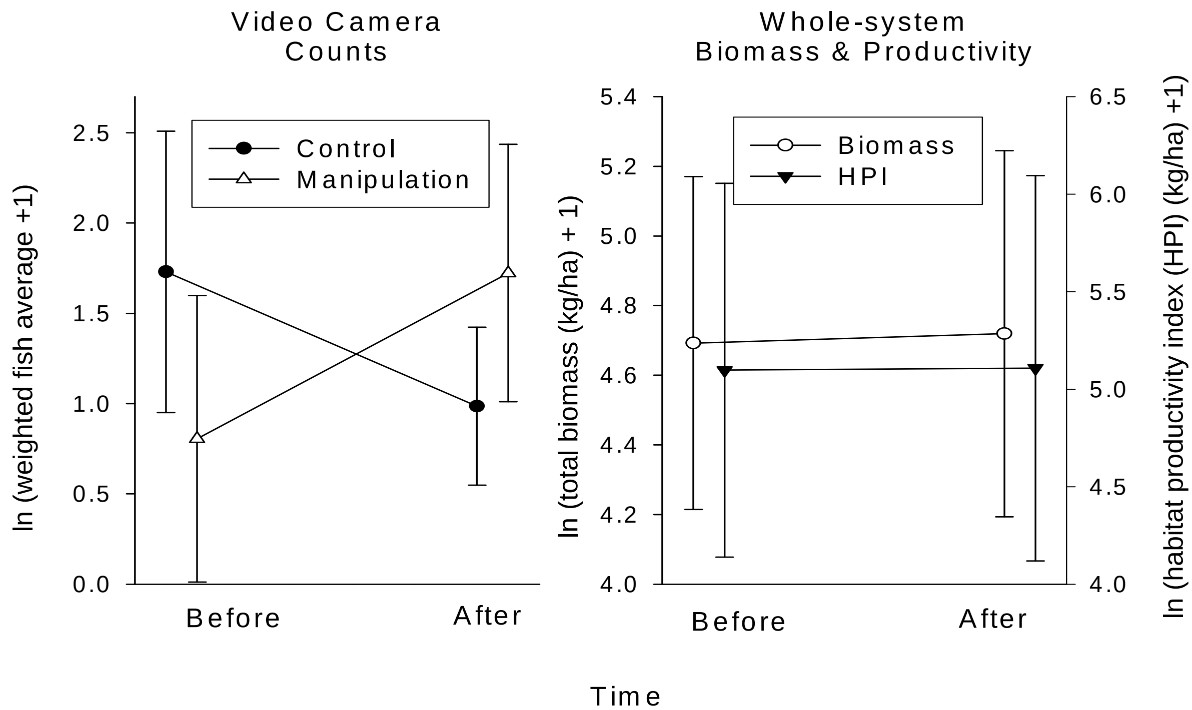

Figure 21. Comparison of weighted fish averages from underwater video filming (left-hand panel) and whole-system biomass and habitat productivity indices (right-hand panel) before and after habitat manipulations from Bayside Quarry and Gibb Pitt. Error bars represent 95% confidence intervals.

6 DISCUSSION

Understanding to what degree physical habitat structure is important in maintaining fish production remains a critically important question for those interested in the conservation of aquatic resources. In marine systems, the extensive debate around the artificial reef attraction-production continuum provides the strongest example of uncertainties surrounding the importance of habitat on fisheries production (Bohnsack 1989). In freshwater systems, manipulations to improve fish habitat abound without the same level of scientific scrutiny (Smokorowski et al. 1998), despite the fact that the closed nature of these systems present researchers with opportunities for insight through experimental study. We were able to partially address this question by conducting experimental habitat manipulations in a suite of small, closed abandoned aggregate sites. While we found evidence that a spatial redistribution of fish occurs within a system with the addition of heterogeneous structural habitat, we found no evidence that the habitat enhancement had a positive and lasting effect on whole-system fish biomass or production.

6.1 CHEMICAL LIMNOLOGY

Water chemistry results indicate that all systems are moderately basic, with substantial capacity to neutralize acidic inputs such as acid rain. Each of the three manipulated systems increased pH after habitat additions, with the increases in Van Limbeek (8.3 to 8.6, $p=0.06$ two tailed t-test) and Gibb (8.6 to 9.1, $p = 0.07$) both moderately significant. The increased pH still leaves the systems at less than the 9.5 threshold at which increasing pH begins to negatively affect biotic communities (Wetzel 1983). The 9.5 pH threshold is not absolute, however, as fish biomass per hectare values in Stoney Creek Quarry were among the highest found in all systems between 1998 and 2000, when pH ranged from 10.0 to 10.4. After the presumed winter kill of 2000/01, pH values declined below threshold (9.3 in 2002 and 9.2 in 2003), without a concomitant increase in total fish biomass.

Nutrient supply identifies the systems as mesotrophic to mildly eutrophic, hence nutrient deficiency is not suppressing potential productivity. In Bayside Quarry and Gibb Pit, average total phosphorus, total nitrogen, and chlorophyll *a* concentrations remained within the mesotrophic range from before to after habitat alteration. In Van Limbeek Pit and Stoney Creek Quarry, nutrient concentrations were consistently high, and both systems could benefit from a reduction in nutrient loading to prevent or lessen the effects of eutrophication.

Eutrophy can result in a reduced state of biotic stability. High nutrient levels result in dense plant growth, and subsequent large accumulations of dead organic matter (detritus) at the substrate. Most organisms that feed on detritus are aerobic and can exert a large oxygen demand at the site of consumption. In some conditions this can result in mortality to other organisms that require oxygen. One example would be winter kills of fish, where ice cover prevents the diffusion oxygen to the water from the air and from wind mixing of oxygen. High oxygen demand by detritivores can reduce the dissolved oxygen content of the water to below levels required to sustain fish, inducing fish mortality (note: fish species vary in their tolerance of low oxygen levels). Once the ice melts, and dissolved oxygen concentrations increase, growth rates of the remaining fish and survival rates of newly-hatched fish can increase, and the age at which sexual maturity is reached can decrease (Fox and Keast 1991). Over time, fish community abundance and/or biomass can fluctuate widely on either side of the theoretical carrying capacity for the water body, therefore the greater the magnitude of these fluctuations, the greater the chance of extirpation of a species from that water body, or the outright collapse of the fish community (Tonn and Magnuson 1982; Tonn and Paskowski 1986; Hall and Ehlinger 1989)

The Van Limbeek aquatic vegetation enhancement was partially designed to see if established wetland plants would bind some of the nutrients in the system. Although the establishment of plants is still ongoing, average total phosphorus, total nitrogen, and chlorophyll *a* concentrations have all declined from before excavation, although the reductions are not statistically significant (p=0.50, 0.35, 0.11 respectively). Analysis of the biofilm on the artificial substrate tiles also demonstrated a declining trend in organic matter (ash free weight) and chlorophyll *a* from before to after enhancement. Construction of a fence around the excavated area by the landowner that restricts access to the system by horses may also have contributed to a reduction in nutrient inputs.

Dissolved oxygen deficiency is not an issue in Gibb Pit or Bayside Quarry. From 1998 through 2001, water deeper than 3.5 to 4.0 m was oxygen deficient in Van Limbeek Pit, restricting aerobic biotic production in the deepest, coolest portions of this system. Conditions in Van Limbeek may be improving, as an oxygen deficiency was not detected in 2002. We were unable to confirm whether the improved conditions persisted into the summer of 2003, due to an equipment malfunction. The trend towards lower nutrient supply, however, should reduce incidents and severity of declining oxygen in the future. A dissolved oxygen deficiency is the most likely cause of the substantial reduction in the biotic community in Stoney Creek Quarry between July 2000 and June 2001.

The greater ion concentration in quarries over the pits is probably a function of geology, as the weathering of rock is one major source of ion input. Both quarries have long expanses of exposed limestone bedrock along shore, while the shorelines of the pits are more densely vegetated. There were no instances where metal concentrations were of concern. Water samples were not tested for complex organic and inorganic compounds such as pesticides, herbicides, and organo-chlorine complexes, as such tests are extremely expensive (can exceed $1,000 per sample), and were beyond the scope of this study. In general, however, we found nothing to indicate the input of toxins to the systems were an issue in any year. The one possible exception is the substantial reduction in fish biomass in Stoney Creek Quarry between July 2000 and June 2001. Given the shallow, eutrophic, densely vegetated state of this quarry, however, a winter-kill due to an oxygen deficiency seems far more plausible than a one-time toxic chemical spill.

6.2 BIOLOGICAL LIMNOLOGY

Zooplankton diversity, abundance, and distribution in lakes change with season and time of day (lower in the water column during the day, with an upward migration at night), and is known to be patchy (Wetzel 2001). The zooplankton monitoring program associated with this study was designed to provide a snapshot assessment of planktonic secondary production in each system. The same pattern of reduced zooplankton densities occurred in each system after 2000.

Zooplankton are an important component of the diet of the young of all fish species found in the pits and quarries, and continue to be an important component of the diet of juveniles and adults of some smaller species (e.g. shiner, minnow species). The observed reductions in zooplankton densities that were found resulted from suppressions of abundances across taxonomic groups, not the collapse of one or more taxa. This implies that zooplankton in general are responding to either an overall decrease in nutrients which may have led to a reduction in phytoplankton (bottom-up control), and/or a change in predation by fish (top-down control). The bottom-up theory is partially supported by chlorophyll *a* and nutrient data in Van Limbeek and Stoney Creek. Increasing reproductive success of fish would result in increased predation pressure on zooplankton by young-of-the-year fish (and adults of some species), which would also decrease the standing crop of zooplankton.

Like zooplankton, sampling for benthic invertebrate communities was designed to provide a relative measure of benthic secondary production available in the systems. Unlike zooplankton, many benthic invertebrates (e.g. insects) also have terrestrial life stages, and can thus be influenced by factors outside of the systems themselves. Within aquatic systems, benthic communities can vary with season and habitat. Randomly-placed artificial substrates, left in place for a similar duration (approx. 4 weeks) during the same time of year (July – August, each of 1999 through 2003) were selected to provide a standardized relative measure of the benthic community in the three experiment systems.

The average number of invertebrates on the artificial substrates varied widely between years, with the pattern of change driven by dipteran larvae (true flies) in each system. Bayside Quarry ranged from 65 (2001) to 504 (1999) benthic invertebrates per substrate, Van Limbeek

Pit ranged between 78 (1999) and 363 (2001), and Gibb Pit ranged between 65 (2002) and 413 (1999). It is not unusual for benthic invertebrate proportions to demonstrate large inter-annual variation. In each year we installed artificial substrates in the pit and quarry systems, we conducted similar sampling in lakes in the Algoma district of Ontario, and found that colonization densities were similar across systems.

Changes in benthic invertebrate abundances within each system were compared qualitatively to changes in total fish biomass between the same years (Table 34). In nine of the twelve year to year comparisons, invertebrate relative abundances decreased when total fish biomass increased, or vice versa, including all four periods in Bayside Quarry. This suggests that benthic invertebrate standing crops may regulated by predation pressures exerted by fish, a phenomenon observed in biomanipulation experiments in natural systems (e.g. Leppae et al. 2003).

Table 34. Comparison of changes in benthic invertebrate relative abundances between years and total fish community biomass between the same years.

System	Measure	Years			
		1999 - 2000	2000 - 2001	2001 - 2002	2002 - 2003
Bayside	Invert. Abundance	Increase	Increase	Decrease	Increase
	Fish biomass	Decrease	Decrease	Increase	Decrease
Van Limbeek	Invert. Abundance	Increase	Increase	Decrease	Decrease
	Fish biomass	Increase	Decrease	Increase	Decrease
Gibb	Invert. Abundance	Decrease	Decrease	Decrease	Increase
	Fish biomass	Increase	Decrease	Increase	Decrease

There were 21 taxonomic groupings used when identifying and enumerating the benthic invertebrate samples. These included hydra, worms, leeches, insects with aquatic life stages, and snails. The number of taxa present in the samples ranged from 9 (Bayside 2000) to 17 (Gibb 2002), with a mean value of 13.2. Similar artificial substrates were used over the same years in lakes in the Algoma Region of Ontario and accumulated between 5 and 16 taxa per lake-year

(Smokorowski, unpublished data). Given that some of the groups would be expected to be found somewhat rarely in closed systems, and that fewer taxa were sampled in natural lake systems, it is surmised that the results represent unimpaired benthic communities.

Benthic invertebrates are an important food source for fish. Like the smaller zooplankton, benthic invertebrates are consumed by the young of all fish species in the systems. The difference is that benthic invertebrates continue to be a major food source for the juveniles and adults of most fish species found in the systems. Of the benthic invertebrates, dipterans (true flies, including crane flies, mosquitoes, black flies, midges, etc.) are one of the most important food sources for fish and were the most abundant taxon in 13 of the 15 system-years.

There was no relationship detected between invertebrate relative abundance and species richness. For example, the highest number of species found in Van Limbeek Pit was in the same year (2001) as the highest relative abundance, while the highest number of species found in Gibb Pit was in the same year (2002) as the lowest relative abundance.

Benthic invertebrate diversity index values (Shannon-Wiener Index, Evenness, Table 9) were compared from before to after habitat alteration in the systems. The mean annual values did not change significantly for either measure in any system (two-tailed t-test, $0.26<p<0.92$), and there was no consistent upward or downward trend in values among systems. As there are no significant changes in diversity, abundance, or dipteran-dominance (by numbers) in the systems, it is concluded that habitat alteration did not produce a measurable impact on the benthic invertebrate communities.

6.3 FISH

6.3.1 Whole System Biomass and Production

Mean total system fish biomass and production (Figures 22-25) increased from before the treatments to after in both Bayside Quarry and Van Limbeek Pit, although these increases were not statistically significant (i.e. $p>0.05$). Note that in all cases the variability in biomass and production estimates increased after treatment, which decreases the likelihood of changes in mean values being statistically detectable.

Stoney Creek Quarry was the intended control system for the study. Unexpectedly, the quarry exhibited a dramatic reduction in total fish biomass between sampling events in June of 2000 and June of 2001. As explained earlier, the most plausible explanation is that a winterkill event happened in the intervening period. Total fish biomass prior to the presumed winterkill averaged about 1125 kg; this declined to an average of about 250 kg in the years 2001 through 2003.The presumed winterkill event is used as the dividing point for Stoney Creek Quarry. The only statistically significant change was the decrease in fish biomass in Stoney Creek Quarry. As it is believed that the reduction in Stoney Creek Quarry was the result of system-specific conditions, and not natural environmental fluctuations in southern Ontario, this system was no longer a suitable control system to use in the BACI analysis.

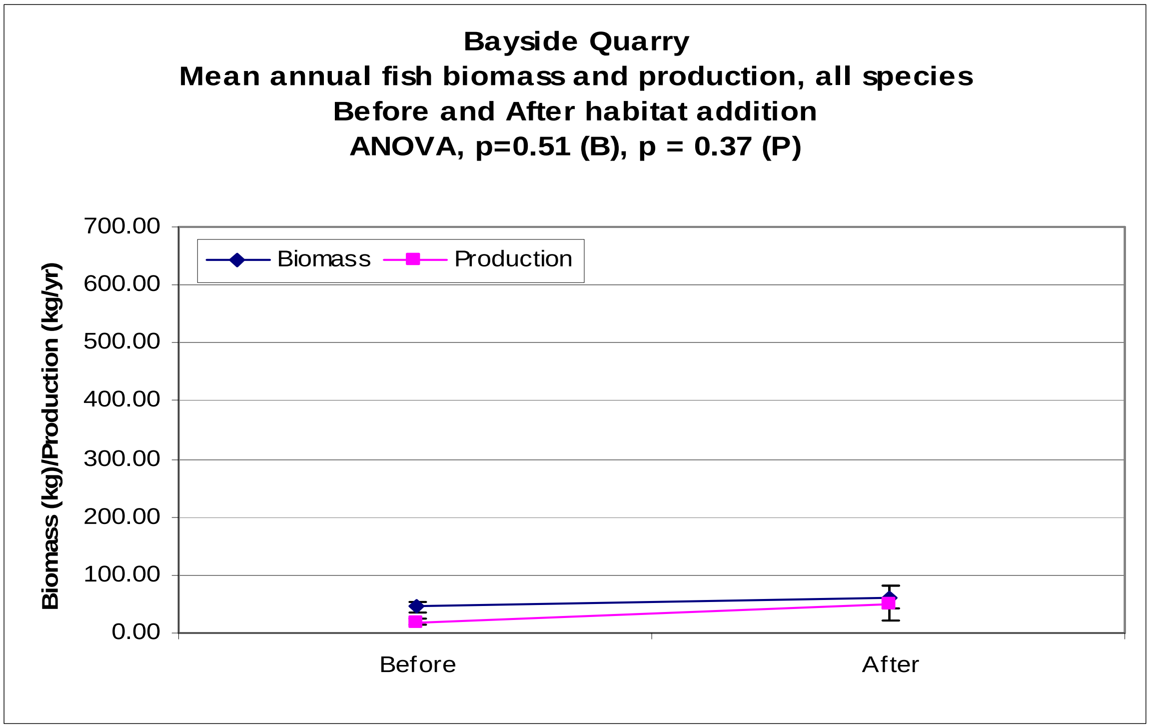

Figure 22: Comparison of mean (±SE) total fish biomass, all species combined, for year before and after habitat additions for Bayside Quarry, 1998 through 2003.

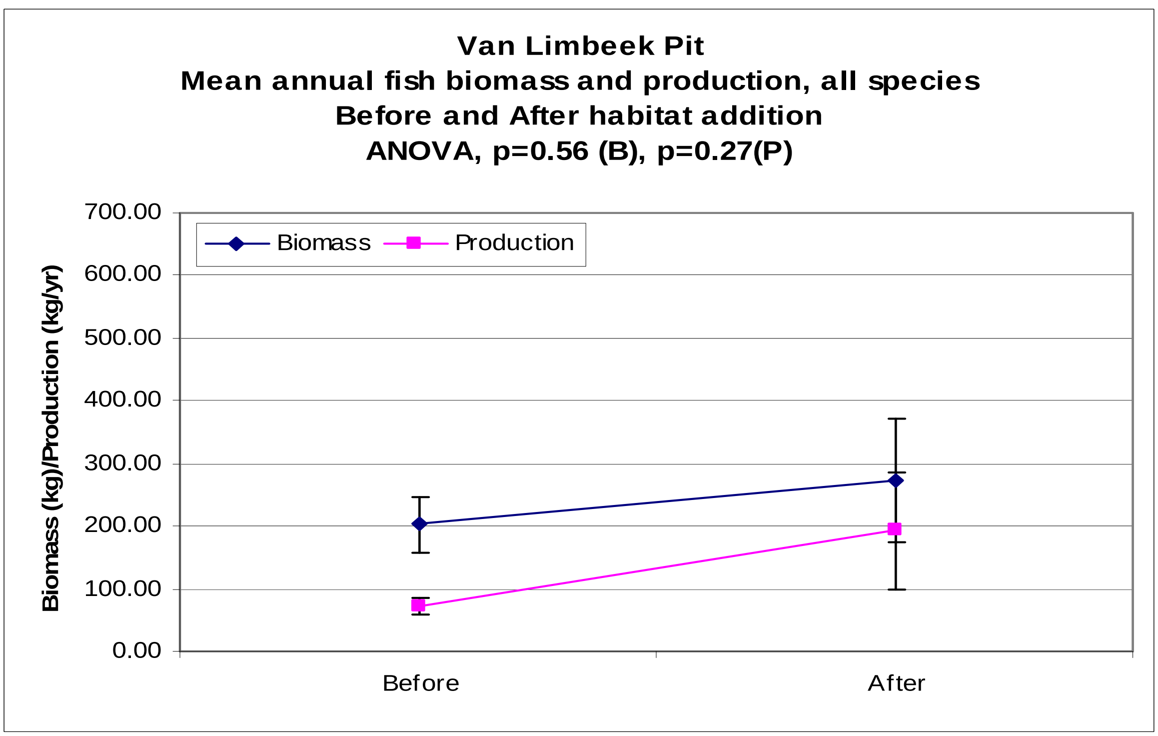

Figure 23: Comparison of mean (±SE) total fish biomass, all species combined, for year before and after habitat additions for Van Limbeek Pit, 1998 through 2003.

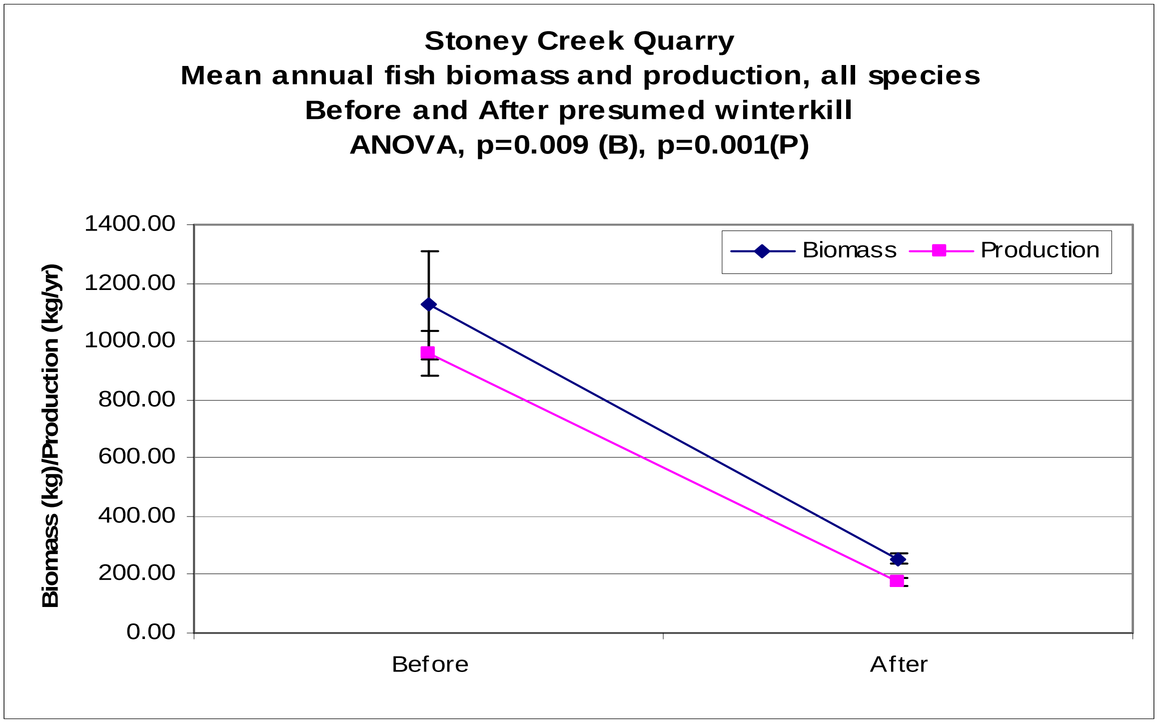

Figure 24: Comparison of mean (±SE) total fish biomass, all species combined, for year before and after habitat additions for Stoney Creek Quarry (before and after presumed winterkill), 1998 through 2003.

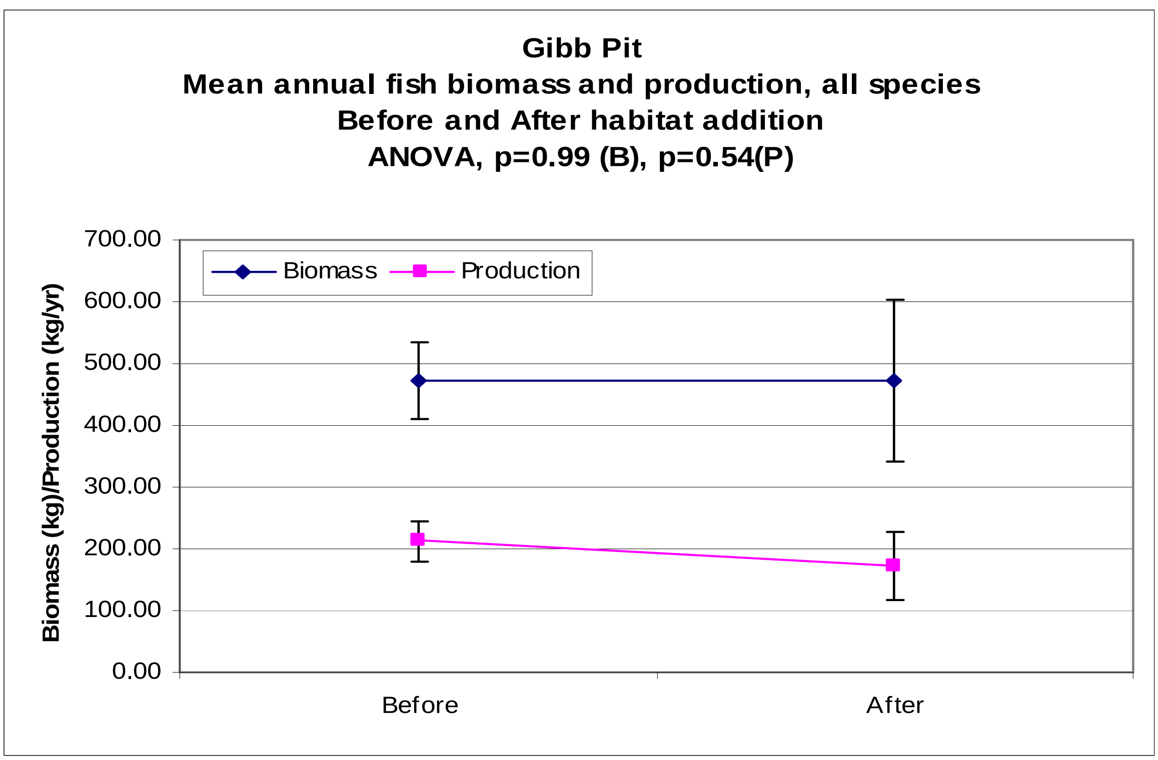

Figure 25: Comparison of mean (±SE) total fish biomass, all species combined, for year before and after habitat additions for Gibb Pit, 1999 through 2003.

Unfortunately, the reduction in Stoney Creek Quarry occurred after the treatment dates in both Bayside Quarry and Van Limbeek Pit, so replacing the control with another more suitable system in southern Ontario was not possible. The loss of the intended control system does not mean that the study lacks value. Fish community (and other) attributes were still measured before and after treatments. Detections of changes within the systems, if any, remained the focus of the study. Loss of the control system simply confounds interpretation of the study results, particularly the attributing of cause to any change detected. However, when the control data arose from within the same system (i.e. video camera counts, control or unaltered sites within a system), the MBACI model was used in data analysis.

6.3.1.1 Whole System Biomass In Comparison To Natural Lakes

Since early in fisheries research, a variety of system characteristics have been used to predict fish standing crop, biomass, yield or production in an attempt to determine what drives fish productivity, facilitate predictions in the absence of field sampling, or facilitate comparisons among systems. The models fall into categories based on input parameters, but are generally determined indirectly by regressing physical/chemical parameters (e.g. mean depth, total dissolved solids, thermal volume, or nutrients; for examples see Ryder 1965, Schlesinger and Regier 1982, Christie and Regier 1988), or biological parameters (e.g. chlorophyll *a* or primary production, see Downing et al. 1990) from a range of systems against fish data. The most commonly used and accepted models, however, were derived using long term data from very large systems (e.g. Ryder’s MEI model was developed using systems with an average area of 1,400,000 ha).

Because the pit and quarry systems used in this study are very small and closed, most of the published and accepted models are not applicable to facilitate comparison to natural systems.

However, Schneider (1973, 1978) published the results of whole lake fish biomass estimates for 64 natural lakes in Michigan which ranged from 0.5 ha up to 2000 ha, with the majority less than 500 ha. The author used fish biomass data in combination with lake characteristics to derive a predictive model for whole lake fish biomass as follows:

$$\text{Log standing crop} = 1.104 + 0.36\,\text{PI} + 0.034(1/\log \text{Secchi}) + 0.45\log \text{VI} + 0.00029\,\text{CI} - 0.11\log \text{area} + 0.5336\,\text{RFI}.$$

Where PI = panfish index = proportion of total biomass as sunfish
CI = climate index = average growing degree days
VI = vegetation index = subjective, from 1 (sparse) to 5 (dense)
RFI = rough fish index = proportion of total biomass as bullheads, carp, goldfish, and suckers combined.

While the model accounts for only 56% of the variation in fish standing crops in the Michigan Lakes, it may provide insight into how pit and quarry fish biomass compares with natural systems of similar longitude and latitude. Characteristics of the pits and quarries were plugged into the predictive model and the results were compared with total fish biomass estimates from this study. In the three treatment systems, the estimated total fish biomass exceeded the predicted biomass, whereas the results were the opposite in Stoney Creek Quarry, due in part to the presumed winter kill, and also the very shallow depth of the quarry (mathematical effects within the model that will not be discussed here).

The data from which the model was derived were from lakes of various sizes, locations, and fish communities throughout Michigan. Pit and quarry total fish biomass estimates were then compared against only small (<20 acres) lakes in the southern third of the state, as these tended to have higher biomass per unit area estimates than larger, more northerly lakes. These lakes were also more directly comparable to the pits and quarries in terms of size, fish communities, and climate. The mean biomass for the pits and quarries was 201 $kg \cdot ha^{-1}$ (range of 79 to 604), while the Michigan lakes averaged 207 kg·ha^{-1} (range of 63 to 305, 15 lakes), implying that total fish biomass in the pits and quarries is comparable to the high range found in natural systems.

6.3.2 Fish Community Data

6.3.2.1 Community response to habitat additions

It was hypothesized that addition of the reef in Bayside Quarry would increase fish production (and persist as increased biomass) by increasing the availability of prey organisms, and increase the survivorship of small fish species and young of the larger species, and our abundance results are consistent with the hypothesized effect. It is unclear whether fish production in the quarry has increased. While mean annual fish biomass has increased from before to after reef addition, the increase is not significant and is driven by the single large pulse increase in sunfish biomass found in 2003 that may not be sustainable. In addition, fish condition has decreased for those species that comprise the majority of the fish biomass in the system.

It was hypothesized that the excavation and establishment of aquatic plants in Van Limbeek Pit would provide cover for small fish and increases the spawning success of species such as northern pike and brown bullhead. As the establishment of aquatic plants is incomplete, cover in the excavated area is still sparse. In 2003, each of the small species found annually in the system (blacknose shiner, banded killifish, fathead minnow) were at their lowest level of biomass over the duration of the study. Mean brown bullhead biomass has increased since excavation. While mean northern pike biomass decreased, a greater percentage of small pike were caught in 2003 than in any previous year. In 2003, northern pike 300 mm or less comprised 14.7% of the total catch. Prior to 2003, the highest percentage of catch for small pike was 4.3% (1998), while no small pike were found in the years 1999 through 2001.

It was hypothesized that the addition of habitat in Gibb Pit would increase the cover for, and survival rate of, small fish, and increase the reproductive success of yellow perch. With only two years of post-treatment data, and the presence of only longer-lived species in the pit, it is too early to be able to quantitatively assess the effect of habitat addition. There was a non-significant increase in mean annual minnow trap CUE from before to after habitat addition, attributable completely to Age 1 and Age 2 yellow perch, however the effectiveness of minnow traps in capturing perch appears to be quite poor in this system, with fewer than one fish captured on average per trap set.

6.3.2.2 Fish Diversity

In all cases, our diversity measure (PIE) appeared to be on an increasing trend from before to after treatment, with a significant change observed in Stoney Creek Quarry. For the three treatment systems, mean total fish biomass either increased or stayed the same from before to after habitat addition. Pits and quarries were chosen for this study as they were closed systems with a relative lack of habitat diversity. Increasing habitat diversity presumably would increase the number of ecological niches available, through provision of a greater array of spawning, nursery, feeding, and/or cover habitats. If physical habitat characteristics are at least a partial determinant of biotic community attributes, then it follows that increasing habitat diversity could cause changes in community composition.

Results for Stoney Creek, by catch, illustrate a caveat of index values in general. From 1998 through 2000, the relatively low index value (0.068) can also be interpreted to mean that there was a greater than 93% chance that any two randomly-sampled individuals from the community would be the same species (sunfish sp.), while from 2001 forward there was a less than 43% chance that the two would be the same. The increase in index value could be interpreted as a positive result, representing greater balance in species distribution within the community, and potentially a community less susceptible to the density-dependent effects of overpopulation (poorer individual condition, winterkill events, disease, year-class failures). Yet, the change was due to an over 80% decline in mean annual sunfish catches, and an over 50% decline in the catches (and over 75% in terms of biomass) of all species present, which in itself could be viewed as a negative change. The statistically-significant increase is driven mostly by the collapse of the dominant species between the 2000 and 2001 sampling periods, and therefore greater relative contribution of lesser abundant species to the catches. Interpretation of index values must therefore be conducted in conjunction with analysis of community dynamics as a whole.

6.3.2.3 Whole System Fish Species Richness In Comparison To Natural Lakes

In natural systems, species distributions across regions are strongly influenced by postglacial dispersal processes and climate (Mandrack 1995), but at a more local scale, species richness has been shown to be a function of lake size, pH (Jackson and Harvey 1989) and habitat heterogeneity (Eadie and Keast 1984). In a study of 82 Ontario lakes, fish species richness was found to be significantly correlated with lake surface area (Eadie et al 1986), and predictive equations for species richness in lakes were derived using the surface areas of all 82 lakes combined, and for the subset of lakes in southern Ontario (n=13). While the sample size for southern Ontario lakes was smaller, the predictive equation derived was stronger ($r^2 = 0.969$ as compared to $r^2 = 0.796$ for all 82 lakes). Although pit and quarry systems are relatively new, disconnected from natural watersheds, and contain fish mainly because of human introductions, surface areas were input into the southern Ontario equation, as if they were natural systems, to predict the number of fish species expected (Table 35).

Table 35. Comparison of predicted and observed fish species richness, before and after habitat addition (presumed winterkill in Stoney Creek Quarry) in the pits and quarries.

System	Area (ha)	Predicted # of species	Range of observed number of species per year	
			before	after
Bayside Quarry	0.35	1.7	4 - 6	6
Van Limbeek Pit	0.76	2.1	8 - 11	7 – 9
Gibb Pit	4.29	3.4	3	3
Stoney Creek Quarry	4.69	3.5	3 - 5	4 - 6

A species is only counted in the observations in Table 35 if five or more individuals were caught in the June sampling period in a year. Bayside Quarry and Van Limbeek Pit consistently support a greater diversity of species than would be expected in a natural lake of similarly small size. Stoney Creek Quarry, despite the observed instability of the system, still supported as many or more species than would be expected. Gibb Pit supported about as many species as expected.

6.3.2.4 Catch Per Unit Effort (CUE)

CUE data provides a relative measure of fish abundance in a system, and has advantages over direct abundance estimation techniques. Estimation of abundances is useful for describing the fish community each year, and is a required element of biomass and production estimation, but it only yields a single number per year. For this study the result is only three data points before and three after (two in Gibb Pit) treatment. This small sample size, and the natural variation present in fish communities, means that tests for differences before and after treatment are only likely to indicate statistical significance for very large changes. Using CUE data to provide a relative indication of changes within the communities gets around the limitations of small sample sizes, as each gear set is counted as a single data point. In this case that means that a minimum of four data points per year are available for trap net data, and up to 116 data points per year are available for minnow trap data, greatly increasing the reliability of our statistical tests.

Table 36. Mean annual catch per unit effort (CUE) values for before and after habitat additions, all systems, and June sampling data. Minnow trap (MT) and trap net (TN) catches reported per overnight set. Gill net (GN) catches are reported per 30 minutes of fishing time.

System	Gear	Mean CUE (pre)	Mean CUE (post)	t-test p value
Bayside Quarry	MT	5.15	7.95	<0.001
	TN	32.27	89.20	0.094
	GN	1.15	0.79	0.311
Van Limbeek Pit	MT	32.73	17.26	<0.001
	TN	10.21	14.71	0.364
	GN	0.94	1.28	0.126
Gibb Pit	MT	0.35	0.53	0.355
	TN	5.60	2.25	0.003
	GN	2.61	4.97	0.015
Stoney Creek Quarry	MT	44.18	20.02	<0.001
	TN	197.75	108.33	0.082

Before and after mean values were compared using a two-tailed Students t-test to identify statistically significant changes in CUE values (Table 36). Significant changes (Bonferroni corrected $\alpha = 0.004$) were found in all systems.

There was a significant increase in minnow trap catches in Bayside Quarry from before to after habitat addition. As the openings at either end of a trap are 2.5 cm in diameter, minnow traps are only effective in capturing small fish species and the young of larger species. It was hypothesized that the addition of the rock reef would increase food supply and cover for smaller fishes, thus increasing their survival rates. It is thus plausible that the rock reef did contribute to an increase in small fish abundance in Bayside Quarry. Mean trap net catches also increased, driven largely by the 2003 increase in sunfish catches. From ageing information for 2003, we know that roughly 90% of the sunfish caught were 2 years of age. We do not know yet whether this strong year class will survive to maturity (usually 3-4 years) and sustain the relatively high 2003 abundance and biomass levels.

Unlike Bayside Quarry, there was a significant decrease in minnow trap catches in Van Limbeek Pit. In Van Limbeek Pit, a gently-sloped littoral area was excavated into the land surrounding the system. While wetland plant species have been added to this excavated area, their establishment and proliferation have not been rapid, thus there is as yet limited cover available. Mean catch rates of larger fish in trap nets and gill nets increased, but not significantly.

Changes in Van Limbeek appear to be related to changes in the rock bass population. In 1998 and 1999, there were around 15 adult rock bass in the system, aged between 4 and 6 years, but no young. In 2000, the first Age 1 rock bass were found, although the abundance estimate remained at the relatively low value of 370 (roughly 15 adults aged 6 years, and 355 Age 1). This estimate was probably understated, as is not atypical when small fish first become recruited to the sampling gear. In 2001, subsequent to the excavation, the abundance estimate for rock bass jumped to 8102, two-thirds of which were Age 1. In 2002, the abundance estimate declined to 3062, although total rock bass biomass increased from 91.91 kg to 168.76 kg due to the growth of the surviving individuals. Of note is that the 2002 rock bass biomass estimate was roughly equal to the combined biomass of all species in the system in 1999 (169.46 kg), and exceeded the estimate for all species combined in 1998 (147.17 kg). In 2003, only a single rock bass was captured in the system.

In 2000, the total June catches of the small species blacknose shiner, banded killifish, and fathead minnow was 832. In 2001, the first year of the dramatic increase in rock bass abundance, the total catch of these species was 596. In 2002 and 2003 the total catches of the formerly common species in the system dropped to 51 and 33 respectively. The major declines in small species catches thus correspond to the second year of growth of the extremely strong 2000 year class, when rock bass would be switching their diet from mostly invertebrates to include other small fish. The decline in minnow trap catches may be a reflection of the suppression of small species abundance that became evident in 2002, and the collapse of the rock bass population by June 2003.

The reason for the collapse of the rock bass population between 2002 and 2003 is not known. One possibility is the absence of suitable quantities of food, as evidenced by the decline in invertebrate abundance on artificial substrates from 2001 to 2002 and from 2002 to 2003, as well as the declining small fish abundances. Other possibilities exist, including increased predation pressures from northern pike, disease, and mortality due to limited winter oxygen supply. The total estimated system fish biomass of 603.64 kg • ha-1 in 2002 was 2.27 times higher than the mean estimated biomass in Van Limbeek Pit from the other 5 years of study, and from 2.1 to 7.6 times higher than the biomass per unit area in either of the other two habitat addition systems in any year. It may simply be that this level was beyond the system's ability to sustain, and a variety of factors worked together to effect a correction in the total standing crop of fish in the system.

Results of CUE analyses for Gibb Pit are mixed and, due to the previously explained issues of limited post treatment data and presence of solely longer-lived species, and as such should be viewed cautiously. In addition, largemouth bass, representing 29% to 65% of the total fish biomass in Gibb Pit, are poorly recruited to the suite of fishing gears used in CUE analysis in comparison to other systems. In the years 2000 through 2003, an average of 6.5 largemouth bass per year were captured in trap and gill nets combined (zero in minnow traps or hoop nets), while 99.2 per year were captured by angling. The apparently contradictory significant decrease in mean trap net CUE (p=0.003) and increase in gill net CUE (p=0.015) is thus partially explained by having only two years of post manipulation data, and the fact that these fishing gears are not effective in capturing one of the two major species present.

The declines in mean CUE values in Stoney Creek Quarry weren't unexpected, given the declines in biomass and production noted earlier.

From a fish community perspective, there are consistent increases in variation, in annual biomass and production estimates, increases in mean diversity index values, and statistically significant changes in CUE, from before to after treatment. Combined, these factors indicate that changes are occurring to fish communities in the treated systems. Changes to whole system biomass and production were, in mean terms, either positive or neutral. It is uncertain that observed increases in total fish biomass and production will persist in the treated systems. The pits and quarries already contain a similar biomass of fish as do the more productive natural systems of similar size and climate. The increases in mean biomass and production estimates in Van Limbeek Pit in the first two years following habitat addition were not sustained in 2003. It is unknown whether the post-addition increases in Bayside Quarry will persist, and changes in Gibb Pit, if any, have as yet not been fully manifested. The changes that are occurring, therefore, seem more likely to be shifts in the allocation of biomass within the systems, and not increase in the biological carrying capacities of the systems.

6.3.3 Underwater Visual Methods

Underwater visual methods were included in the overall study design to investigate some of the potential causal mechanisms behind the anticipated shifts in whole-system production with the habitat additions. One of the main limitations with these methods is visibility, and only two of the four systems had water quality suitable for underwater visual methods. A number of techniques have been used to successfully document fish habitat use at a site- or microhabitatlevel, including a variety of active and passive gears and underwater census techniques (e.g. Werner et al. 1977, Weaver et al. 1997, Pratt and Smokorowski 2003). On the whole, these studies have identified that structurally complex habitats contain higher fish densities than more exposed habitats. Our data trends somewhat supported this concept, but open habitats did not clearly contain lower fish densities than other habitats as in most other studies. The snorkelling technique, distance sampling, was able to identify differences in fish use among the same broad habitat types in lake systems (Pratt 2004). This suggests that the inability of the underwater video to do likewise is a limitation of the camera or our data collection protocol, and not a function of fish distribution within these systems. Our failure to distinguish differences in fish habitat use among habitats is likely a combination of the limited field of view provided by the camera, a short filming duration and the freeze frame sub-sampling procedure. As a result, filming data were highly variable, with many frames having zero observations. Similar problems were documented in other underwater video investigations (Posey & Ambrose 1994, Davis et al. 1997). Re-analysis using the total number of fish observed in the five minute trial, as opposed to using the weighted averages provided by the sub-sampling procedure, reduced variability by reducing the number of zero observations, but we were still unable to separate habitat types. Two suggestions for improving the ability to discriminate among habitats is to increase the number of filming sites while concurrently increasing the length of filming at each site, which should help reduce both within- and among-site variability. Alternatively, studies that have successfully differentiated among habitats using underwater video have used linear transects (Lawson & Rose 1999, Auster et al. 2003). Changing from a stationary, fixed station method to a mobile transect approach would also increase the number of fish observed. Any combination of longer filming duration, more sites or changing to a mobile transect method would likely address the data deficiencies that limited our ability to make site-level inferences about fish habitat use. The second, more powerful distance sampling methodology that was incorporated after the first year of camera use, was able to detect changes in the distribution of fishes in Gibb Pit.

In addition to habitat use data, we believed that our underwater video data could provide behavioural information that might allow inferences about habitat quality, including how long fishes remain in a habitat patch and whether fish are feeding in a given habitat type. Researchers have used fish movement data from underwater video to document activity costs for bioenergetic modeling (Boisclair 1992), and a number of techniques, including tagging, telemetry, stable isotope and microchemistry analysis, have been used to investigate broad-scale movement among habitats (e.g. Robertson & Duke 1990, Northcote et al. 1992, Morinville & Rasmussen 2003), but data on how long fish remain in micro-habitat patches is absent. Likewise, studies using underwater video to quantify predator-prey interactions and fish feeding behaviour are also rare (but see Collins 1989, Collins & Hinch 1993). While we detected no differences in residency time and only one lake showed feeding differences among habitats, it was nevertheless surprising that vegetated areas had the similar or lower mean residency and feeding attempts than open habitat. Vegetated areas consistently contain high fish densities, and aquatic macrophytes are hypothesized to attract fish because they provide cover from potential predators and contain colonization sites for invertebrates, resulting in high food availability (Savino & Stein 1982, Rozas & Odum 1988). We are uncertain as to why the vegetated sites in this study would be functionally different than vegetation in other aquatic systems.

The question of whether habitat additions increase fish production, or simply redistribute already available individuals, is a complex yet vital problem for fisheries managers. Our underwater video protocol was successful at assessing site-level fish habitat use responses to habitat manipulations, particularly in context of the whole-system response. In the aggregate systems where habitat was added, we documented a significant shift in fish habitat use towards the addition sites and away from control sites, but no corresponding increase in system-wide fish biomass or production. This outcome lends credence to the hypothesis that artificial structures may simply affect fish distribution by attracting and concentrating individuals that ultimately would have survived and grown at similar rates in alternate habitats (Bohnsack 1989). There is even concern that artificial habitats may harm fish populations by making them more vulnerable to exploitation (Bohnsack 1989). The abandoned aggregate systems were limited in physical structure prior to the habitat additions, so the utilization of the new sites was not unexpected given fishes propensity for favouring structurally complex habitats (e.g. Werner et al. 1977, Weaver et al. 1997).

Fish in Bayside Quarry tended to inhabit more structurally complex habitats, as expected. Structurally complex habitats provide cover for young fish and more surface area for food production. Preferences for vegetated and rocky substrate areas were not as strong as many other waterbodies for some species, such as bluntnose minnow, however, which is likely attributable to the absence of an obligate piscivore in the quarry.

7 CONCLUSION

There is an assumption by resource managers that habitat quality is positively and directly related to productive capacity. An alternate theory is that more general characteristics such as nutrient supply, climate, and lake morphometry are the main determinants of productive capacity, with habitat quality perhaps only influencing the distribution of biomass among the species present. One outcome from this study has been to establish that the pits and quarries already had standing stocks at the high end of the natural lake range for similar location, area, and climate, even without the habitat diversity one would expect in a natural setting. The systems also support, in general, a greater diversity of species than natural systems of similar size.

Fish communities in the habitat addition systems do seem to be undergoing change, and, in terms of total fish biomass, these changes range from neutral to positive. There is as yet no indication, however, that positive changes to total biomass of the fish communities will be sustained. There is evidence that the habitat additions have changed the distribution of fish within the systems, both in terms of the allocation of biomass among species (Bayside Quarry, Van Limbeek Pit), and in the physical distribution of fishes within the systems (Bayside Quarry, Gibb Pit). Changes to the fish communities in the habitat addition systems do not seem to be driven by changes to water chemistry or plankton or benthic invertebrate communities.

The Management of Abandoned Aggregate Properties Program of APAO entered into this study to determine if structural enhancement of abandoned pond systems would improve the ecology and productivity of the systems. In advance of the study, very little was known about how well these systems function as an aquatic ecosystem, and what level of effort should be placed in system rehabilitation, or system structuring prior to abandonment and filling. We have demonstrated that these systems, abandoned without consideration to structural enhancement, have developed into highly productive and functioning aquatic ecosystems. The ambiguity of the ultimate result from the habitat additions remains, but it is clear that habitat additions did not significantly increase system productivity in the short term.

To obtain a more definitive picture of the effect of habitat additions, from both a scientific perspective and for MAAP to be able to clearly recommended standard decommissioning procedures for aquatic systems, the study would need to be extended. Reasons for extending the study include provision of suitable time for full generational responses in all species in all systems, and for the systems to reach their ‘new’ states of dynamic equilibrium. Adding years is also likely to reduce post manipulation variability in the data, thus increasing likelihood of detecting statistically-significant changes. Presuming that changes to the fish communities are the main focus for the study, sampling could be reduced to the usual level of fishing effort along with a simplified suite of water chemistry analyses. Should large scale, and unexpected, changes become apparent, then components of the original methodologies can be added back in as needed.

The main reason why continuation of the study might not be beneficial is the loss of the control system, which could mean that it is unlikely that causality for changes to fish communities will be defensibly attributable to the habitat manipulations. While the ability to detect changes should be enhanced, the inability to conclusively rule out external environmental factors as contributing to that change limits the interpretation of the results. One potential solution to this concern would be to use data from natural lake systems, sampled in a similar manner over the same time period, as the control for the aggregate ponds. Fisheries and Oceans Canada has such data available, although from a different region in Ontario, and would be willing to discuss its use in further data analysis.

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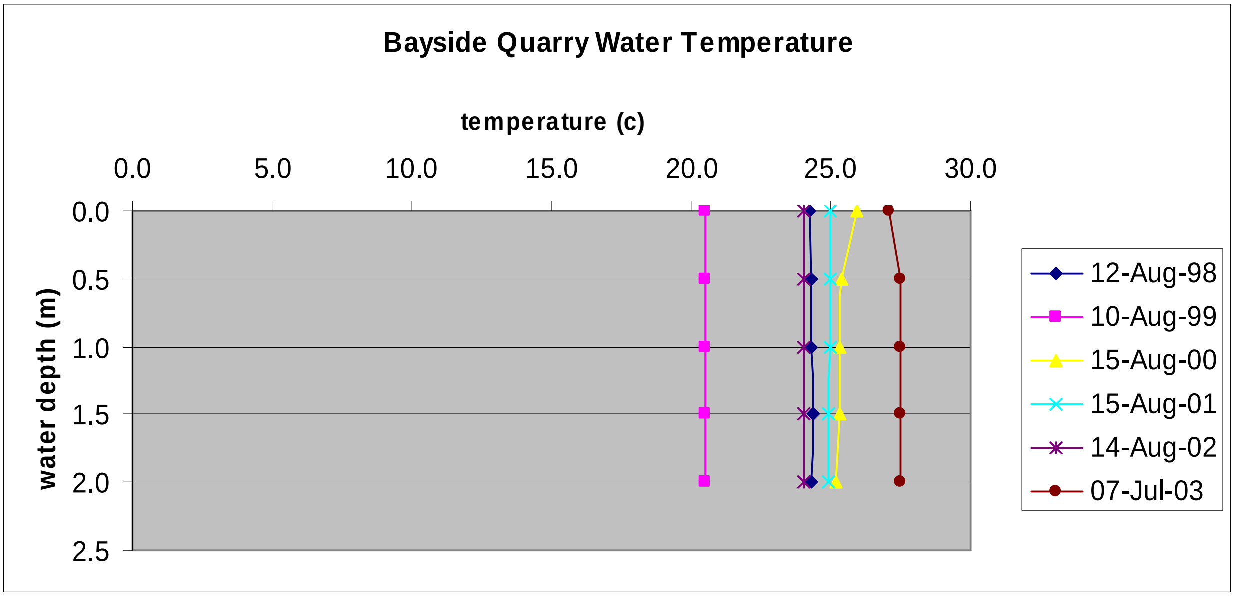
9 APPENDICES

9.1 APPENDIX A - Depth contour maps of Bayside Quarry, Van Limbeek Pit, and Gibb Pit.

9.2 APPENDIX B - Temperature and dissolved oxygen profiles



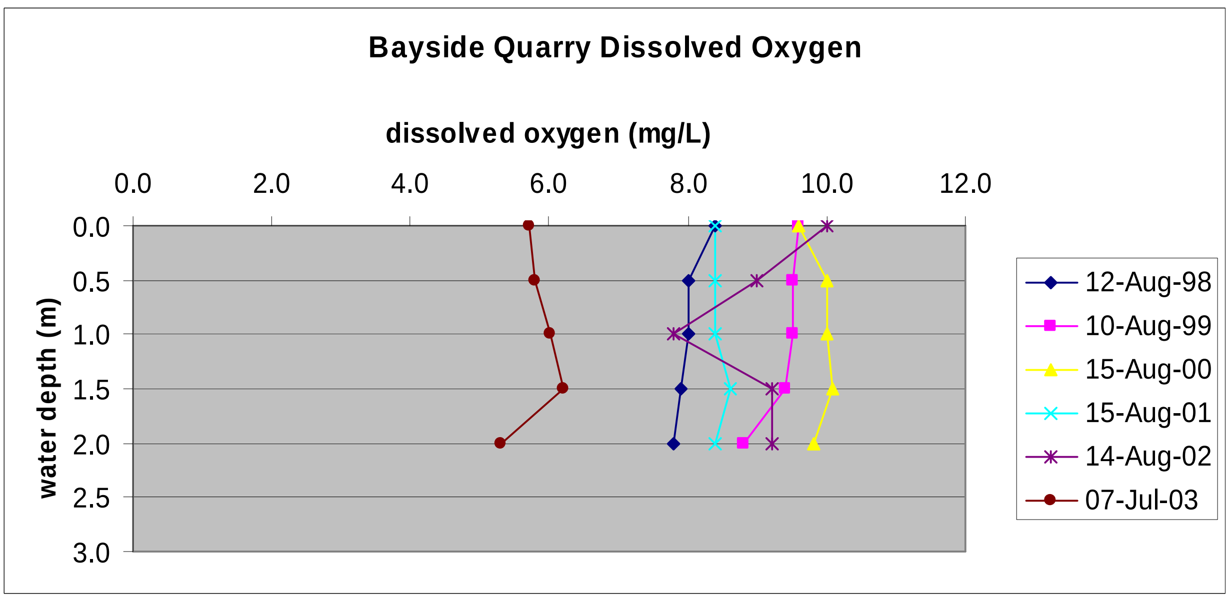
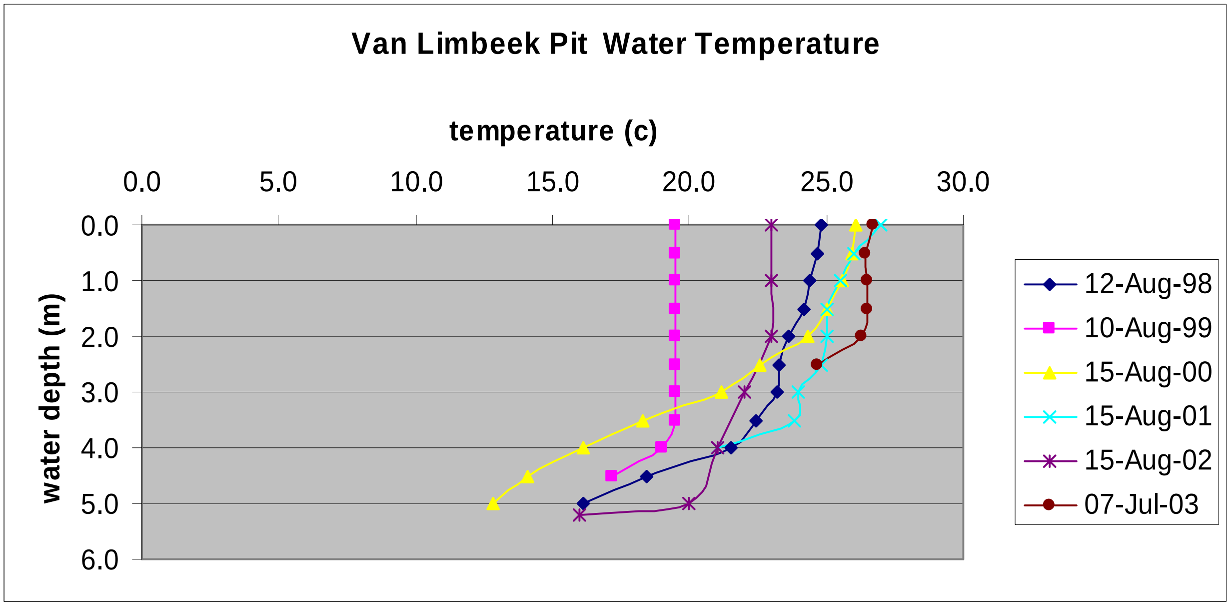


Figure B.1. Temperature and dissolved oxygen profiles from August 1998 through 2003, Bayside Quarry.



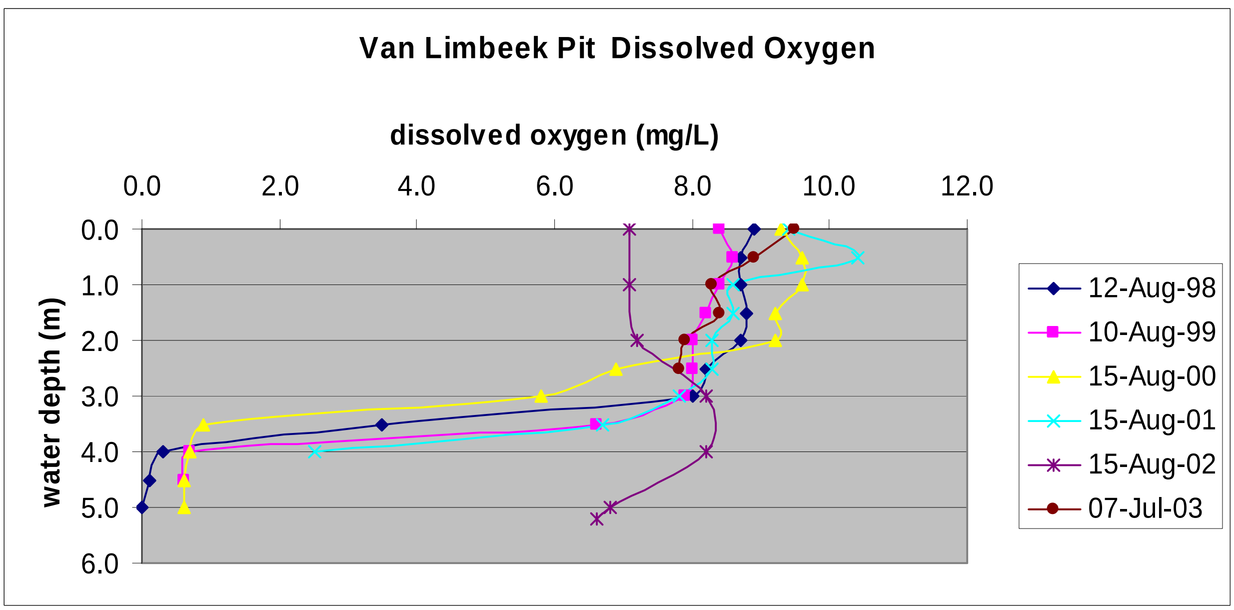
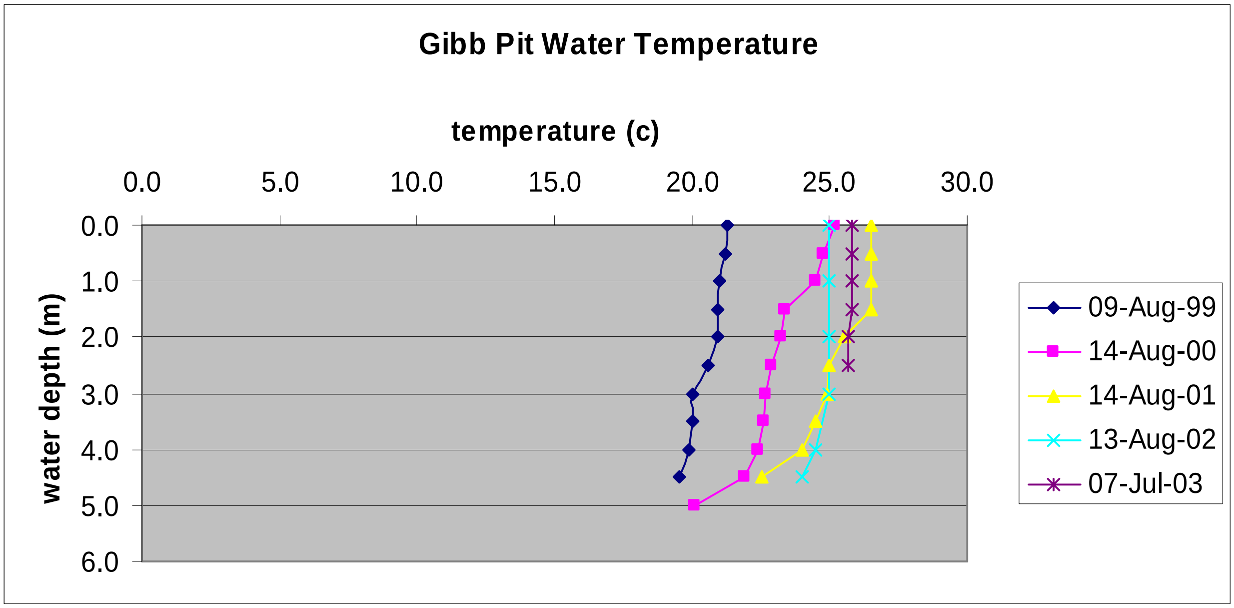


Figure B.2. Temperature and dissolved oxygen profiles from August 1998 through 2003, Van Limbeek Pit.



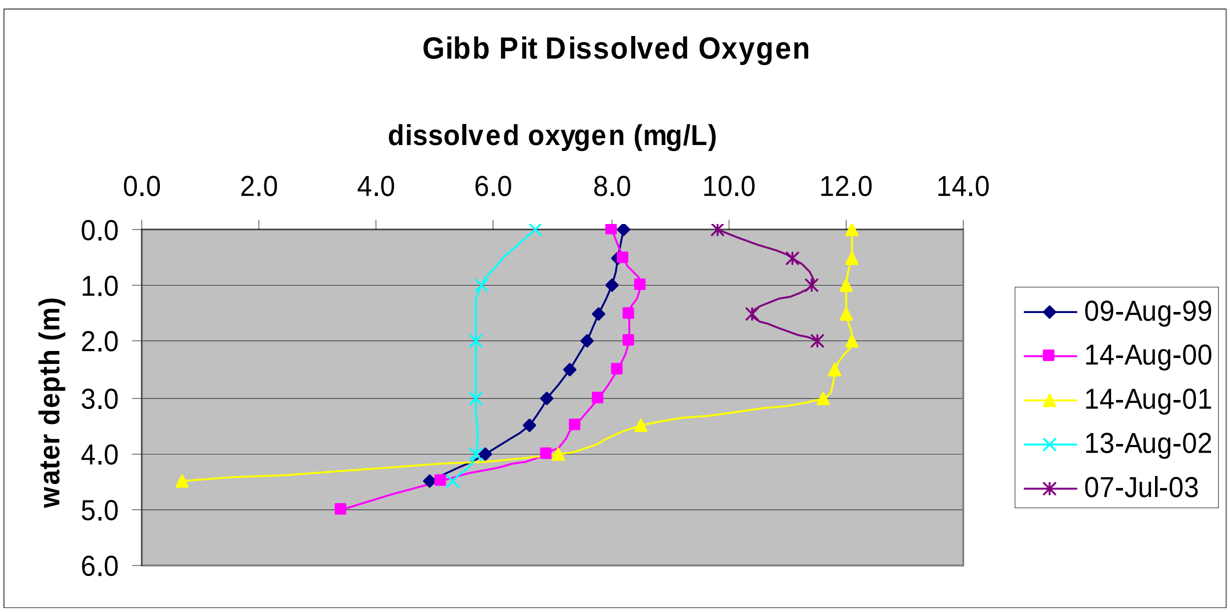
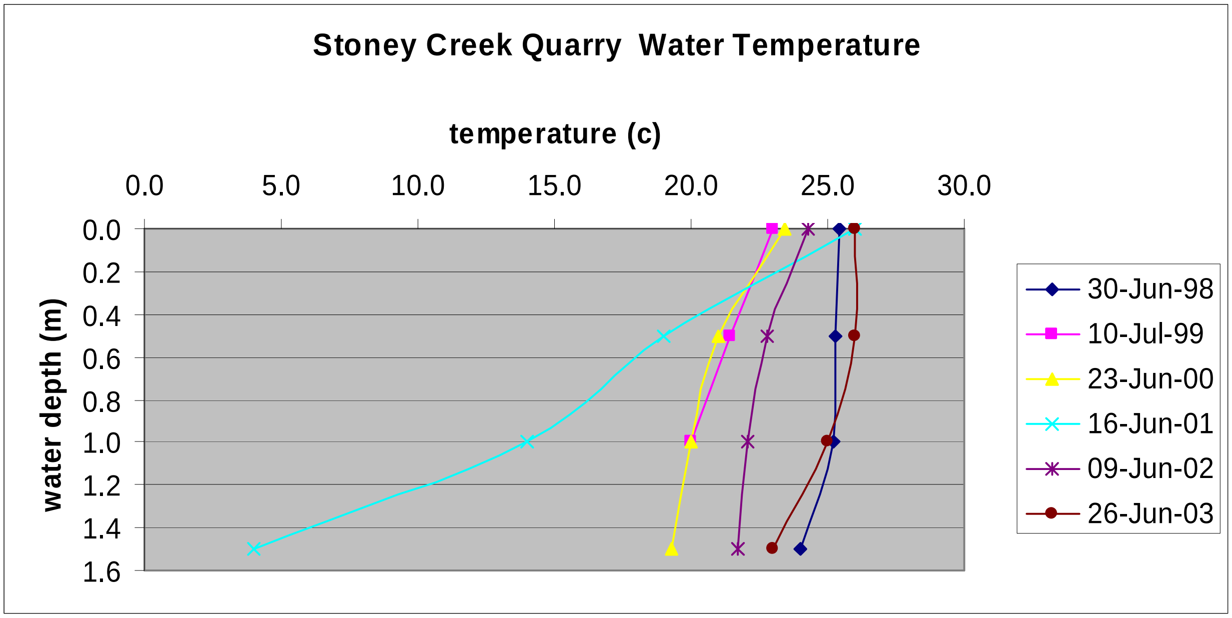


Figure B.3. Temperature and dissolved oxygen profiles from August 1999 through 2003, Gibb Pit.



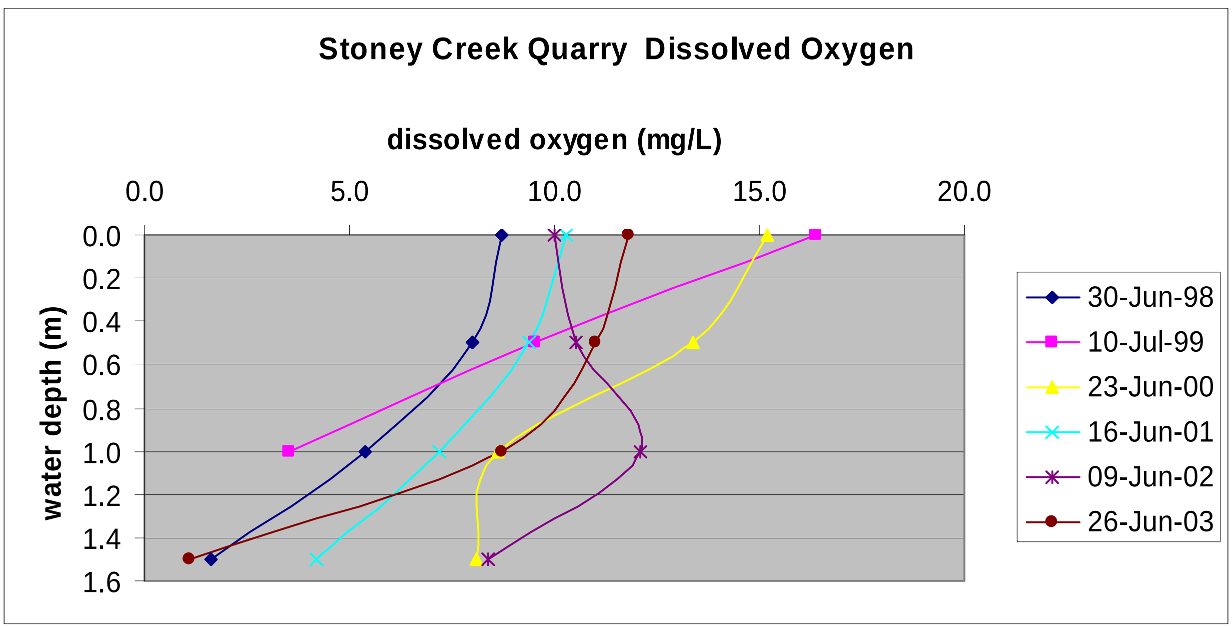


Figure B.4. Temperature and dissolved oxygen profiles from June or July sampling, 1998 through 2003, Stoney Creek Quarry.

9.3 APPENDIX C - System of taxonomic classification used in describing the benthic invertebrate community in the pit and quarry systems

Scientific Name	Common Name	Taxonomic Classification
Coelenterates	Hydroids	Phylum Coelenterata
Turbellarians	Flatworms	Phylum Platyhelminthes, Class Turbellaria
Nematodes	Roundworms	Phylum Nematoda
Oligochaetes	Aquatic earthworms	Phylum Annelida, Class Oligochaeta
Hirundineans	Leeches	Phylum Annelida, Class Hirudinea
Isopods	Aquatic sow bugs	Phylum Arthropoda, Class Crustacea,Order Isopoda
Amphipods	Scuds and swimmers	Phylum Arthropoda, Class Crustacea, Order Amphipoda
Arachnids	Spiders, mites, and ticks	Phylum Arthropoda, Class Arachnida
Collembolans	Springtails	Phylum Arthropoda, Class Insecta, Order Collembola
Ephemeropterans	Mayflies	Phylum Arthropoda, Class Insecta, Order Ephemeroptera
Anisopterans	Dragonfly nymphs	Phylum Arthropoda, Class Insecta, Order Odonata, Suborder Anisoptera
Zygopterans	Damselfly nymphs	Phylum Arthropoda, Class Insecta, Order Odonata, Suborder Zygoptera
Plecopterans	Stoneflies	Phylum Arthropoda, Class Insecta, Order Plecoptera
Hemipterans	True bugs	Phylum Arthropoda, Class Insecta, Order Hemiptera
Megalopterans	Alderflies, dobsonflies, and fishflies	Phylum Arthropoda, Class Insecta, Order Megaloptera
Trichopterans	Caddisflies	Phylum Arthropoda, Class Insecta, Order Trichoptera
Lepidopterans	Aquatic caterpillars	Phylum Arthropoda, Class Insecta, Order Lepidoptera
Coleopterans	Beetles	Phylum Arthropoda, Class Insecta, Order Coleoptera
Hymenopterans	Ants, bees, wasps, sawflies	Phylum Arthropoda, Class Insecta, Order Hymenoptera
Dipterans	True flies	Phylum Arthropoda, Class Insecta, Order Diptera
Gastropods	Snails and limpets	Phylum Mollusca, Class Gastropoda

9.4 APPENDIX D - Scientific names of fish species captured in the pit and quarry systems

System & Common Name		Scientific name (Genus and species)
Bayside		
Rock bass		Ambloplites rupestris
Bluntnose minnow		Pimephales notatus
Yellow perch		Perca flavescens
Brown bullhead		Ameiurus nebulosus
Banded killifish		Fundulus diaphanus
Pumpkinseed		Lepomis gibbosus
Bluegill		Lepomis macrochirus
Fallfish		Semotilus corporalis
Longnose gar		Lepisosteus osseus
Van Limbeek		
Pumpkinseed		Lepomis gibbosus
Blacknose shiner		Notropis heterolepis
Banded killifish		Fundulus diaphanus
Golden shiner		Notemigonus crysoleucas
Northern pike		Esox lucius
Brown bullhead		Ameiurus nebulosus
Rock bass		Ambloplites rupestris
Fathead minnow		Pimephales promelas
Northern redbelly dace		Phoxinus eos
Yellow perch		Perca flavescens
Emerald shiner		Notropis atherinoides
Brook stickleback		Culaea inconstans
Gibb		
Largemouth bass		Micropterus salmoides
Yellow perch		Perca flavescens
White sucker		Catostomus commersoni
Rock bass		Ambloplites rupestris
Stoney Creek		
Pumpkinseed		Lepomis gibbosus
Green sunfish		Lepomis cyanellus
Brown bullhead		Ameiurus nebulosus
Fathead minnow		Pimephales promelas
Goldfish		Carassius auratus
Yellow perch		Perca flavescens
Banded killifish		Fundulus diaphanus
Golden shiner		Notemigonus crysoleucas
Blacknose shiner		Notropis heterolepis
Central mudminnow		Umbra limi
White sucker		Catostomus commersoni
Iowa Darter		Etheostoma exile
Brook stickleback		Culaea inconstans
Channel catfish		Ictalurus punctatus

9.5 APPENDIX E – Catch per Unit Effort (CUE) by system, year, species and gear type.

Table E.1. **Bayside Quarry - 1998 through 2003 - Catch per Unit Effort Summary**

Mean Catch per Unit Effort **June sampling periods only**

Fish Species	Gill net						Trap net						Minnow trap						Hoop net				
	1998	1999	2000	2001	2002	2003	1998	1999	2000	2001	2002	2003	1998	1999	2000	2001	2002	2003	1999	2000	2001	2002	2003
Rock bass	0.85	0.52	0.30	1.09	0.18	0.11	36.50	2.00	25.50	65.00	24.00	9.33	2.69	1.43	1.29	1.02	2.16	2.74	31.67	25.00	9.25	7.44	1.50
Yellow perch	1.48	0.60	0.19	0.33	0.18	0.14	5.50		8.50	5.00	4.20	4.67	0.20	0.10	0.25	0.77	0.21	0.39	2.00			0.22	1.67
Bluntnose minnow													0.78	3.43	4.23	9.07	5.97	1.13		0.13	0.25		10.17
Banded killifish													0.31	0.23	0.10	0.11	0.03	0.01		0.13			0.67
Spottail shiner															0.56					0.25			
Brown bullhead	0.11				0.12		1.25		3.75	1.25	0.80	4.00	0.02			0.02			0.33	0.25			
Sunfish *						0.28	0.50		0.50	5.50	3.60	126.33					0.28	1.14		0.63		0.11	0.25
Longnose gar		0.08		0.22			0.50				0.20	0.17											
Fallfish					0.06																		
Total effort **	283	749	616	276	487	1069	4	3	4	4	5	6	55	30	48	44	58	69	3	8	8	9	12

* Includes pumpkinseed and bluegill, and hybrids between these two sunfish species

** Gill net catches reported as mean catch per 30 minutes of netting time, effort is reported as total minutes nets were fished

** Catches for all other gears reported per overnight set, effort is the total number of overnight sets

Table E.2. **Van Limbeek Pit - 1998 through 2003 - Catch per Unit Effort Summary**

							Mean Catch per Unit Effort						**June sampling periods only**										
Species	**Gill net**						**Trap net**						**Minnow trap**						**Hoop net**				
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**1999**	**2000**	**2001**	**2002**	**2003**
Pumpkinseed	0.22	0.07	0.05	0.23	0.13	0.04		0.25		0.17	9.17	0.60	4.72	3.79	5.93	10.13	10.33	6.69	60.13	29.00	68.55	22.70	3.00
Blacknose shiner													0.36	0.48	1.20	0.06	0.09		162.38	29.00	45.36	2.80	1.50
Banded killifish															0.27	0.01	0.10	0.10	8.13	4.55	4.27	0.10	0.70
Golden shiner	0.04	0.07		0.08	0.14	0.11			0.17		1.67	43.20	1.17	2.73	50.02	9.28	6.93	0.60	11.25	176.64	6.18	9.10	15.30
Northern pike	0.56	0.68	0.41	0.45	0.48	0.59	2.50	2.25	2.50	1.00	1.17	1.60									0.09		
Brown bullhead	0.26	0.07	0.14	0.43	0.43	0.23	0.25	11.25	6.67	2.83	7.00	3.80							0.38	1.27	0.64	0.50	0.30
Rock bass	0.07	0.14	0.08	0.19	0.09		1.75	2.25	0.83	0.50	10.83				0.35	3.18	2.34	0.02	0.25	1.27	3.36	16.50	
Fathead minnow													5.00	6.35	2.97	0.58	0.09	0.08	3.25	3.73	0.27	0.10	
Yellow perch			0.02	0.02	0.07	0.02				0.17	0.33	0.20			0.27	0.10	0.40			0.82	0.27	1.20	
Brook Stickleback															0.05								
Nor. Redbelly Dace															0.07					0.45			
Total effort *	810	444	1909	1549	1673	1578	4	4	6	6	6	5	36	48	60	71	58	62	8	11	11	10	10

* Gill net catches reported as mean catch per 30 minutes of netting time, effort is reported as total minutes nets were fished
* Catches for all other gears reported per overnight set, effort is the total number of overnight sets

Table E.3. **Gibb Pit - 1999 through 2003 - Catch per Unit Effort Summary**

June sampling periods only

Mean Catch per Unit Effort

Species	**Gill net**					**Trap net**					**Minnow trap**					**Hoop net**					**Angling**				
	1999	**2000**	**2001**	**2002**	**2003**	**1999**	**2000**	**2001**	**2002**	**2003**	**1999**	**2000**	**2001**	**2002**	**2003**	**1999**	**2000**	**2001**	**2002**	**2003**	**1999**	**2000**	**2001**	**2002**	**2003**
Yellow perch	1.77	2.10	2.97	8.08	1.33	7.60	4.80	1.80	1.50	1.50	0.27	0.28	0.32	0.42	0.65	0.40	1.08		0.67	0.80	0.42	1.90	4.74	1.67	2.57
Largemouth bass	0.12	0.13	0.10	0.07	0.15	0.60	0.20	0.80	0.17	0.50											2.63	5.64	6.41	5.33	5.69
White sucker	0.24	0.29	0.21	0.72	0.38	0.20		0.40	0.17	0.50									0.11	0.10					
Rock bass						0.20			0.17																
Total effort *	1016	1786	576	873	1018	5	5	5	6	6	62	72	60	65	60	10	10	12	9	10	9.5	15.3	17.3	18.0	18.3

* Gill net catches reported as mean catch per 30 minutes of netting time, effort is reported as total minutes nets were fished

* Angling catches reported as catch per angler-hour, effort is reported as total angler-hours

* Catches for all other gears reported per overnight set, effort is the total number of overnight sets

Table E.4. **Stoney Creek Quarry - 1998 through 2003 - Catch per Unit Effort Summary**

Species	Mean Catch per Unit Effort						June sampling periods only										
	Trap net						Minnow trap						Hoop net				
	1998	1999	2000	2001	2002	2003	1998	1999	2000	2001	2002	2003	1999	2000	2001	2002	2003
Sunfish	82.60	77.60	365.33	11.17	29.67	90.67	48.76	50.99	32.36	0.70	18.15	5.29	126.20	10.67	1.00	20.80	3.09
Brown bullhead	9.20	13.00	7.00	42.00	19.33	130.83	0.96	0.44	0.09	0.17	0.03		0.30	0.58	15.73	1.50	8.82
Fathead minnow							0.20	0.65	0.14	8.12	23.05	0.03	18.20	2.17	6.36	15.80	0.18
Golden shiner												0.01			0.09	0.20	
Blacknose shiner							0.13										
Yellow perch	1.20	0.60	0.17														
Goldfish		0.20	1.00			1.00				2.60	0.96	0.19			0.18	2.10	0.09
Central mudminnow							0.02			0.02	0.02	0.01					
Iowa darter										0.04	0.19					0.10	
Brook stickleback										0.02	0.15	0.01					
Banded killifish										0.03					0.27	0.30	
White sucker	0.20																
Channel catfish						0.33											
Total effort *	5	5	6	6	6	6	110	88	116	109	110	111	12	12	11	10	11

* Catches for all gears reported per overnight set, effort is the total number of overnight sets

9.6 APPENDIX F - Expenditure Breakdown: February 1, 2003 to January 31, 2004

ITEM	COST
Salary support (note 1)	25000.00
K. Keizer – ageing of fish scales (pending)	1312.85
T. Honsberger – ageing of fin rays	486.00
Travel – Sudbury conference – K. Smokorowski	258.38
Travel – June sampling – W. Gardner	2100.72
Travel – June sampling – D. Geiling	2285.08
Travel – June sampling – D. Bauman	1307.69
Travel – June sampling – L. O'Connor	1292.17
Travel – July, underwater visual surveys, install art. substrates – T. Pratt	870.92
Travel – July, underwater visual surveys, install art. substrates – L. Voigt	1111.94
Travel – August art. substrate retrieval, L. Voigt	340.50
Travel – August art. substrate retrieval, D. Bauman	345.48
Reagents, filters, glassware, field gear, net repair, weigh scales, etc. (est.)	300.00
Total, February 1, 2003 to January 31, 2004	37,011.73

Notes:

1. The cost shown is a conservative estimate of the salaries paid to DFO term, contract, and intern staff for their time spent working on this program. This includes data compilation, analysis, and writing (D. Geiling), and field and laboratory technical assistance (D. Geiling, L. Voigt, L. O'Connor, N. Van Nie, B. McNevin, D. Bauman). No salary amounts are included for DFO full time staff that are participating in this program, including Dr. K. Smokorowski (program direction, supervision, analysis & writing), Dr. T. Pratt (underwater visual surveys), W. Gardner (field technical assistance) and M. Thibodeau (laboratory assistance).

Gas, oil, and maintenance charges for DFO trucks used for this program have not been included**.**