Winter Survival Strategies of Benthic Invertebrates in Temporary Habitats in a Northern Minnesota Lake

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During the winter months in the northern hemisphere, above 40 degrees latitude, a freezing event occurs that can last several months. Some lakes may have large portions of the shallow littoral zone frozen completely solid down into the sediments. Invertebrates affected by these events have developed survival strategies to cope with the harsh environment. The two main strategies for invertebrates in these areas are to either migrate to a different area and recolonize the original area when it becomes available again, or to burrow into the sediments and withstand the freezing. A 1-month study took place on Lake Bemidji (Bemidji, MN) in the spring of 2013 to identify the survival strategies of these organisms. Core samples were taken in shallow littoral areas to estimate invertebrate densities and determine where in the sediment column the invertebrates were located. When analyzing the samples, it did appear that different survival strategies were being utilized in the different study areas. The deeper sampling locations had the majority (90%) of invertebrates in the top 3 cm of substrate, which favors a recolonization strategy. In contrast the shallow sampling depths showed invertebrates in larger numbers burrowed deeper into the substrate (50% at or below 3 cm). While both strategies were identified while analyzing the data set, migration was ruled out as most Chironomidae were found inside of a cocoon. This lead to the conclusion that burrowing into the sediments was the preferred form of survival in these shallow littoral areas.

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Introduction

During the winter months in the northern hemisphere above 40 degrees latitude, solid ice forms over many lakes and streams. As latitudes reach further north, the depth of ice that forms increases as well as the duration of ice cover. In shallow littoral areas, the water column can freeze solid down into the sediments for many months. Although lakes provide a permanent habitat for aquatic invertebrates, this deep freezing causes small portions of the lake to be classified as temporary habitats and unavailable to organisms. These temporary areas can be defined as those that, from time to time, substantially and suddenly change in suitability (Frouz et al., 2003).

Many aquatic invertebrates have developed physiological and behavioral adaptations to survive in harsh environments, such as extreme temperatures and adverse chemical conditions (Frouz et al., 2003, Tahseen, 2012). These organisms have developed adaptions due to their regular use of temporary habitats, such as small ponds, moist soils, flooded areas, and in the case of this study completely frozen shallow littoral areas of lakes. Chironomids are no exception to these adaptations, but freezing can substantially reduce populations of chironomid larvae (Jackson and McLachlan, 1991). These insects, belonging to order Diptera, are distributed world-wide and use a variety of habitats, aquatic and terrestrial. However, few studies have addressed seasonal variations in chironomid development and densities (Mousavi and Amundsen, 2012), and even fewer Chironomidae studies occur during periods of extended ice cover. Furthermore, the life history of Chironomidae in cold subarctic lakes is not well known (Tokeshi, 1995).

When shallow littoral zones in lakes begin experiencing seasonal freezing, the chironomids in these regions may select to migrate to a more suitable habitat and return to recolonize the original area later. Alternatively, they may construct a cocoon and burrow deep into benthic sediments and remain in their temporary habitat until it returns to a suitable state (Frouz et al., 2003). Each mechanism, migration or burrowing, has advantages and disadvantages. Migration allows the development of larval instars to continue throughout the year. Chironomids overwinter exclusively as larvae (Tokeshi, 1995), but are known to be very active in streams during winter in Minnesota, and can also emerge from those waters during winter (Anderson, 2012). This in turn gives them an advantage over those chironomids that build cases and burrow, however migration does leave them susceptible to predation (Hershey, 1985). Burrowing and building a cocoon does offer protection from predators and reduces the chance of death from environmental stress, but slows growth. Overwintering cocoons are formed by some chironomids that prefer shallow littoral areas containing macrophytes (Saether, 1962). These cocoons can protect them from adverse conditions such as desiccation and freezing, and are constructed with saliva and benthic particles from the area (Frouz et al., 2003).

The purpose of this study is to identify which mechanisms (migration versus burrowing) are used to survive the winter months in a northern Minnesota lake. If migration is found to be the dominant survival strategy, the result of invertebrates condensing into a reduced amount habitat could lead to increased competition between invertebrates, as well as provide an increased food supply to yellow perch (*Perca flavescens*) and other predators.

Materials and Methods

Study Area: The study took place on Lake Bemidji in Bemidji, Minnesota. The lake is located in northern Minnesota and is part of the Mississippi River headwaters drainage basin. The Mississippi River flows into Lake Bemidji from Lake Irving, which is located less than 1.6 km southeast. It then flows out east to Stump Lake. Lake Bemidji covers 2,662 (763 littoral) hectares and has a maximum depth of 23 m. It is in the early stage of eutrophism with an average secchi depth of 2.9 m. The lake experiences ice cover 6-7 months of the year on average. To sample invertebrates, two sampling locations were selected on the western shoreline of Lake Bemidji. Both locations were similar in depth (between 0.32 – 0.38 m for shallow depths and between 0.59 – 0.63 m for deep depths) and substrate composition (fine sand/sand mix).

Data Collection: Data collection took place over a 4-week span starting on 9 April 2014 and ended on 2 May 2014. Preliminary drilling was done to locate the exact point where the water column transitioned into solid ice for each location. Once the ice/water transition zone was located another hole located exactly 0.6 m north (which is parallel to the shoreline) was drilled and marked as the center shallow depth. Re-drilling was done because locating the ice/water transition disturbed much of the sediment. After locating the center shallow sampling hole, two more holes were marked 3 m away from it, one north and one south. Next, 7.6 m was measured out into deeper water from each hole and then marked, and then the distances between each of the deep holes were measured to be exactly 3 m. Once the deep holes were marked, each hole to hole distance was re-measured, and minor adjustments were made to ensure the sampling rectangle was square before drilling (Figure 1).

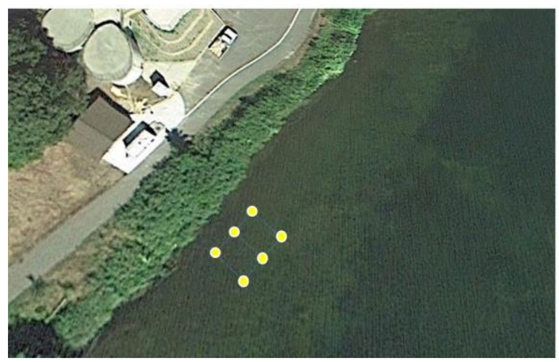
Figure 1. Satellite photo of location 1 on Lake Bemidji and the sampling rectangle. Circles represent holes that were drilled.

A 25.4 cm diameter ice auger was used to drill holes in the ice. To greatly reduce disturbing the sediment, holes were only drilled until the tip of the blade of the ice auger punctured the center of the hole allowing water to slowly fill the hole. Once the ice hole was filled with water to the top of the ice, the remaining ice at the bottom of the hole was chipped away slowly until there was enough room to collect a sample. Holes were measured for water depth, thickness of ice, and the amount of liquid water available under the ice.

After the first sampling date, each of the 12 holes were marked with small underground wire warning flags pushed into the sediment. When re-sampling took place the following weeks, core samples were taken from new holes 0.3 m to the north of the previous week’s to prevent resampling a disturbed sediment column.

Sediment samples were taken in the form of core samples. Core sample tubes were 50.40 cm long with an inside diameter of 4.45 cm. Core samples tubes were manually pushed into the sediment. Each tube was uncapped and pushed into the sediment as far as possible. Once the tube would go no deeper, the top was capped under water creating a vacuum, allowing the tube to be pulled up far enough to cap the bottom without losing sediment. One core sample was taken from each hole for a total of six samples per location per sampling day. The first 12 core samples from the first sampling day were drained of water and alcohol was added to preserve them, however the following 36 samples were processed immediately after sampling. This allowed invertebrates to remain alive while the samples were processed making it easier to locate them.

Each core sample was processed in 1 cm increments totaling 13.96 cm^3 per section. Each section was put into a 20.32 x 25.40 cm white sorting pan and submerged in water. Each sample was examined for a minimum of 5 minutes to ensure maximum invertebrate findings. When invertebrates were found, they were placed into a vial of 70% isopropyl alcohol and marked with a date, sample number and the depth in cm they were found. Organisms were later classified down to family (except for roundworms, segmented worms, and leeches, which were classified down to Nematoda, Oligachaeta, and Hirudinea, respectively) using a dissecting scope.

Data Analysis: To calculate the invertebrate density per 1 cm^3, the total amount of invertebrates were divided by volume (13.96 cm^3) of the sample. Once the density was calculated, invertebrate distribution throughout the sediment column was compared against time in graphs.

Results

Ice Cover: Ice covered the entire lake at the beginning of the study, and began receding throughout the study. The study sites only remained completely frozen for the first week of the study, with the ice receding from the shore and into deeper water as the study progressed (Figure 2).

The study locations may have encountered sporadic ice cover well after ice had receded from the sites initially, due to large ice sheets floating in the center of the lake being blown into the shore from high winds. This was not considered to have any major impacts on invertebrate survival strategies, and was not monitored.

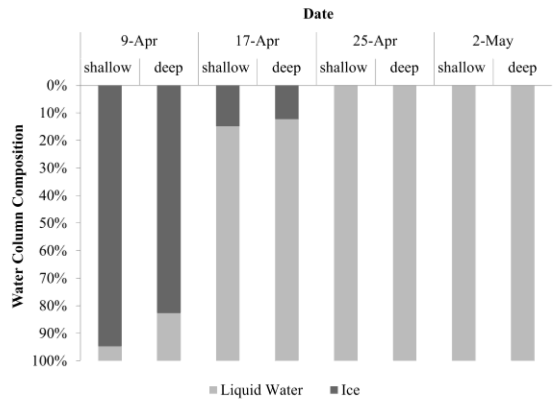

Figure 2. The average percent of the water column that was frozen at shallow and deep depths at each sampling date during the study.

Invertebrate Populations: Multiple taxon of invertebrates were found at both locations, with a large majority (70%) belonging to Chironomidae (Table 1).

Table 1. All taxa found during the sampling period at sampling dates as well as percent each taxa contributed to total invertebrate count.

Taxon	**9-Apr**	**17-Apr**	**25-Apr**	**2-May**	**Total**	**% of Total**
Bivalvia	2	0	3	0	5	4
Chaoboridae	0	1	0	0	1	1
Chironomidae	19	15	30	32	96	70
Emphemeroptera	0	0	2	3	5	4
Gastropoda	1	0	0	0	1	1
Hirudinea	4	3	1	3	11	8
Nematoda	2	2	2	1	7	5
Oligachaeta	0	3	1	0	4	3
Planaria	0	1	0	0	1	1
Trichoptera	1	0	0	0	1	1
Unknown	2	2	2	0	6	4
Total	31	27	41	39	138	

Chironomidae was the most sampled invertebrate and comprised 70% of the total invertebrates found, followed by Hirunidae (8%) and Nematoda (5%). No other taxa comprised more than 5% of the total invertebrate composition (Table 1). Of the Chironomidae that were found 92% of them were enclosed inside of a protective cocoon.

Over the course of the study there was a noticeable increase of invertebrate numbers. A steady increase in invertebrate numbers for both locations suggests that invertebrates were recolonizing both areas as the ice receded (Figure 3). In comparison of populations between the two sites, the deep sampling depths had much higher densities in general versus the shallow sampling depths. This increase was found with

Chironomidae by itself, as well as with all other invertebrates combined (Figure 3).

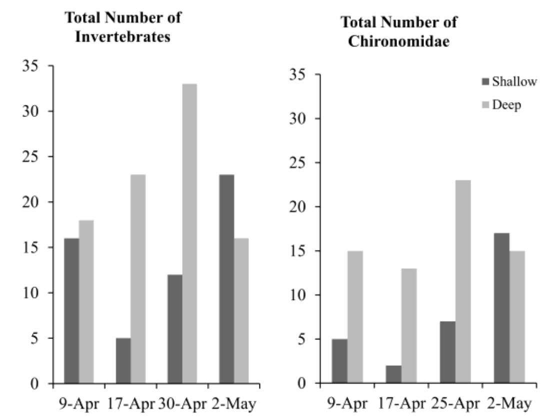

Figure 3. The number of all invertebrates found as well as specifically Chironomidae at both the shallow and deep depths at different dates during the study.

Invertebrate Distribution: Invertebrate densities were found to increase at more shallow depths in the sediment throughout the study at shallow locations sampled (Figure 4).

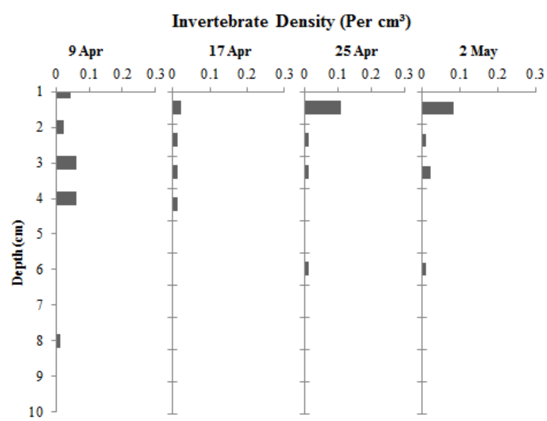

Figure 4. Comparison of invertebrate density (per cm³) at specific depths in the sediment with data collected from Lake Bemidji 9 April to 2 May 2014. This data was collected from areas in the littoral zones at an average water column depth of 0.35 m.

Burrowing into deeper sediments and then returning to the top 1cm of substrate as ice cover receded was the preferred survival strategy at the shallow sites (Figure 4). A significant portion of invertebrates (>50%) were found at or below 3 cm during the first sampling day. The density distribution then shifted, with the final two sampling days having the majority (>50%) of invertebrates residing in the top 1 cm of the sediment (Figure 4). The increase in invertebrate density at different depths in the sediments was not nearly as significant at the deep locations sampled (Figure 5).

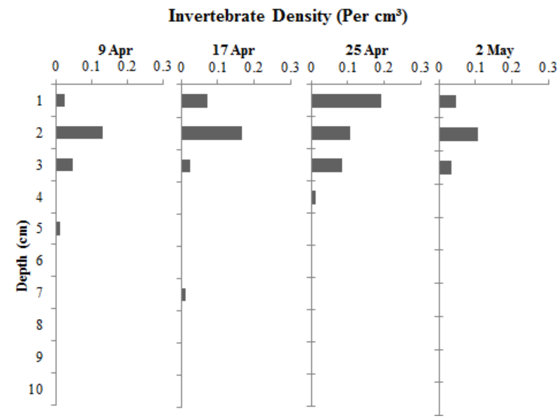

Figure 5. Comparison of invertebrate density (per cm³) at specific depths in the sediment with data collected from a study on Lake Bemidji from 9 April to 2 May 2014. The data was collected in the littoral zone at an average water column depth of 0.61 m.

Discussion

Based on the findings from this study, it appeared that invertebrates at shallow sampling areas that experienced a complete freeze chose to burrow into the sediments as a survival strategy during the winter months. Invertebrates in the deep areas did not show the same strategy and the majority remaining near the top of the substrate for the entirety of the study. However, both sites did appear to be recolonized as the ice receded at steady rates, which was shown by the increase in Chironomidae as well as the other invertebrate densities. The results of this study provide evidence to suggest that invertebrates will use both burrowing and the migration and recolonization strategies. Which strategy was used seemed dependent on depth, but may also be influenced by a number of environmental factors such as how fast the freezing event occurs.

The large majority, 92%, of Chironomidae found were fully enclosed inside of a cocoon which they construct to survive in harsh situations. This survival strategy was used with no evident relationship to depth in the substrate or depth of water, and appeared to be the universal strategy of survival for these taxa. This provides evidence to suggest that migration (since they cannot travel in cocoons) does not occur in these areas. It is very likely that Chironomidae burrow as deep as needed and then construct a cocoon and reside there until their environment returns to suitable conditions. Shallow depths would require burrowing deeper into the sediments to avoid the solid freeze than the deeper depths, which would explain why very few invertebrates were found below 3cm at the deeper depths.

Understanding how invertebrates react to winter conditions could be a very useful tool to help fisheries managers understand the ecosystems they are working in. In the case of Lake Bemidji, yellow perch, a very important game and forage fish may be greatly affected by the survival strategies of these invertebrates. Yellow Perch begin their lives feeding on zooplankton, and then progress to feeding on benthic macro invertebrates (Persson and Greenberg, 1990). Age 0 and 1 yellow perch prefer *Daphnia spp.* and Chironomidae larvae in many aquatic systems, but as *Daphnia spp.* become less available throughout the season yellow perch diets shift to almost exclusively benthic invertebrates (Mills and Forney, 1981), of which more than 64% is chironomids (Persson and Greenberg, 1990). Since yellow perch are the most numerous game fish in Lake Bemidji (MNDNR, 2012), and support a large walleye (*Sander vitreus*) fishery, information related to the timing of an invertebrate migration would be very beneficial.

Identifying a dominant risk-reward survival strategy of aquatic invertebrates during winter may lead to continued and more intensive research on the implications they could have on an entire lake community during the winter months. Future scientist should consider collecting samples prior to the freezing period, which would help give a baseline estimate to accurately monitor invertebrate densities in the shallow littoral zones. The sampling techniques for this project were chosen to effectively capture Chironomidae, which limited the sampling of other invertebrates. Other researchers in the future might consider different sampling areas and habitats, such as the undersides of large logs and rocks. These areas provide habitat for a diverse number of aquatic invertebrates. Monitoring the water temperature as well as other abiotic factors such as light during the spring melt may also help identify any environment queues that trigger Chironomidae migration and re-colonization.

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