Natural development of biological communities in water-filled gravel pits and quarries in Southern Ontario

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Abstract

Extraction of aggregates (sand and gravel, limestone) below the water table results in the creation of pit and quarry ponds. Under the Aggregate Resources Act, rehabilitation plans are required to obtain an aggregate extraction license. The aquatic landscape is difficult to address in the rehabilitation plan, as minimal scientific data exists regarding pit and quarry pond productivity and rates of natural succession. These sites frequently gain the attention of the surrounding community with controversy over the proper stewardship of these areas and end-use plans.

Water chemistry and productivity of the ponds depend on surrounding land use, geology and other watershed activities. Similarly, these sites should be considered in the overall watershed management as they can influence the nearby water systems and groundwater flows.

During this study we surveyed 12 pits and 3 quarries. Examples will be shown of pits and quarries in Southern Ontario at various stages of rehabilitation and pond naturalization. Some of these sites include intentional measures to provide fish habitat.

Throughout this study we examined: (i) the morphometric (e.g. bathymetry), chemical (e.g. pH, dissolved oxygen, alkalinity), physical (e.g. total suspended solids, temperature) and biological features (e.g. primary production, zooplankton, benthic invertebrates) that determine the potential of aggregate ponds for fish habitat; and (ii) the rates of succession that occur in early development stages of pit and quarry ponds.

Field studies are now complete and results have shown that macroinvertebrates and macrophytes begin to colonize these ponds rapidly even while extraction is ongoing. Observations indicate that these ponds can provide a productive biological environment, which could be used for a variety of after uses such as sport fisheries opportunities, or a conservation area, to fit into the surrounding land use. This also opens opportunities to match end-use plans with the wants and needs of the community, with due consideration of watershed management concerns.

Introduction

Intent to rehabilitate aggregate lands is required in order to obtain an aggregate extraction license under the Aggregate Resources Act (ARA) (Province of Ontario, 1995; Government of Ontario, 1997). Extraction of aggregates or limestone below the water table creates a pit or quarry that will fill with water from run-off or groundwater sources. When this occurs the “aggregate ponds” are generally left to colonize naturally. The aggregate ponds are of two distinct types, “quarry ponds” and “pit ponds”, depending on the nature of materials and extraction activities.

While there are general guidelines for rehabilitation of lands and considerable information on general rehabilitation techniques, this information largely deals with the terrestrial components of aggregate sites. Very little information is available regarding the morphometry, chemistry and biology of aggregate ponds. This study was undertaken to establish baseline data and gain a better understanding of aggregate pond productivity.

It was predicted that pond morphometry and age directly affect the productivity of quarry and pit ponds. The primary objectives of this study are to determine the effect of age (i.e. 0-25 years) and size (i.e. volume which integrates surface area and depth) on development of aquatic communities. A wide range of habitat features were measured including the morphometric (e.g. bathymetry), chemical (e.g. pH, dissolved oxygen, alkalinity), physical (e.g. total suspended solids, temperature) and biological features (e.g. primary production) of these ponds. These measurements were related to pond age and volume to determine rate of natural succession and potential of these ponds as fish habitat.

Methodology

Studies were conducted on twelve pits and three quarries in Southern Ontario during spring/summer of 2001 and spring 2002.

Site Characterization

Bathymetry was measured for each pond in order to determine surface area, mean depth and volume. Aerial photographs were used to determine surface area (A_0) and shape of ponds. Shoreline length (L) and development, D_L (= $L/2\sqrt{\pi A_o}$) were also calculated from this data. Volume (V) was determined from the bathymetric data collected and used with surface area estimates to calculate mean depth (i.e. mean depth = V/A_0).

The pH was determined for each pond monthly (May to September), using a WTW Multiline water analyzer. Hardness and alkalinity variables were also measured monthly in each pond using Hach kits.

Physical Water Parameters

Secchi depth was measured biweekly for each pond. Thermal depth profiles and summer dissolved oxygen depth profiles were determined for each pond using a WTW Multiline water analyzer with a 30 m cable. The dissolved oxygen was measured at 1-m intervals from the pond bottom to the water surface.

Chemical Water Parameters

Composite water samples were collected for total nitrogen from each of the ponds in summer 2001 and spring total phosphorous samples were collected in 2002. Samples were sent to Geosciences Laboratories for analysis. All composite water samples (1L) were collected using clear plastic tubing, bottled and placed in coolers to be kept cold and dark upon return from the field.

Biological Parameters

Composite water samples were collected for analysis of Chlorophyll *a* during spring 2002. The water for these samples was collected from the top 3m of the water column only. Sample bottles were covered in tinfoil, to ensure the sample was not exposed to light, and then transported back to the University of Guelph as described above. In the lab, samples were filtered using a Millipore Filtration apparatus (within 24 hours) using GF/C glass fibre filter papers. The filtered samples were folded, wrapped in tinfoil and frozen. Filter papers were macerated in 8ml of acetone to extract the chlorophyll then transferred into glass vials and read using a Turner Fluorometer.

Macrophyte samples were collected to estimate biomass and diversity. All macrophyte growth above the substrate surface was clipped from within each of five 1-m^2 quadrats in each pond in July and again in August for a total of ten samples per pond. The quadrats were placed randomly within 1 m of water. All plants were identified then dried at 60 °C and weighed for estimates of species' biomass per square meter. Plant identification was confirmed at the University of Guelph herbarium.

Zooplankton samples were collected to estimate abundance and species composition. Three replicates were collected using a 20-cm diameter Wisconsin net pulled vertically through the water column at the deepest site in each pond at monthly intervals from June to August for a total of nine samples per pond. The plankton were identified to at least genus (using Pennak 1989) and then enumerated. Abundance is expressed as number per cubic meter for each depth. Species richness (number of species) was calculated for each monthly sample for each pond.

Artificial substrates were used to estimate abundance and species richness of benthic macroinvertebrate and periphyton growth. Each set of artificial substrates consisted of a stack of four vinyl plates on a "T" shaped metal post that is inserted in the lake bottom of the littoral zone (Figure 1a) or suspended 0.5m above the substrate in the profundal zone using a float and anchor (Figure 1b). For the purpose of this study the littoral zone was the area of the pond around the shoreline where emergent and floating plants were dominant. The profundal area was defined as the depths at which too little light is available for plant growth[1].

Each set for the littoral zone consisted of 2 components. The benthic macroinvertebrate colonization component consisted of 4 horizontally oriented rectangular vinyl plates (each 10 cm x 15 cm, total surface area of 4 plates = 1200 cm^2) that are spaced along a single, central vertical post that hangs off of one end of the "T" (dendiplate modification). The second component consisted of a single 10 cm by 15 cm plexiglass plate suspended vertically from the opposite end of the "T" for periphyton colonization. Results of the periphyton portion are not discussed here, however, they can be found in Guenther, 2003.

A total of 6 artificial substrates were installed in the littoral zone and 6 artificial substrates (lacking periphyton component) in the profundal zone of each pond to assess relative benthic macroinvertebrate diversity, biomass and abundance and relative periphyton biomass. Half of the samples (3) were removed from each of the littoral and profundal areas were removed after six weeks. The remaining samples were left in the ponds and removed after an additional six weeks.

Benthic invertebrates were identified and enumerated to at least genus level for each plate using appropriate taxonomic keys. Abundance, species richness (number of taxa) and the species diversity index ($n_i/N \, Log_{10} \, n_i/N$) (Wilhm and Doris, 1968) were calculated for each sample for each pond. The species diversity index incorporates the species present and their relative abundance.

[1] Where a true profundal zone was not present, the area of maximum depth was used.

Results and Discussion

Site Characterization

Ponds ranged in age from 0 to 25 years. Extraction was still ongoing in three ponds. These ponds were considered to be age “0”. There was a wide range of pit sizes and depths as summarized in Table 1.

Table 1. Range of Physical Characteristics in 15 aggregate ponds in Southern Ontario, 2001/2002

Parameter	Range
Age (years)	0 - 25+
Surface Area (m^2)	3,488 - 225,058
Volume (m3)	7,980 - 2,050,305
Maximum Depth (m)	2.0 - 21.0
Mean Depth (m)	0.6 - 9.2
Perimeter (m)	283 - 6137
Shoreline Development	1.1 - 3.6
PH	8.0 - 8.7
Conductivity (uS)	298 - 1236
Ca Hardness (mg/$CaCO_3$)	120 - 280
Mg Hardness (mg/$CaCO_3$)	80 - 420
Total Hardness (mg/$CaCO_3$)	200 - 680
Alkalinity (mg/L)	100 - 220

Physical Parameters

Mean Secchi depth values ranged from 1.4m to 7.5m (Table 2) and no discernable relationship could be found between age or volume and Secchi depth. Ranges are provided in Table 2 for the determination of trophic status as provided by Mackie (2001). Summer indicated mesotrophic conditions with only two exceptions. The two oldest ponds had Secchi depths typical of oligotrophic water bodies. Three ponds that have ongoing extraction had shallow (near eutrophic) Secchi depths but this is most likely due to disturbance of sediments and re-suspension of particulate matter.

The majority of the ponds demonstrated clinograde summer oxygen profiles and only the two largest ponds demonstrated positive heterograde profiles. These were the only ponds that had definitive hypolimnions. Most of the ponds are less than 10m in maximum depth.

Chemical Parameters

Detailed water chemistry analysis was conducted for total nitrogen, total phosphorous and metals. In general the phosphorous values ranged from <0.005 mg/L to 0.114 mg/L and nitrogen values ranged from 0.105 mg/L to 0.755 mg/L. The metals analysis yielded generally low metal levels which did not exceed Provincial Water Quality Objectives (PWQO). Detailed water chemistry is provided in Guenther 2003.

Table 2 Comparison of mean Secchi depth and average summer chlorophyll *a* levels of 15 aggregate ponds in Southern Ontario.

	Mean Summer Secchi Depth (m)	Average Summer Chlorophyll *a* (ug/L)
Oligotrophic	>5 m	<2 ug/L
Mesotrophic	2-5 m	2-5 ug/L
Eutrophic	<2 m	>5 ug/L
D1	4.3	2.20
D2†	2.1	0.28
D3†	2.4	0.36
D4*	Bottom (2m)	4.04
BC1*	2.6	-
BC2	1.5	-
BC3	2.3	0.64
BC4	3	0.35
BC5	4.2	-
BC6	3	2.01
BC7†	3	2.44
N1*	bottom (5-6m)	0.24
N2	3.81	2.32
O1	7.5	2.40
O2	1.4	2.27

* quarry pond

† ongoing extraction

Biological Parameters

Chlorophyll *a* levels did not illustrate any clear trends with age or volume. Simple linear regression did not yield any significant relationships (P>0.05). Chlorophyll *a* concentrations ranged from 0.28 to 4.04 µg/L. Results (average of two replicates) are listed in Table 2.

The macrophyte communities usually consisted of low species richness. The most prominent species found were *Chara*, *Typha augustifolia* and *Myriophyllum spicatum*. These species were the most commonly occurring and the most abundant. *Chara*, was the most common macrophyte and is known to be found in lentic systems as an enriched, hard water indicator. This plant was observed in all 15 of the ponds. Myriophyllum was found in six sites and *Typha*, known for its ability to take up nutrients, particularly phosphorous, was found in five of the sites.

Regression analysis showed that macrophyte biomass collected in August 2001 had a significant positive relationship (P<0.05) with age and volume. Macrophyte species richness had a significant positive relationship with pond age but not with volume. In general, lower species richness was found in the more disturbed sites (extraction ongoing or nearby) while the highest species richness was found at the oldest pond and the most actively rehabilitated ponds, respectively.

The number of zooplankton taxa was not related to pond age or volume. Despite ongoing extraction, the youngest ponds had 3 to 10 taxa which was comparable to the older ponds (>10 yrs) which had 5 to 10 taxa. In general, cladocerans dominated the zooplankton communities while rotifers were uncommon.

Zooplankton density (number of organisms/m^3) showed large variation between ponds and between sampling events. The samples yielded relatively low biomass in the younger, larger ponds while the smaller, older ponds were considerably more productive at this trophic level.

Ignoring volume and age, the three quarry ponds had low zooplankton density results during all three sampling events. They also demonstrated a general decline in density as the season progressed. In other words, June density results were higher than August. Results did not yield any significant relationships with age or volume based on linear regression analysis.

Up to 30 taxa of benthic macroinvertebrates were identified in the littoral zone of three age

"0" ponds (sites D2, D3, and BC7) while extraction was still ongoing (Table 3). Although the oldest pond (O1) had the highest species richness with 40 taxa, species richness was not statistically related to pond age. Likewise the youngest (BC7) and oldest ponds had similar results for the total number of organisms.

Chironomids and gastropods were the predominant invertebrates collected on the artificial substrates. Gastropods were the greatest contributor to the community composition in the three quarries. In the pit ponds the greatest contributor was the chironomids accounting for 25 – 84% of the composition in the littoral zone of pit ponds.

Profundal (or maximum depth) samples had 8 – 94% Chironomids (Table 3). Two sites had high gastropods numbers, however, these ponds did not have true profundal zones and were likely collecting organisms indicative of the littoral community.

Insects generally did not make a large contribution to the community composition in any of the samples. However, there were generally more insects in the littoral samples in relation to the profundal samples.

When species diversity index results were plotted against age and volume, no trends were observed. However, the littoral diversity was consistently higher than diversity in the corresponding profundal/pelagic samples.

Statistical analysis (ANCOVA) showed that habitat type (littoral or profundal), was the only variable that showed a significant relation with benthic diversity (of age, habitat, and the age-habitat interaction).

Basic physical, chemical and biological information are needed to help determine the current "trophic status" and general characteristics of each pond. For example, if the ponds are to support trout, an "oligotrophic" pond with a cool, well-oxygenated hypolimnion would be desireable. The information can be used to determine what morphometrics and physical and chemical factors are important in any modeling used for determining the potential of an aggregate pond for supporting a specific fishery.

This study examined data for a variety of man-made freshwater systems using standard limnilogical methods and established indices designed for natural lakes and ponds. The resulting information serves several purposes. It provides quantitative and qualitative baseline information that can be used by the aggregate industry, for habitat enhancement and reclamation. It also helps regulatory agencies better understand these water systems and how they are similar to or differ from natural systems.

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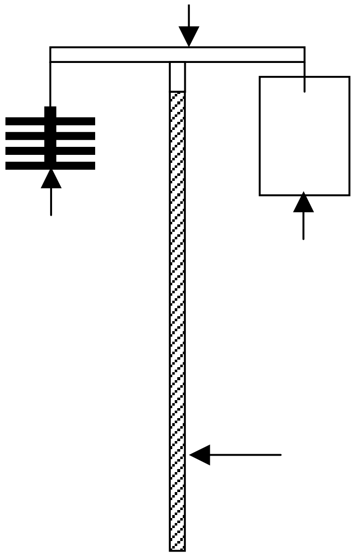

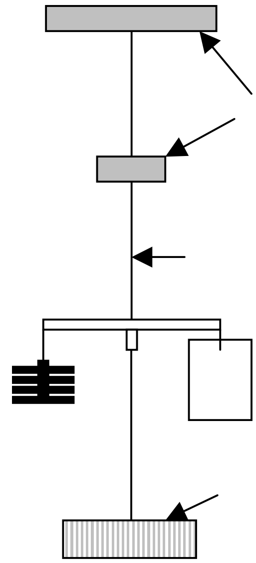

Table 3 Summary of benthic macroinvertebrate results in littoral areas of 15 aggregate ponds in Southern Ontario in 2001.

	N1*	N2	O1	O2	D1	D2†	D3†	D4*	BC1*	BC2	BC3	BC4	BC5	BC6	BC7†
No. of Organisms	67	64	486	118	331	86	50	17	460	301	N/A	47	67	544	438
No. of Taxa	8	12	40	21	33	24	18	8	22	16	N/A	20	21	19	30
% chironomids	1	83	62	25	84	75	30	24	77	83	N/A	38	52	66	77
% gastropods	94	1	1	6	0	4	0	53	0	0	N/A	0	2	0	1
% insects	0	15	27	51	7	18.8	44	6	21	1	N/A	28	18	2	5
% other	5	1	10	18	10	3	26	17	2	16	N/A	34	28	32	18

* quarry pond
† ongoing extraction

Table 4 Summary of benthic macroinvertebrate results in maximum depth areas of 15 aggregate ponds in Southern Ontario for 2001.

	N1*	N2	O1	O2	D1	D2†	D3†	D4*	BC1*	BC2	BC3	BC4	BC5	BC6	BC7†
No. of Organisms	276	15	2	250	300	0	25	N/A	108	14	74	52	55	339	268
No. of Taxa	15	10	2	20	11	0	5	N/A	12	5	12	5	10	12	20
% chironomids	2	79	100	75	92	0	12	N/A	94	86	8	17	67	94	93
% gastropods	76	1	0	0	0	0	0	N/A	1	0	77	0	4	0	2
% insects	2	10	0	11	0	0	8	N/A	5	0	11	0	2	0	3
% other	20	10	0	15	7	0	80	N/A	0	14	4	83	27	6	2

* quarry pond
† ongoing extraction