Mine Closure 2015 – A.B. Fourie, M. Tibbett, L. Sawatsky and D. van Zyl (eds)

From tailings basin to aquatic ecosystem: the ecological recovery of two waterbodies in Kirkland Lake, Ontario, Canada

A. Chute *Klohn Crippen Berger, Canada*

N. Dombrowski *Kirkland Lake Gold, Canada*

Abstract

*A study of the aquatic ecosystems of Kinross Pond and the Eastmaque tailings basin were conducted in the summer of 2012 to assess the recovery of these former tailings facilities. The objective of the study was to evaluate the potential for a closed tailings basin, proposed as a closure lake, to support aquatic life once it is flooded at closure. A study of water quality, sediment quality and aquatic communities was conducted on the Eastmaque basin and Kinross Pond as analogue representation to the proposed closure lake. Fish populations were sampled using minnow traps, seine nets and gillnets. Benthic invertebrate, sediment and water quality sampling were also completed in each pond. Kinross Pond and the Eastmaque basin support different productive fish communities. Kinross Pond supports a fish community composed of four small-bodied fish species: northern redbelly dace (*Chrosomus eos*), finescale dace (*Chrosomus neogaeus*), golden shiner (*Notemigonus crysoleucas*) and brook stickleback (*Culaea inconstans*). Evidence of recruitment between size classes of each species (i.e. the presence of young-of-year) was documented. The Eastmaque basin supported five species of fish: yellow perch (*Perca flavescens*), northern pike (*Esox lucius*), spottail shiner (*Notropis hudsonius*), blacknose shiner (*Notropis heterolepis*) and common shiner (*Luxilus cornutus*). Young-of-year northern pike and yellow perch were captured along with large adult individuals of each species. The ecological recovery of Kinross Pond and the Eastmaque basin assessed during this study indicates that in the years after the Lakeshore basin becomes part of a closure lake, it will potentially sustain a relatively complex community of fish and benthic invertebrates. This study has shown that viable aquatic ecosystems can be restored in bodies of water previously used for industrial purposes, specifically for the storage of gold mine tailings. Removal of these tailings, and the passage of time, can return a tailings storage basin to a pond or lake with a functioning aquatic ecosystem with few additional rehabilitation measures.*

1 Introduction

The Lakeshore basin originally formed the southern lobe of Kirkland Lake prior to its use as a tailings storage facility (TSF). It is located immediately to the south of the Eastmaque TSF, which was developed in the northern lobe of the former Kirkland Lake. The Lakeshore basin TSF was dewatered in the mid-1990s to allow reprocessing of the majority of the impounded tailings. Tailings removal and the mining of the near-surface crown pillars within the Lakeshore basin are believed to have improved the hydraulic connection between the former lake and the active underground mine workings. Accordingly, Kirkland Lake Gold (KLGold) seasonally pumps water accumulating in the Lakeshore basin to reduce infiltration and water management requirements underground in the Macassa Mine.

In 2011, Klohn Crippen Berger (KCB) assessed the potential for the Lakeshore basin to flood following closure. It was concluded based on these hydrologic and hydrogeologic studies that re-establishing a lake following closure would be practical and would have the benefits of improving the aesthetics of the area and preventing access to mine openings and the crown pillar within the footprint of the former lake.

The purpose of this study was to evaluate whether the Lakeshore basin closure lake could support aquatic life in the future once flooded. The evaluation was based on data collected from two nearby "analogue" sites (i.e. two historic tailings facilities that have been allowed to recover naturally over several decades), namely, the Eastmaque basin and Kinross Pond (formerly the Don Lou tailings basin).

1.1 Analogue site histories

Limited data are available describing tailings removal from Kinross Pond; however, according to a tailings re-milling report, two-thirds of the tailings contained in Kinross Pond had been removed by 1993. The dredged area was then backfilled with sand and gravel (Golder Associates Ltd., 1993). It is understood that the remaining tailings were removed in the early 1990s.

Eastmaque Gold Mines mined tailings in the Eastmaque basin commercially from 1989 to 1992. Three diesel power dredges were used to mine the sulphide-rich tailings, which were then processed in the mill (Kinross Gold Corp., 1995).

Kinross Pond and the Eastmaque basin were allowed to re-fill with water and naturally revegetate; that is, no active re-vegetation efforts were initiated. Kinross Pond and the surrounding area are now owned by the Town of Kirkland Lake. A walking path surrounds the pond, and the land past the northern shore is a landscaped park area that was sodded and outfitted with recreation structures at the time of the field investigations in summer 2012. The Eastmaque basin is publicly accessible via Goodfish Road. A city snow dump area is located east of the basin.

2 Methods

Field sampling was completed in the Eastmaque basin and Kinross Pond to assess the fish community, benthic invertebrates, sediment quality and water quality.

Field sampling completed at the Lakeshore basin included the collection of in situ water chemistry data, aquatic vegetation presence and distribution, and the documentation of fish presence.

2.1 Fish community

A mark-recapture study was planned for both the Eastmaque basin and Kinross Pond. A permit to collect fish in these water bodies for scientific purposes was obtained from the Ontario Ministry of Natural Resources (MNR) (Permit 1069429). The mark-recapture study methodology was preferred because it generates an estimate of common fish species abundance (as defined by the statistical precision of the population estimate, where the 95% confidence interval is ≤ 20% of the estimate), biomass and fish community composition. Minnow trapping was the primary method of capture in both ponds. Minnow traps with mesh sizes of 6 mm and 3 mm were used to capture fish. The majority of traps had a mesh size of 6 mm.

2.1.1 Kinross pond

Minnow traps were set in Kinross Pond during the mark portion of the study (August field investigation) for approximately 24 hours per day over three days. Eleven traps were set on the first and second nights, and 21 traps were set on the third night. Traps were secured to shoreline emergent vegetation and tossed to a distance of approximately one to four metres from shore. Fish caught in the traps were kept in a bucket, measured for fork length to the nearest millimetre, marked by partial excision of the anal fin and moved to a recovery bucket. Fish were then released back to the pond. Sufficient numbers of fish were caught during the marking phase to justify completion of the mark-recapture study.

The recapture portion of the study occurred in Kinross Pond during the September field investigation. Minnow traps were also used as the capture method. Five clusters of traps were set in groups of five, approximately one metre apart from each other and approximately one to two metres from shore. Trap locations were chosen to cover each type of habitat. Traps were set for a period of approximately 20 hours per day, over two days. Representative subsamples (five fish per 10 mm size class of each species) were weighed to the nearest 0.1 gram using a calibrated electronic balance.

Catch per unit effort (CPUE) was calculated for fish catches from Kinross Pond. Fish catches were calculated by hour per trap, and then multiplied by 24 hours to obtain a standard catch of fish per trap per day (24-hour fishing period).

Mark-recapture data were analysed according to the Lincoln-Petersen method (Ricker, 1975). This method depends on the site being visited two times: once to mark fish and once to recapture a portion of those fish after they have mixed back into the population. The Lincoln-Peterson method assumes that no fish leave the population, immigrate to the population, lose their markings, die or are born. The estimated population size would be:

$$N = \frac{MC}{R} \tag{1}$$

A more representative estimate of the population size is as follows:

$$N = \frac{(M+1)(C+1)}{R+1} \tag{2}$$

N = the number of individuals in the population

M = number of fish marked and released in period one

C = the number of fish captured in period two

R = the number of fish marked in period one that are recaptured in period two

The number of recaptures, *R*, is treated as a Poisson distribution when the number of individuals recaptured is less than 30. Ricker (1975) includes multipliers to calculate the fifth and ninety-fifth confidence intervals for small recapture numbers. These values allow confidence intervals to be calculated while accounting for the likelihood that the population has been underestimated, which tends to occur when few individuals are recaptured. The size range of fish smaller than the minimum size of the recaptured individuals was excluded from the calculation of population abundance to account for growth between the mark and recapture periods.

A population estimate using the above method was calculated for each species of fish recaptured in the September field investigation: dace spp. and brook stickleback. The population estimate represents the number of fish present in Kinross Pond at the time of marking (August field investigation).

A biomass estimate was calculated using the truncated length frequency of the marked fish from period one, the population estimate and the length-weight relationship. The length frequency was truncated to ensure that the biomass in each size class reflected the fish captured in that size class. The equation used for this calculation is:

$$Biomass = \sum \frac{(number\ in\ size\ class)}{(total\ marked)(population\ estimate)(predicted\ weight\ for\ mid\text{-}point\ of\ size\ class)} \tag{3}$$

2.1.2 Eastmaque basin

Minnow traps were deployed in the Eastmaque basin during the mark portion of the study (August field investigation) for approximately 24 hours per day over two days. Fourteen traps were set on the first night, and six traps were set on the second night. One trap was lost in deep water after the first night of deployment. Traps were deployed from a boat along the shoreline. Traps were set approximately one to two metres from the shoreline and tied to emergent vegetation or structures along the shoreline. The first 24 hours of fishing caught one fish in one minnow trap. Traps were set for a second night and only two individuals were captured. A mark-recapture study was ruled out, and other sampling methods were chosen to document common species occurrence and relative abundance.

Floating gillnets and seine nets were deployed in an effort to capture fish in the Eastmaque basin. The gillnets were 75 m long and 2.5 m in depth, with a float line and a lead line. Gillnets were composed of three 15 m panels with a 50 mm stretched mesh size, and two 15 m panels with a 25 mm stretched mesh size. Two gillnets were deployed once per day over two days of sampling. Gillnet sets occurred in the largest basin of the lake, where the depth was consistently greater than 2.5 m. Nets were secured on or near shore (i.e. to a tree stump, protruding log, etc.) and set perpendicular to shore. Gillnet set times were kept short (approximately 1.5 hours) to reduce fish mortality. Fish caught by gillnet were identified, measured for fork length (mm) and released from the boat. A seine net was deployed in two areas: one in a small bay where fish had been observed from the boat, and the second in a relatively shallow area (approximately 0.5 m to 1 m deep) with a shoreline composed of cattails. The seine net was 9 m long and 1.5 m deep. Seine netting locations were chosen based on the ease with which sampling could occur using one individual in a boat and one in the water, and the presumed likelihood that fish would be caught there. Fish captured by seine net were collected in a bucket and roughly enumerated and identified before being returned to the water. Seine catches were large (> 200 fish), and fish were too numerous and small to justify length measurements.

Fish catch information from the Eastmaque basin was used to generate CPUE for each method used, and length frequencies were generated for each species and fishing methodology.

2.1.3 Lakeshore basin

General observations of fish presence were made during a walk-around survey of the Lakeshore basin. Shallow, accessible areas were investigated visually, including the west, north and east shorelines of the east basin, and the east and west shorelines of the west basin. Fish presence was noted where observed.

2.2 Benthic invertebrates

Benthic invertebrates were collected using an Ekman dredge (23 × 23 × 23 cm) at locations in Kinross Pond and the Eastmaque basin. Samples were collected at stations chosen based on observed vegetation and likelihood of encountering benthic invertebrates. Sampling was biased owing to the nature of the pond substrates. Very few benthic invertebrates were collected in the dredge in an unbiased sampling trial; therefore, the sampling methodology was altered to ensure that a variety of benthic invertebrates could be sampled.

Two invertebrate samples in Kinross Pond were collected by dredge sampler in deeper sediments (1–1.5 m in depth). Dredge sampling in the Eastmaque basin occurred at one site located in a shallow area (1 m deep), which had abundant submerged aquatic vegetation, and one site in the deepest section of the lake (8 m deep). These samples were kept for further analysis; however, additional sampling was completed in an effort to capture more of the invertebrate diversity present in each pond. One sample was collected in each pond at a location close to shore among shallow submerged and emergent aquatic vegetation. Invertebrates were sampled by collecting and picking through submerged plants and shallow sediments. A canoe paddle was used to lift vegetation and sediment into the boat (in the Eastmaque basin) or onto the shore (in Kinross Pond), and invertebrates observed were collected and placed in a sampling jar for further identification.

Invertebrates caught as by-catch in minnow traps in Kinross Pond were also kept and preserved for further identification. Four benthic invertebrate samples were taken from Kinross Pond, and three samples were taken from the Eastmaque basin. Samples were sent to ALS Environmental Laboratories in Winnipeg for sorting, and invertebrates were identified to the lowest taxonomic level possible (generally genus or species).

2.3 Sediment

Sediment samples were collected during the September field trip. Samples were collected at the deepest points in both Kinross Pond and the Eastmaque basin. A 23 × 23 × 23 cm Ekman dredge was used for sampling. Samples were analysed for metals, total organic carbon (TOC) and particle size at Accuracy Environmental Laboratories Ltd. in Kirkland Lake.

Sediment quality results were compared to the provincial sediment quality guidelines (PSQG), which have two effect level values: lowest effect level (LEL) and severe effect level (SEL) (Ontario Ministry of the Environment, 2008). Results were also compared to the Canadian sediment quality guidelines (CSQG), which includes the interim sediment quality guideline (ISQG) and probable effect level (PEL) (Canadian Council of Ministers of the Environment, 2001). These sets of guidelines outline sediment contamination levels that, if exceeded, can present a risk to aquatic life. Results occurring below method detection limits (MDL) were halved to estimate their concentration before being compared to guidelines.

2.4 Water chemistry

Water samples were collected from each pond during the August field trip to provide a snapshot of the water chemistry. Parameters analysed included free cyanide, specific conductivity, hardness, ammonia, total suspended solids (TSS), total dissolved solids (TDS), pH, alkalinity, acidity, TOC, dissolved organic carbon (DOC), dissolved oxygen (DO), oxidation reduction potential (ORP), total phosphorus, ferrous and ferric iron, nitrate and nitrite, phosphate, sulphate, anions (Br, Cl, Fl), total metals and dissolved metals.

Water samples were collected from the surface water of the Eastmaque basin near the deepest part of the waterbody. Water samples from Kinross Pond were collected from the north end of the pond. Water samples were analysed by Accuracy Environmental Laboratories Ltd. in Kirkland Lake.

Surface water samples, including those collected on other occasions by KLGold staff, were compared to provincial water quality objectives (PWQO) (Ontario Ministry of Environment and Energy, 1994). Results measuring below MDL were halved to estimate their concentration before being compared to the guidelines.

2.5 In situ physical and chemical analysis

In situ physical and chemical parameters of water were measured using a multi-parameter meter during the August field investigation and a pH/temperature probe during the September field visit. The multi-parameter meter measured temperature, specific conductivity, TDS, salinity, DO and pH. The pH probe measured pH and temperature.

A DO and temperature profile was measured in the Eastmaque basin during the August field investigation. The profile was measured in the deepest part of the lake; temperature and DO readings were taken at each meter throughout the water column. A DO and temperature profile was not taken in Kinross Pond; the multi-parameter meter was not available when boat work occurred on the pond.

3 Results

3.1 Fish community

The fishing efforts that took place in each pond during each field investigation is presented in Table 1.

Table 1 Fishing effort and total fishing time in Kinross Pond and the Eastmaque basin during August and September field sampling investigations

Field visit	Waterbody	Gear[1]	Total fishing time (hours)	No. of traps[2]/sets	Mean set duration (hours)	Standard deviation of set duration (hours)
August	Kinross Pond	MT	1079	43	25	3.8
	Eastmaque	MT	408	19	22	1.9
	Eastmaque	GN	6	4	1.5	-
	Eastmaque	SN	-	2	-	-
September	Kinross Pond	MT	1010	1010	21	2.7

Notes: (1) MT = Minnow traps; GN = Gillnets; SN = Seine nets. (2) Traps tampered with or lost were excluded from analysis.

3.1.1 Kinross Pond

A total of 482 fish were caught in Kinross Pond during the August field investigation. The fish species caught were northern redbelly dace (*Chrosomus eos*), finescale dace (*Chrosomus neogaeus*), golden shiner (*Notemigonus crysoleucas*) and brook stickleback (*Culaea inconstans*). Differentiating between finescale and northern redbelly dace was difficult because they have similar traits and they tend to hybridise; therefore, analysis of mark-recapture data was based on combined dace spp. numbers. A total of 686 fish were caught in Kinross Pond during the September field investigation. The same fish species were captured during both field investigations.

CPUE in Kinross Pond during the August field trip was 11 ± 15 fish/trap/day using 6 mm mesh traps. Fish catches during the September trip were 18 ± 67 fish/trap/day when one 3 mm mesh trap was used during the first day of trap sets. The 3 mm mesh trap was not used during the August field investigation, and was removed from the study after the first day of use in the September field investigation owing to an inflated catch of small-bodied fish (30 to 45 mm). CPUE during the September trip, when the small-meshed trap was removed from the analysis, was 8 ± 12 fish/trap/day.

Population estimates based on the mark-recapture data could be generated for dace spp. and brook stickleback. No marked golden shiners were recaptured; therefore, no population estimate or biomass estimate could be generated for this species. Five fish that had been marked were caught during the recapture portion of the study: four dace spp. and one brook stickleback. The population estimate generated for dace spp. represents the fish population in the 45 mm to 85 mm size classes (truncated length frequency due to recapture lengths). The population estimation for brook stickleback represents the fish population in the 50 to 55 mm size classes (truncated length frequency). Population estimates and 95% confidence intervals are presented in Table 2.

Table 2 Population estimate and confidence intervals of dace spp. and brook stickleback captured in Kinross Pond

Species	Population estimate	Lower 95% confidence limit	Upper 95% confidence limit
Dace spp.	27,900	12,500	69,750
Brook stickleback	550	170	1,000

The abundance and biomass of dace spp. and brook stickleback per size class are presented in Table 3 and Table 4.

Table 3 Abundance and biomass estimates per size class of dace spp. captured in Kinross Pond

Size class (mm)	Number marked	Abundance	Predicted weight (g)	Biomass (kg)
45	105	8,002	0.7	6
50	135	10,288	1.0	11
55	54	4,115	1.4	6
60	44	3,353	1.8	6
65	18	1,372	2.4	3
70	6	457	3.0	1
75	3	229	3.7	1
80	1	76	4.6	0
85	0	0	5.6	0
	Total abundance	27,892	Total biomass	34

Table 4 Abundance and biomass estimates per size class of brook stickleback captured in Kinross Pond

Size class (mm)	Number marked	Abundance	Predicted weight (g)	Biomass (kg)
50	15	518	0.9	0.5
55	1	35	1.3	0.0
	Total abundance	553	Total biomass	0.5

The population and biomass estimates for dace spp. and brook stickleback present in Kinross Pond are based on a limited number of recaptures from a limited number of size classes. The estimates do not represent precise or accurate population and biomass numbers. Large 95% confidence intervals reflect the conservative nature of the population estimates. Recapture rates were very low, which may be due to mortality or decreased fitness of marked fish caused by handling and fin clipping. These activities could make them more susceptible to predation. Fisheries management decisions should not be made based on the aforementioned population estimates.

Length frequencies for dace spp., brook stickleback and golden shiner are shown in Figures 1, 2 and 3, respectively.

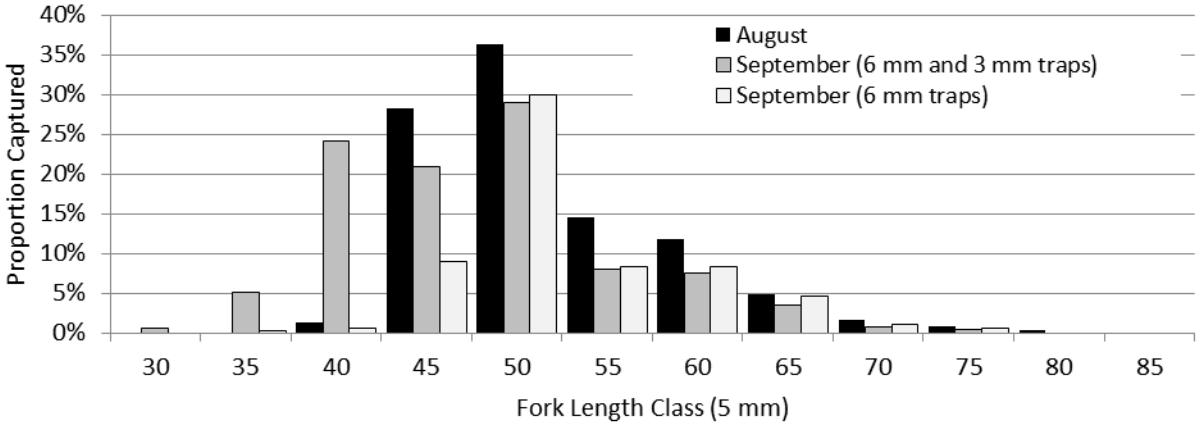

Figure 1 Length frequency of dace spp. caught in Kinross Pond

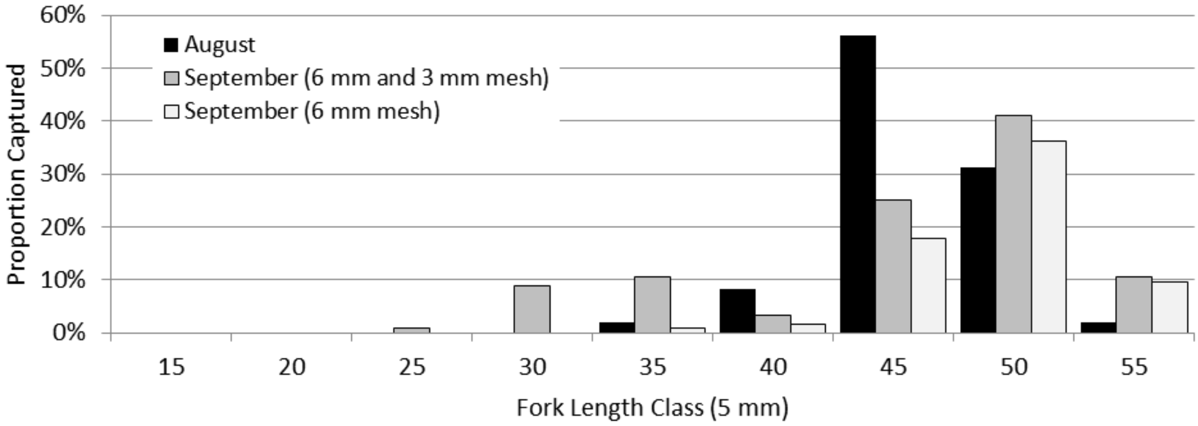

Figure 2 Length frequency of brook stickleback caught in Kinross Pond

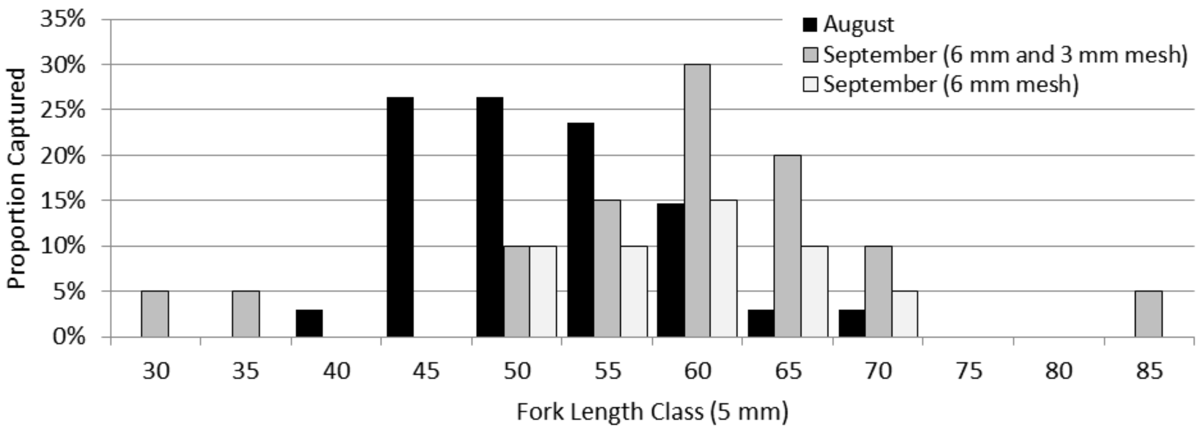

Figure 3 Length frequency of golden shiner caught in Kinross Pond

3.1.2 Eastmaque basin

A total of 31 fish were caught in the Eastmaque basin in the minnow traps and gillnets, and approximately 400 fish were captured during two deployments of a seine net. Species caught included yellow perch (*Perca flavescens*), northern pike (*Esox lucius*), spottail shiner (*Notropis hudsonius*), blacknose shiner (*Notropis heterolepis*) and common shiner (*Luxilus cornutus*). Table 5 includes a summary of fish catch and fish length associated with each methodology used in the Eastmaque basin.

Table 5 Eastmaque basin catch summary by fishing method and fish species

Gear	Fishing effort (h)	Fish species	Total catch	Average length (mm)	Standard deviation (mm)
MT	408	Yellow perch	1	51	-
		Northern pike	2	112	18
GN	6	Yellow perch	25	111	20
		Northern pike	4	573	91
		Common shiner	2	142	3.5
SN	2 deployments	Spottail shiner	8	40–50	-
		Blacknose shiner	400	30–50	-
		Yellow perch	40	40–50	-

Note: MT = Minnow traps; GN = Gillnets; SN = Seine nets.

The length frequency of fish caught in the Eastmaque basin is displayed in Figure 4.

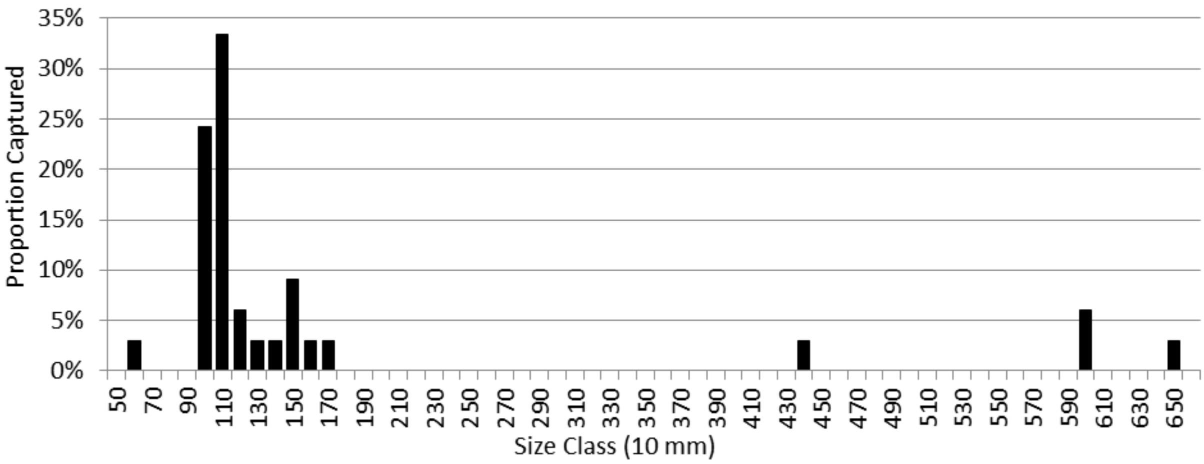

Figure 4 Length frequency of fish caught in Eastmaque basin (GN and MT)

The CPUE of gillnets deployed in the Eastmaque basin was 6.1 ± 5.5 fish/net/hour. The CPUE of the minnow traps was 0.18 ± 0.63 fish/trap/day.

3.1.3 Lakeshore basin

Observations along the eastern shoreline of the west Lakeshore basin revealed a deceased dace spp. minnow. Unidentified small-bodied fish were observed swimming in the shallow portions along the east shoreline of the east Lakeshore basin.

3.2 Benthic invertebrates

The sediments sampled using the dredge in each waterbody were very fine and did not appear to provide high-quality habitat for invertebrates upon inspection in the field. Abundance and diversity of invertebrates in the sediment samples were low. Samples taken in each waterbody from near-shore areas among the submerged and emergent aquatic vegetation displayed higher numbers of organisms and more orders.

Invertebrates captured by the dredge sampler in Kinross Pond included genera from the following orders: Odonata, Diptera, Basommatophora, Trombidiformes, Oligochaeta and Veneroida. A total of 31 individuals were sorted out of these sediments. The remaining invertebrates were recovered either from minnow trap catches or from the shoreline sampling. These invertebrates belonged to genera from the following orders: Ephemeroptera, Trichoptera, Odonata, Amphipoda, Diptera, Hemiptera, Homoptera, Basommatophora, Oligochaeta, Hirudinea and Veneroida. A total of 110 individuals were captured in the minnow trap and shoreline samples.

Invertebrates captured in the Eastmaque basin by dredge were composed of 50 individuals from genera of the following orders: Ephemeroptera, Odonata, Diptera, Basommatophora, and Oligochaeta. The sample taken by dredge at the deepest part of the lake (a depth of 8 m) contained 66 individuals from two genera of the Diptera order. The sample collected from the shoreline contained 158 individuals from genera of the following orders: Ephemeroptera, Trichoptera, Odonata, Diptera, Basommatophora, Isopoda, Amphipoda, Oligochaeta and Hirudinea.

3.3 Sediment

Sediment analysis results revealed some elevated metal(loid)s in the sediments in Kinross Pond. Arsenic, copper, lead and mercury exceeded CSQG ISQG and PEL, and the PSQG LEL and SEL. Cadmium, chromium, nickel, zinc and TOC also exceeded the PSQG LEL. The sediment sample from the Eastmaque basin had exceedances of the CSQG ISQG and PSQG LEL for chromium, copper and lead. Nickel exceeded the PSQG LEL. Sediment chemistry results are displayed in Table 6.

Table 6 Sediment parameters compared to Canadian and provincial sediment guidelines

Parameter	Units	CSQG		PSQG		Kinross Pond	Eastmaque basin	Macassa tailings[1]
		ISQG	PEL	LEL	SEL			
Arsenic (As)	µg/g	5.9	17	6	33	47	4.3	6.1
Cadmium (Cd)	µg/g	0.6	3.5	0.6	10	0.87	0.57	0.17
Chromium (Cr)	µg/g	37.7	90	26	110	28	65	50
Copper (Cu)	µg/g	35.7	197	16	110	393	55	59
Lead (Pb)	µg/g	35	91.3	31	250	1,240	74	93
Manganese (Mn)	µg/g			460	1,100	434	763	990
Mercury (Hg)	µg/g	0.17	0.486	0.2	2.0	37	1.3	0.10
Nickel (Ni)	µg/g			16	75	52	45	28
Zinc (Zn)	µg/g	123	315	120	820	149	98	69

Note: (1) Typical tailings chemistry in the Macassa Tailings Storage Facility (Average values from July and January 2011 and June and August 2012).

The metal concentrations of the Eastmaque basin sediment sample are typical of tailings produced from Kirkland Lake camp mines. Concentrations of chromium, copper, lead and nickel were elevated but did not exceed probable or severe effects limits. The sediment sample from Kinross Pond had elevated levels of arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc. Probable and severe effects limits for arsenic, copper, lead and mercury were exceeded. A single sediment sample was analysed from each pond, and observed chemistry may be limited to a small area.

The PSQG SEL indicates a level of contamination expected to be detrimental to the majority of sediment-dwelling organisms. Sediment chemistry alone, however, cannot be used to predict biological effects (Ontario Ministry of the Environment, 2008).

3.4 Water chemistry

One PWQO exceedance occurred in the Eastmaque basin water sample taken in during the August field investigation. Total cyanide exceeded the PWQO in the Eastmaque basin water sample. Previous sampling of water quality in the Eastmaque basin occurred in April and May of 2012, and in September (two sampling events), October and November of 2011. During these sampling rounds, there were exceedances of ammonia (November 2011), and total cyanide, total copper, total iron, total molybdenum and total silver (September 2011).

Water quality in the study basins was good, with only one exceedance of PWQO observed for each. The concentration of water parameters in Kinross Pond, indicated by PWQO exceedances, did not correlate with the high levels of mercury, lead, copper and arsenic found in the sediment.

3.5 In situ physical and chemical analysis

Physical and chemical parameters collected during the August field investigation using a multi-parameter meter are shown in Table 7.

Table 7 In situ physical and chemical parameters

Site	Date	Temp (°C)	Conductivity (µS/cm)	TDS (g/L)	Salinity (ppt)	DO (mg/L)	pH (units)
Kinross Pond	13 August 2012	20	490	0.32	0.24	0.17	7.0
Eastmaque tailings basin	14 August 2012	21	310	0.20	0.15	7.6	8.1
Lakeshore west basin	14 August 2012	21	870	0.56	0.43	11	8.2
Lakeshore east basin	14 August 2012	22	380	0.25	0.18	8.4	9.2

Note: Probe of multi-parameter meter was deployed within a depth of one metre from the surface.

The DO and temperature profile from the Eastmaque basin are shown in Figure 5.

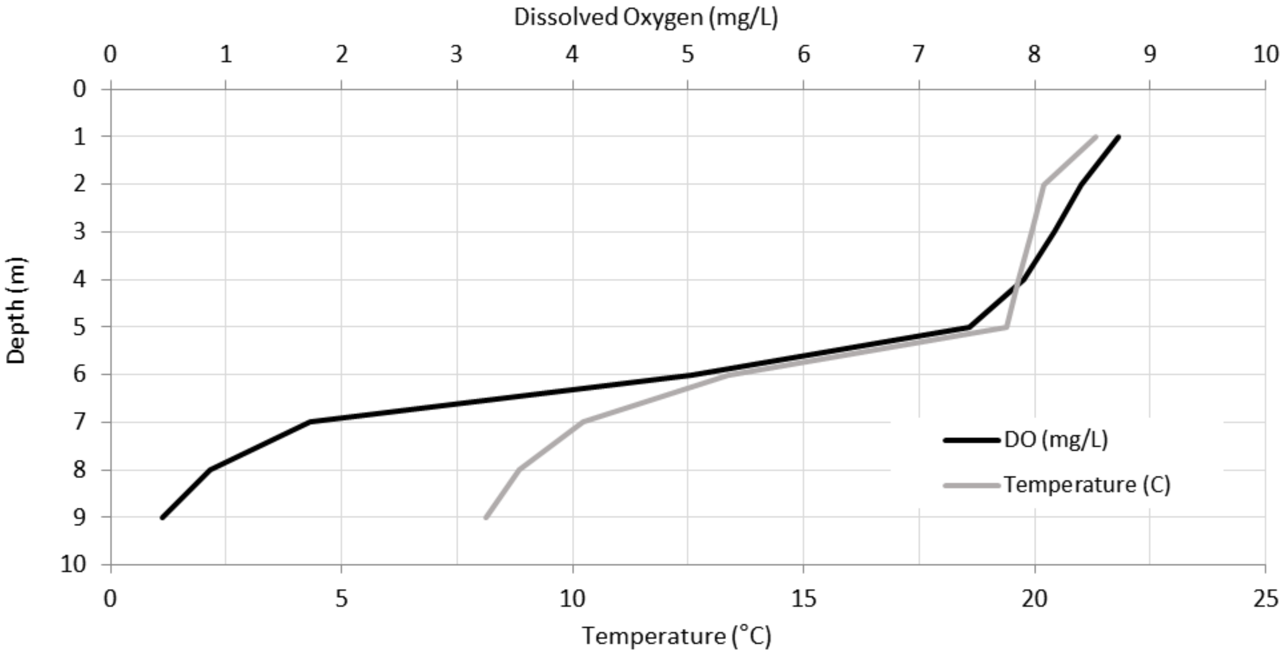

Figure 5 Eastmaque basin dissolved oxygen and temperature profile

4 Discussion

4.1 Kinross Pond

Kinross Pond represents a system that has progressed from a tailings storage area to a productive ecosystem inhabited by a variety of aquatic organisms. Kinross Pond has a high abundance and biomass of small-bodied fish species. The Kinross Pond community is diverse for a waterbody of its size. The four fish species found in the pond feed on plankton and insects.

Kinross Pond is not a deep waterbody and contains dense submerged and emergent aquatic vegetation. It is likely that these factors will limit the productivity of the pond, and it is unlikely that the pond could provide habitat for larger bodied fish. The limited depth and excess of vegetation observed in Kinross Pond likely limit DO, and possibly deplete it beyond levels suitable for some fish to survive. A low DO value was observed during in situ chemical analysis using the multi parameter meter (Table 7). Since the study, a fountain has been installed in the deeper part of the pond. A fountain may have the effect of increasing mixing in the pond and therefore increasing the concentration of DO.

High sediment metal(loid) concentrations were observed in Kinross Pond; however, these may remain contained in the sediments and have limited bioavailability. The presence of aquatic vegetation such as cattails may help absorb heavy metals and aid in the remediation of the pond (Padmavathiamma and Li, 2007). Benthic invertebrates captured in Kinross Pond were composed of pollution-sensitive taxa such as Trichoptera, Ephemeroptera and Odonata, which indicates that despite possibly harmful levels of metal(loid)s in sediments, invertebrates are present and can provide an abundant food source for fish. The community of fish and amphibians in the pond was also diverse and abundant despite the measured metal concentrations in the single sediment sample.

Kinross Pond appeared to provide a good environment for fish: the shift in the length frequencies (Figures 1, 2 and 3) indicates that fish grew (recruitment occurred) between sampling periods.

4.2 Eastmaque basin

The Eastmaque basin has shown evidence of recovery since a large proportion of tailings was removed from the basin. The Eastmaque basin has a more diverse fish community than Kinross Pond; it is composed of five fish species. The fish community contains multiple trophic levels, including those that feed on invertebrates (common shiner) and plankton and invertebrates (spottail shiner and blacknose shiner), as well as omnivores (yellow perch) and carnivores (northern pike). Large-bodied perch (>150 mm) and northern pike (>650 mm) were captured in the Eastmaque basin. The presence of large-bodied omnivores and carnivores may explain the low capture rates of minnow traps. Minnow traps are passive gear and rely on fish movement. The presence of large predators in a lake would cause smaller prey species to remain in cover, reducing their encounter rate with minnow traps. The minnow traps did, however, catch juvenile northern pike, and the seine net deployments caught juvenile yellow perch. The capture of these juveniles indicates that reproduction of the large predators in the lake is occurring. Reproduction of the species in the lake is a positive sign of recovery; however, when the length frequency of fish caught in the Eastmaque basin was generated, a gap appeared in the middle size classes (Figure 4), from the 180 mm to 430 mm size classes. This gap may have been due to gear selectivity, because minnow traps catch smaller fish and gillnets catch larger fish.

Effects of metal exposure on yellow perch have been investigated along contamination gradients in Sudbury, Ontario, and Rouyn-Noranda, Quebec (Campbell et al., 2003; Rasmussen et al., 2008; Pyle et al., 2008). These studies indicate that while yellow perch are generally metal-tolerant, they experience indirect and direct effects caused by metal contamination by copper, nickel and cadmium. Direct effects included those on a cellular level, which influenced organs, tissues, individuals and populations. Indirect effects included food web–mediated effects caused by the lack of preferred food sources (large metal-sensitive benthic invertebrates) and replacement by smaller metal-tolerant invertebrates. The extent of potential metal exposure on yellow perch in the Eastmaque basin is unknown; however, it should be noted that concentrations of nickel and cadmium were often below detection limits, and copper rarely exceeded PWQO.

4.3 Lakeshore basin

The present study investigated the ecology of analogue sites in an effort to assess the likelihood that the proposed Lakeshore closure lake will be able to support an aquatic community. Observations of the Lakeshore basin were limited to in situ water chemistry, fish presence, vegetation type and distribution, and presence of other organisms. These observations revealed that acceptable levels of DO were present in the east and west basins, and that fish were present in the west basin. The closure lake will be created when the barrier between the Lakeshore (west) and Eastmaque basins is removed, and the Lakeshore basin is allowed to fill with water over time.

It is anticipated that the fish species present in each basin will mix, and that the resulting fish community will be composed of multiple feeding levels, similar to the community of the Eastmaque basin. Benthic invertebrates, which are likely already present in the Lakeshore basin, will continue to colonise the basin as it floods to become the closure lake. An abundance of submerged and emergent vegetation is currently found in and around the Lakeshore basin. The vegetation will likely recolonise after the water level for the closure lake is established. Sediment quality in the Lakeshore basin area of the closure lake will depend on the current sediment quality in the Lakeshore basin, which was not assessed in this study. Chemical parameters in the sediment of the Eastmaque portion of the closure lake are not expected to be above the any severe or probable effect levels. Water quality in the closure lake will also likely be similar to that found in Eastmaque, with minimal exceedances of PWQO concentrations.

5 Conclusion

This study has shown that viable aquatic ecosystems can be restored in bodies of water previously used for industrial purposes, specifically for the storage of gold mine tailings. Removal of these tailings, and the passage of time, can return a tailings storage basin to a pond or lake with a functioning aquatic ecosystem with few additional rehabilitation measures.

The Lakeshore basin, which has been dredged of tailings, is predicted to form a hydrologically stable lake when combined with the Eastmaque basin upon closure (KCB, 2011). Based on the work completed during this study, the closure lake will have a high potential of supporting benthic invertebrate production, a complex fish community with multiple trophic levels and other organisms such as amphibians, mammals and birds. It is likely that benthos and fish currently reside in the Lakeshore basin, and the creation of a closure lake will enhance the amount and quality of habitat available to these aquatic species.

This study has raised some further questions and possible paths forward with respect to waterbody recovery and ecosystem health:

- Kinross Pond sediment contamination: The contaminated sediment in Kinross Pond revealed that even though a pond can support an abundance of fish and invertebrates, it can have high levels of metals in some habitats. The extent of this contamination is not known, based on the scope of this study. Similar levels of contamination were not observed in the Eastmaque basin. An investigation directed towards identifying the extent of sediment contamination in the pond would be beneficial to understanding the pond recovery. Contaminant testing on fish living in the pond would also reveal if fish are being noticeably affected by this sediment contamination.
- Fish population estimates: The population estimates of fish from Kinross Pond calculated based on the data collected in this study may not accurately reflect actual numbers of fish in Kinross Pond. An additional season of fieldwork with a larger scale mark-recapture experiment using a more diverse array of gear would be required to generate a usable population estimate. A larger scale mark-recapture experiment could also be completed in the Eastmaque basin to determine the population size and biomass of fish present in the basin.

Information collected about the Eastmaque basin may make the basin a possible candidate for fish stocking in the Kirkland Lake area. The lake has public access, and information about the fish community, benthos, water chemistry, sediment chemistry and DO profile is now available. The process to determine whether a lake can or should be stocked can take up to two years (Vascotto, 2012).

The multiple feeding groups documented in the Eastmaque basin may have implications for the level of metal bioaccumulation and biomagnification that can occur in the aquatic food web. An assessment of metal levels in fish tissue would provide an indication of the extent to which metal concentrations in the system are affecting fish, and would be recommended prior to evaluating the stocking potential of the lake.

References

Campbell, P.G.C., Hontela, A., Rasmussen, J.B., Giguère, A., Gravel, A., Kraemer, L., Kovesces, J., Lacroix, A., Levesque, H., and Sherwood, G. (2003) Differentiating between direct (physiological) and food-chain mediated (bioenergetic) effects on fish in metal-impacted lakes, Human and Ecological Risk Assessment, Vol. 9(4), pp. 847–866.

Canadian Council of Ministers of the Environment. (2001) Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, Publication No. 1299; ISBN 1-896997-34-1.

Ontario Ministry of the Environment. (2008) Guidelines for identifying, assessing and managing contaminated sediments in Ontario: An integrated approach. Queen's Printer for Ontario, PIBS 6658e.

Ontario Ministry of the Environment and Energy. (1994) Water management policies, guidelines, provincial water quality objectives of the Ministry of Environment and Energy, Queen's Printer for Ontario, PIBS 3303e.

Padmavathiamma, P.K. and Li., L. (2007) Phytoremediation technology: Hyper-accumulation metals in plants, Water, Air, and Soil Pollution, Vol. 184, pp. 105–126.

Pyle, G., Busby, P., Gauthier, C., Rajotte, J. and Couture, P. (2008) Seasonal and regional variations in metal contamination and condition indicators in yellow perch (Perca flavescens) along two polymetallic gradients. II. Growth patterns, longevity, and condition, Human and Ecological Risk Assessment, Vol. 14, pp. 126–145.

Rasmussen, J.B., Gunn, J.M., Sherwood, G.D., Iles, A., Gagnon, A., Campbell, P.G.C. and Hontela, A. (2008) Direct and indirect (foodweb mediated) effects of metal exposure on the growth of yellow perch (Perca flavescens): Implications for ecological risk assessment, Human and Ecological Risk Assessment, Vol. 14, pp. 317–350.

Ricker, W.E. (1975) Computation and interpretation of biological statistics of fish populations, Bulletin of Fisheries Research Board of Canada, Vol. 191, pp. 1–382.

Bibliography

Golder Associates Ltd. (1993) Geotechnical investigation for tailings re-milling: Lakeshore Mine, Kirkland Lake, Ontario, prepared for Lac Minerals Ltd., May 1993.

Kinross Gold Corporation. (1995) Revision 11-95 Closure Plan: Macassa and Lakeshore Properties, November 1995.

Klohn Crippen Berger (KCB) (2011) Lake shore property closure lakes phase II assessment – FINAL, prepared for Kirkland Lake Gold Inc., 30 November 2011.

Vascotto, S. (2012) Presentation: The science behind stocking – why we do what we do, prepared and presented on behalf of the MNR, 27 November 2012.