REPORT OF ACTIVITY IN THE FRAMEWORK OF THE SHORT TERM MOBILITY 2014-

PROF. N.D. YAN

The research project funded in the framework of STM Program 2014 allowed, Norman Yan, Full professor at the Department of Biology, York University, Toronto, Canada. to work with me at the Institute .Professor Yan is one of the most outstanding aquatic ecosystem scientists in North America.

Here in Pallanza we study lakes; my research interest in particular is in zooplankton, a key component of lacustrine food webs. Norman Yan's enormous experience and skills in the study of zooplankton and lakes at ecosystem level is, simply, exceptional and unique. Having been for >20 year scientist and research scientist at the Ontario Ministry of the Environment, he has a deep knowledge of endangered lakes and of how to approach their study and plan ecologically-sound restoration. He is a true limnologist, able to span from the most modern, refined techniques and approaches to more traditional ones, on experimental (included ecotoxicology), mesocosm and field studies. He studied zooplankton communities of hundreds of lakes, affected by a wide range of threats, severely acidified, polluted by heavy metals in mining sites, constrained by calcium depletion, endangered by sodium chloride introduction, invaded by harmful species. He has promoted restoration and studied mechanisms through which it might be achieved. Professor Yan's great knowledge of environmental lake problems and of approaches for their solution is combined with a genuine interest for young researchers and students, and a very collaborative spirit. Not only did he give two seminars and a talk for comparing Lake Orta with lakes in the Sudbury Region, but he also met all people here, technicians, researchers and students, offering help and comments and possible cooperation with other researchers in North America and Europe whom he is presently working with and he worked with in the past.

We discussed approaches we will apply to Lake Orta's case study, a brief description of which is reported below, to address some basic questions never addressed before, on recovery of the lake biota, and of the zooplankton community, in particular, after chemical restoration from severe heavy metal pollution and acidification.

Plan for a review paper

Yan, N.D., M. Manca, J. Bailey, C. Bonacina (plus other contributing Canadian and Italian co-authors)

Title: Comparing long-term zooplankton recovery following the liming of the acid and metal-contaminated Lake Orta in Italy and urban lakes in Sudbury, Canada: Do biogeographic, toxicological or ecological mechanisms regulate recovery?

Possible journals – Ecology Letters, Bioscience, Restoration Ecology, or an article in a collection of papers on recovery of limed lakes, for the Journal of Limnology

Plan of the Introduction:

While the control of atmospheric sulphur emissions is the most effective, long lasting management strategy to curb the damage to lakes and rivers from acid rain (Ref), several nations have also chosen to encourage the recovery process by adding acid neutralizing agents, commonly powdered limestone, to damaged lands and waters (Refs). This is commonly called "liming". While Scandinavian nations implemented the largest liming programs (Ref), there were also well-publicized liming programs in Canada (Ref), especially near Sudbury Ontario (Ref), and in one lake in Italy – Lago d'Orta. These liming programs, both the research (ref) and the management (Ref) efforts, successfully reversed water quality damage. In Sudbury lakes, pH rose and levels of Cu and Ni were dramatically reduced (Ref). In Lake Orta, acidity, and the levels of the most problematic metal, Cu, were also dramatically reduced (Ref), and the timing of water quality recovery matching predictions (Ref). There have also been promising signs of biological recovery in both systems, with evidence of some recovery of phytoplankton (Ref), zooplankton (Ref), benthos (Ref) and fish (Ref), but in general ecological recovery has lagged quite far behind water quality recovery (Ref). This is not really a surprise, on reflection, because the liming efforts were clearly directed at the underlying chemical mechanisms controlling acidity and metal pollution, but they addressed only one of several possible bottlenecks in the ecological recovery process, i.e. the toxicity of the waters. Here our goal is to lay out the other possible bottlenecks, and see which of these might still be limiting recovery in Sudbury lakes and in Lake Orta.

What are the processes that regulate ecological recovery? If the pollution episode is short-lived with respect to organism life times, restricted in area with respect to meta-community interactions, and not severe enough to increase death rates much above birth rates, then populations will fall but will not be locally extirpated. In such cases recovery should be straightforward. Once the pollution episode ends, recovery will follow positive population growth rates. Assuming the sum of colonist immigration rates and the birth rates of residual population exceed their death rates for long enough populations will regrow and presumably persist, i.e. the populations will recover. In contrast, if the damage was severe, widespread and long-lasting, many populations will have been extirpated. This certainly transpired in both Sudbury lakes and Lake Orta (Ref). In such circumstances, ecological recovery of populations will certainly be slower, and may well be less certain, given that many more potential bottlenecks need to be circumvented. Yan et al. (2001) envisaged this sequence of necessary hurdles to recovery in a decision tree framework for returning colonists. Are the waters still toxic to the colonists of that species? Are colonists actually available? Are they abundant enough to overcome Allee effect thresholds so that founding populations may be established? Finally, are there ecological impediments in the altered habitat to the growth of these founding populations to target levels? Put in simpler terms, for post-extinction recovery to occur, colonists

must "arrive alive, survive and thrive". Propagules must be introduced into waters that won't kill them, in sufficient numbers to found a population, and in the presence of habitat, competitor, parasite and predation pressures that will permit the long-term persistence of these populations at numbers, at least for valued species, that are deemed appropriate. Recent work in Sudbury lakes (Palmer et al. 2013), and in Lake Orta (Ref), suggest that the communities of lake zooplankton are improving, but they have not as yet recovered. Here our overall goal is to attempt to identify the barriers to this biological recovery. Our specific objectives are:

1. to compare recovery dynamics of zooplankton in the 4 urban lakes in Sudbury with that of Lake Orta
2. to specify those factors that might lead to differing recovery dynamics of zooplankton in different sites.
3. to attempt, through an examination of the long-term zooplankton data sets, to identify whether the recovery dynamics are currently controlled by biogeographic (i.e regional) or local factors,
4. to determine what those local factors might logically be.
5. to recommend logical additional restorative interventions if we are successful at identifying the current mechanisms that are acting as bottlenecks to more complete or more rapid recovery.

Of courses, there are both similarities and differences in the Orta and Sudbury lakes pollution and subsequent liming stories. Important similarities exist. In both cases, acidification was severe (pH levels near 4), and long-lasting, i.e. for several decades (Refs). There was also severe contamination with metals, principally Cu and Ni in Sudbury and Cu in Lake Orta (Ref), and the acid and metal pollution lead to severe biotic impoverishment in the sense of Woodwell (ref), including complete loss of fish (Ref), and extinction of many species of phytoplankton (Ref) and zooplankton (Ref). Both sets of lakes were also limed quite some time ago, in comparison with the generation times of zooplankton, i.e. in the early and mid-1970s in Sudbury (Ref), and in 1989/90 in Lake Orta (Ref), and in both cases liming raised pH to circum-neutrality and dramatically lowered total metal levels and altered metal speciation to less toxic forms (Refs). There are also many permanent residents and seasonal visitors to both regions, and these visitors may bring colonists with them (Ref).
There are also important differences in the recovery stories. There were more, and up to order of magnitude higher levels of metals in Sudbury lakes. Lake Orta faced NH4 pollution (Ref) in addition to acid and metals, an additional stress that Sudbury lakes did not suffer. Post-liming, levels of problematic metals are now lower in Lake Orta, than in Sudbury's urban lakes, with the possible exception of Cr, suggesting higher possibility of survival of arriving colonists. The Sudbury lakes lie in a region with many other lakes, so more diverse colonist sources may exist for Sudbury lakes. Potentially importantly, Lake Orta lacks planktivorous fish to this day, while planktivores re-invaded the Sudbury lakes over a 10 year period beginning in the late 1980s.

Methods to include:

- Study area description – ie. Morphometry and background chemistry of both study sites (Table 1)
- Liming details
- Sampling and counting details - Cite published sources for all where possible, but detail the zooplankton sample collection methods, frequency and counting protocols
- Methods of documenting recovery pattern, i.e. trend of richness over time

- Methods to estimate recovery mechanisms, i.e. species accumulation curve as a minimum estimator of arrival, and annual persistence as an estimator of whether colonists have thrived. (Perhaps also consider and reject alternative metrics here rather than in the Discussion, if it can be brief).

Results to include:

Table 2 - potential controlling agents of recovery, i.e. arrive, alive survive and thrive compared in both sites, i.e. list and score the potential mechanisms for Sudbury and Orta. For example, this could be

- (Arrival) internal colonist sources, presence of resting eggs? No in Sudbury, yes in Orta
- external colonist sources – natural and human assisted (number of people), purposeful introductions, number of lakes within say a few km. presence of major roads, near both sites
- (survival) toxicological – list Cu, Ni, Cr, Al, vs. LC50s for these metals, list Ca levels in all cases as a competitor, and organic carbon levels as a chelator. Are there bioassays to cite? BLM's to cite?
- (thrive): then list phytoplankton biomass as a food base in both cases – recovered in Sudbury, not in Orta. Presence of planktivores (We have these data for Sudbury, but for Orta there are no planktivores.

Figure 1: photo of liming in both cases, i.e. land and lake in Sudbury, lake in Orta

Figure 2 two panels. Recovery of pH and metals in Sudbury lakes and Lake Orta.

Figure 3: trend of mean richness of Crustacea (Sudbury) and crustacean and rotifer richness in Orta (best would be species/per collection/yr if possible)

Figure 4: species accumulation curves in Sudbury, and Orta – test of arrive, alive

Figure 5: BLM's or bioassays to test survival possibilities. We have this for Sudbury. Should we generate it for Orta?

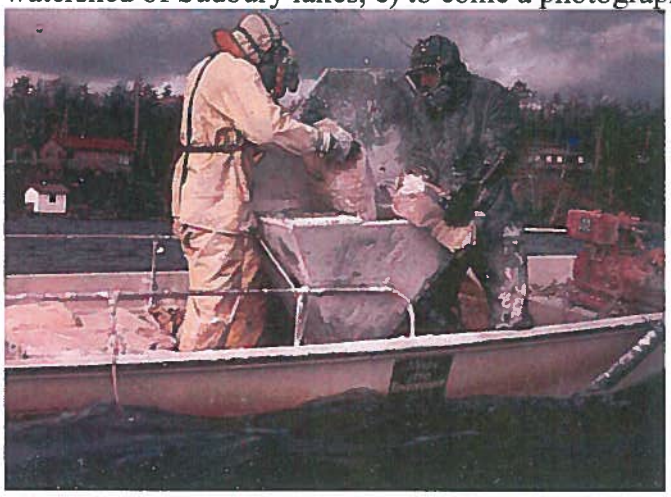
Figure 6: persistence curves in Sudbury and Orta – test of thrive.

Plan for the Discussion – things to include, depending on the Results

- Use of Species accumulation curves to assess arriving alive – problem with species detection limits, i.e. census errors, alternatives are propagule pressure estimates from the invasions literature which are even more indirect (eg. postal codes, and interviews with anglers on where they go). Can use White (2004) Two-phase species-time relationships in North American land birds. Ecology Letters 7:329-336, to estimate census error rate?
- Use of persistence as a measure of thriving – persistence and growth are needed to have enough animals so it makes sense.
- Has recovery of richness occurred, use targets in Dorset for Sudbury (what to use in Orta – Maggiore richness perhaps)

- Consequence of not using the species composition – clearly there is more to recovery than richness, but these methods allow us to identify bottlenecks, and that was our goal
- For Sudbury, the data suggest that differential recovery rates, as measured by pattern of species richness increase, are not controlled by colonist arrival rates. Clearwater gets more species than does Middle consistent with larger lake, more non-acid lakes near by, lower initial metal contamination, more shoreline inhabitants, etc. This suggest that presence of colonists does not limit recovery – they are arriving. What do the Orta data suggest? Are colonists arriving?
- But persistence is higher in Middle than in Clearwater. What is the persistence in Orta? What does this suggest about how the colonists are thriving in the lake.
- Is there a common bottleneck to recovery in both study areas. The bottleneck does appear to be survival in Clearwater, and this could be metal related as Ni is still quite high. In Orta, it isn't Cu, Ni or Al. Might it be Cr?
- What do the results suggest about a logical next intervention to speed recovery of zooplankton? Are there any suggestions for other biota?

Figure 1: photograph of the liming of the study lakes: a) addition of crushed limestone to a hopper during the liming of Middle Lake, Sudbury, in the summer of 1973, b) management liming of the watershed of Sudbury lakes, c) to come a photograph of the liming of Lake Orta in 1989/1990.



b)

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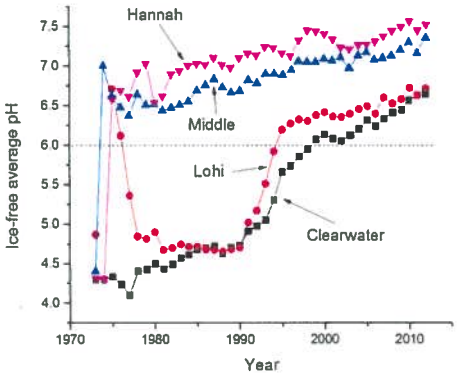
Figure 2: a) recovery of pH, and b) Cu, in 4 Sudbury lakes, and c) recovery of pH and metals in Lago d'Orta.

a)



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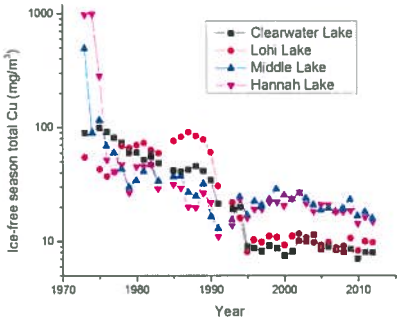

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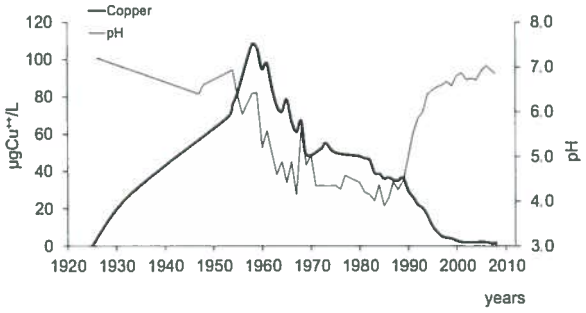


Figure 3: Recovery of crustacean zooplankton species richness (species/sample) average over the ice free season in Sudbury lakes (a), and average over. …in Lake Orta (to come)
a).

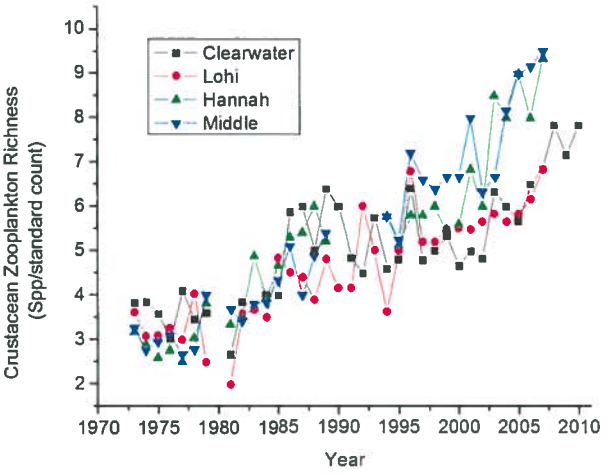


Figure 4. Crustacean species accumulation curve in Clearwater and Middle Lakes in Sudbury (Orta to come)

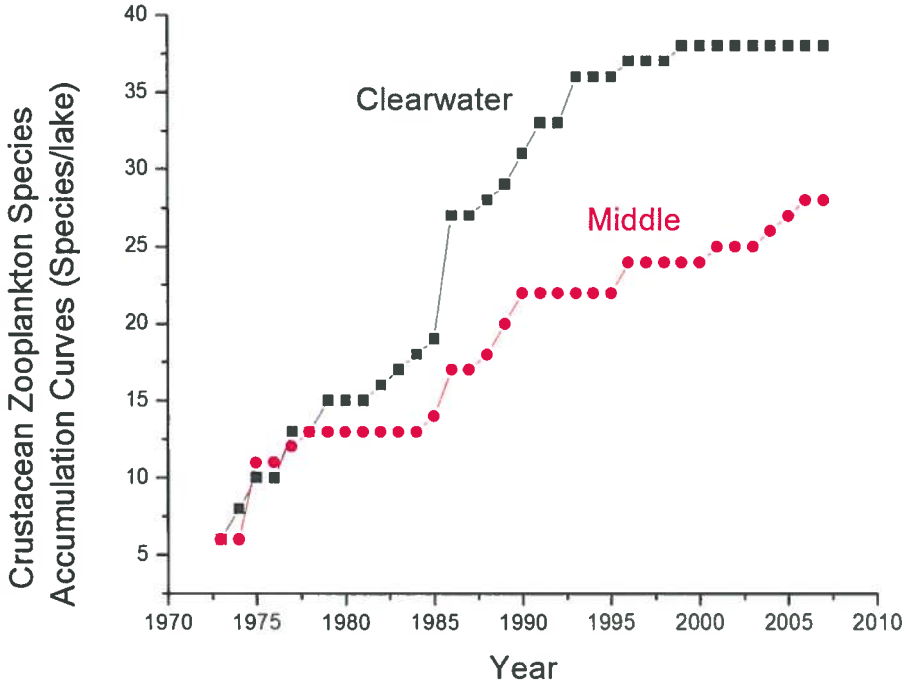
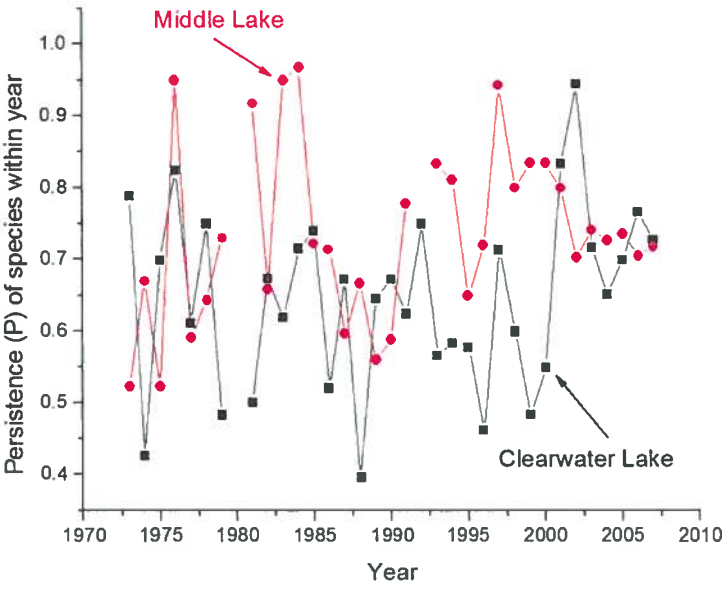


Figure 5. Calculation of annual persistence of crustacean zooplankton species in samples in Middle and Clearwater lakes in Sudbury (Orta to come).



Verbania, September 26th, 2014

Marina Marcella Manca