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CHARACTERIZATION OF VARYING LOCAL WINTER STREAM HABITAT AND ITS IMPACT ON COLDWATER FISHES

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CHARACTERIZATION OF VARYING LOCAL WINTER STREAM HABITAT AND ITS IMPACT ON COLDWATER FISHES

By

Jesse John Haavisto

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ABSTRACT

CHARACTERIZATION OF VARYING LOCAL WINTER STREAM HABITAT AND ITS IMPACT ON COLDWATER FISHES

By

Jesse John Haavisto

Stream dwelling fish in temperate latitudes are subject to widely varying in-stream winter conditions. Understanding the relative importance of the different factors that contribute to these winter conditions is important in predicting how environmental shifts will affect fish communities. In this study, I examined stream sections within 13 streams located in Marquette and Alger Counties within the Upper Peninsula of Michigan. Streams within a small geographical area were chosen to minimize latitudinal climate variation. Many in-stream winter conditions are driven by temperature so the importance of understanding how changing localized climate patterns may affect the structure and condition of fish communities is of paramount importance to predicting the local impacts of global climate change. During the winters of 2011-12 and 2012-13 winter conditions including temperature, ice conditions, and substrate movement were observed. I used K-means cluster analysis to combine scaled data into three stream classifications based upon temperature-driven winter characteristics (Air Driven, Winter Dynamic, and Thermally Stabilized). Using our classifications, I compared stream class against biological components of each study reach collected from fish captured via electroshocking. While there were no statistically significant differences between clusters for species richness, diversity, or change in condition (K), there were trends toward Winter Dynamic stream reaches having lower values.

DEDICATION

This thesis is dedicated to everyone who helped me along the way.

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LIST OF ABREVIATIONS/SYMBOLS

BG	Big Garlic River
CE	Cedar River
FO	Foster Creek
JO	Johnson Creek
LA	Laughing Whitefish River
LE	Le Vasseur River
LI	Little Garlic River
NE	Nelson Creek
NO	Nordwald Creek
OR	Orianna Brook
SA	Sawmill Creek
SI	Silver Creek
WH	Whetstone Brook
AD	Air Driven Cluster
WD	Winter Dynamic Cluster
TS	Thermally Stabilized Cluster
ΔK	Change in condition

CHAPTER 1: BACKGROUND

Winter is an extremely important season for fish communities in northern latitudes. This importance arises from widely varying in-stream conditions, contributing to lowering of fish condition, causing potential winter mortality, especially upon young fish who have inadequate energy reserves (Bennett and Janz, 2007; Biro *et al.,* 2004). While there have been some winter studies on fish (Brown *et al*., 2011; Heggenes *et al*., 1993; Jakober *et al*., 1998; Linnansaari *et al*., 2009; Cunjak and Power, 1986; Palm *et al*., 2009), most studies looking at river environments and communities have been carried out during the ice-free season. In addition, most studies during winter took place on rivers that remained relatively ice free throughout the winter (Jakober *et al*., 1998). This seeming lack of winter research results from the inherent difficulties involved in carrying out research in winter, including high velocity events at breakup (Brown *et al*., 2001), freezing temperatures, ice buildup, and low light conditions (Prowse and Culp, 2003).

Recent awareness of changing global and regional climate conditions has revealed a need for increased research into how changing winter conditions could affect local riverine systems and the aquatic communities they support (Isaak *et al.,* 2012; Chu *et al.,* 2005). Due to rapidly changing global climate conditions, one of the most important questions that can be evaluated in aquatic ecosystems is how they will respond to global climate changes at the local level (Jensen *et al* ., 2008). The focus of this study is to provide an in-depth look at the factors that constitute stream winter conditions, and to describe how these factors may affect the condition of coldwater fish within a series of localized river systems.

Winter in high latitudes presents challenging conditions, commonly including freezing temperatures, high velocity breakup conditions, rapidly changing water levels due to ice blockages, anchor ice covering bottom substrate, low light conditions due to ice cover, and photoperiod shifts (Whalen *et al*., 1999; Quinn and Peterson, 1999; Prowse and Culp, 2003; Palm *et al*., 2009; Linnansaari *et al*., 2008; Linnansaari *et al.,* 2009; Johnson and Douglass, 2009). These rigorous physical conditions, can cause winter fish mortality, and environmental bottlenecks, or even elimination of small or relatively isolated populations of coldwater species (Heggenes *et al*., 1993).

Winter conditions within streams consist of a continuum of factors that impact the environment (Brown *et al.,* 2011). Past studies have defined winter using combinations of biological timing and environmental conditions (Cunjak and Power, 1986; Biro *et al*., 2004; Brown *et al.,* 2011); however, these definitions have limited utility in comparing across stream regions. By studying the individual elements that comprise in-stream winter conditions, I sought to separate functional "winter" conditions from changes linked to latitudinal gradients (e.g. photoperiod and date).

Ice formation is one of the primary changing factors in winter rivers and is responsible for substantial habitat changes as it can alter depth, velocity, and the amount of suitable habitat available (Whalen *et al*., 1999; Brown *et al.,* 2001; Brown *et al.,* 2011; Jakober *et al.,* 1998; Linnansaari *et al.,* 2009). Because ice can cover stream environments, it can significantly affect the movements of fish by decreasing light availability, and allowing nocturnal activities to occur throughout the day (Linnansaari *et al*., 2008; Heggenes *et al*., 1993; Jakober *et al*., 1998; Johnson and Douglas, 2009). Most salmonids undergo a shift in feeding habits during winter months from feeding during daytime to feeding predominantly at night (Linnansaari *et al.*, 2009; Heggenes *et al.*, 2003). This switch to nocturnal feeding is at least partially due to increased predator avoidance behavior, which increases the probability of overwintering survival (Johnson and Douglass, 2009; and Linnansaari *et al.*, 2008). Increased activity during darkened daylight hours is important because some fish (e.g. salmonids) continue to feed throughout the winter months and this behavior can improve fish condition (Heggenes *et al.*, 1993; Johnson and Douglas, 2009).

Habitat selection by aquatic organisms throughout the winter is also very strongly influenced by ice formation (Cunjak and Power, 1986; Jakober *et al.,* 1998; Linnansaari *et al.,* 2009). Ice formation within streams can cause substantial upstream flooding as well as subsequent blowout events which cause large local changes in water depth and habitat area (Brown *et al.*, 2001; Prowse and Culp, 2003). Ice buildup within stream channels or thickening of the ice surface can also reduce the available area for fish to overwinter (Linnansaari *et al.*, 2009; Palm *et al.*, 2009). Additionally, ice may build up as anchor ice on submerged or partially submerged substrate, reducing fish habitat provided by the substrate, and restricting access to potential food resources (Brown *et al.,* 2011; Whalen *et al.*, 1999).

Temperature, directly or indirectly, also plays an important role in winter conditions. While temperature is one of the controlling factors in the shift from diurnal to nocturnal foraging (Cunjak *et al.*, 1998; Heggenes *et al.*, 1993), the prevailing hypothesis for this shift is predator avoidance rather than physiological need (Huusko *et al.*, 2007). Because of this shift to foraging under lowlight conditions, fish found in streams with ice cover that decreases light levels may have longer foraging opportunities and the potential for higher condition than fish in other streams at the same latitude (Johnson and Douglas, 2009).

Temperature is important in regulating the duration of winter conditions, mainly due to the changes occurring during cooling and warming events, with emphasis placed upon changes that pass the 0^{0}C threshold due to ice formation or depletion (Brown *et al.,* 2011; Jakober *et al.,* 1998; Linnansaari *et al.,* 2008). Dynamic temperature events, whether warming or cooling, within riverine ecosystems play an important role in creating conditions needed for the presence of ice (Brown *et al.,* 2011). The presence of this ice can in turn cause increased in-stream movements of fish (Brown *et al*., 2001; Jakober *et al*., 1998; Whalen *et al*., 1999; Roussel *et al*., 2004). These increased movements can lead to additional energy expenditure during a time when fish need to conserve energy and swimming ability is reduced due to decreased metabolic processes (Cunjak and Power, 1986).

Warming sometimes occurs during the winter and can cause ice break-up, which can result in high stress conditions for stream fish (Brown *et al.,* 2001). These break-up events can cause ice dams to form leading to flooding or excess runoff (Brown *et al.,* 2011). When ice dams break, the resulting high velocity water, combined with ice present within the river, can cause scouring that affects the organisms present (Cunjak *et al*., 1998; Prowse and Culp, 2003). Increased frequencies of these break-up events during the winter are thought to have a negative impact upon the fish communities present within each stream (Prowse and Culp, 2003).

Changing climate conditions are predicted to have significant impacts upon habitat availability and fish assemblages present within the Great Lakes drainage basin

(Mohseni *et al*., 2003; Dolan and Miranda, 2003; Chu *et al*., 2005). During the summer rising temperatures cause many coldwater fish to find their range limited by warming temperatures, while warm water species may expand their ranges northward filling the niches left by their coldwater counterparts (Chu *et al* ., 2005). While much work has been done on looking at how warming trends will likely affect fish assemblages and distribution on the regional level, little attention has been paid at a local scale (Chu *et al* ., 2005). This lack of attention to local scale is even more pronounced in respect to winter effects. Winter impacts include not only increases in average temperature, but also more marked swings of both warming and cooling as well as an increase in extreme climatic events (e.g. flooding) (Jensen *et al.,* 2008; Isaak *et al.,* 2012). These swings could lead to greater variation of in-stream winter conditions.

While studies have focused on how increased temperatures in streams may affect coldwater fish assemblages during the summer months (Hari *et al*., 2006; Mohseni *et al*., 2003; Dolan and Miranda, 2003; Chu *et al*., 2005), research into how this affects the condition of fish communities at a local level is lacking. My study seeks to address this by classifying local streams into groups based upon winter conditions and relating them to biological indicators of fish communities (e.g. species richness, diversity, and change in fish condition). These comparisons will provide a link between in-stream winter conditions and fish community structure. Because many of the major components of our stream classifications rely on water temperature-based measurements, which are highly correlated to air temperatures (Hari *et al.,* 2006; Mohseni *et al.,* 2003), these classifications will be highly sensitive to regional temperature changes. Using our stream classifications we hope to make predictions about how reaches will react to warming or cooling trends. These predictions will allow for stream management decisions related to climate change to be made on the local scale that is necessary for day to day management.

CHAPTER 2: CHARACTERIZATION OF VARYING LOCAL WINTER STREAM HABITAT AND ITS IMPACT ON COLDWATER FISHES

CHAPTER SUMMARY

Stream dwelling fish in temperate latitudes are subject to widely varying in-stream winter conditions. The relative importance of the different factors that make up these winter conditions is important in understanding how changes in conditions will affect community complexity and individual fish status within individual streams. This study examined reaches within 13 different streams located in the Upper Peninsula of Michigan to see what conditions streams experience at a local level. During the winters of 2011-12 and 2012-13, winter conditions including temperature, ice conditions, and substrate movement were observed and recorded. I used K-means cluster analysis to combine scaled data into three classifications (Air Driven, Winter Dynamic, and Thermally Stabilized) based upon winter specific characteristics. These classifications consisted of two distinct groups: stable winter environments (Air Driven and Thermally Stabilized) and dynamic environments (Winter Dynamic). Using these classifications I compared stream clusters against fish data collected at the beginning and end of each study winter. There were no statistically significant differences between clusters for species richness, diversity, or condition (K), although there was a trend for the stable winter environments to have higher species richness (mean=6.00 and 3.5) vs (mean=2.67), diversity (mean=2.84 and 2.11) vs (mean 1.89). Change in condition (ΔK) for a common native species, brook trout (*Salvelinus fontinalis*), showed a similar trend with less decrease in condition for both stable clusters (mean -0.0479 and -0.0121) compared to the dynamic cluster (mean= -0.0954) for the <100mm size class. The larger size class (>100mm) of brook trout, as well as larger size class (>60mm) of sculpin

(*Cottus* spp.) shared the same trend: The lone exception to this pattern being ΔK of small sculpin (<60mm) where Air Driven cluster stream ΔK (mean=-0.159±0.118) was lower than either other cluster. These trends suggest a tendency toward stable stream environments, including both Air Driven and Thermally Stabilized clusters, to have higher values for diversity, species richness, and higher fish condition compared to Winter Dynamic systems.

INTRODUCTION

Due to rapidly changing global climate conditions, one of the most important questions that can be evaluated in aquatic ecosystems is how they will respond to global changes at the local level (Jensen *et al*., 1998). While many studies have examined regional climate change (Isaak *et al*., 2012; Mohseni *et al*., 2003; Cline *et al.,* 2013), few have yet looked at how changes in climate will affect streams within a small geographical area, and none have focused on how these changes will affect in-stream winter conditions. Work focusing on finer scales is important because it can allow us to make predictions on specific regional changes that will occur within streams and understand how local stream variability will be affected by global change (Hari *et al.,* 2006). The focus of this study was to examine the factors that constitute in-stream winter conditions, and characterize patterns of local stream variability. Additionally we examined how these patterns may have influenced the condition of coldwater fish, species richness and diversity of local fish communities.

Winter in high latitudes is a combination of changing conditions including freezing temperatures, high velocity breakup conditions, rapidly changing water levels due to ice blockages, anchor ice covering bottom substrate, low light conditions due to ice cover, and photoperiod shifts (Whalen *et al*., 1999; Quinn and Peterson, 1999; Prowse and Culp, 2003; Palm *et al*., 2009; Linnansaari *et al*., 2008; Linnansaari *et al*., 2009; Johnson and Douglass, 2009). Due to these physical conditions, winter fish mortality often occurs and can serve as an environmental bottleneck or, in extreme cases, lead to extirpation of local populations of coldwater species (Heggenes *et al*., 1993). Winter consists of a continuum of conditions that impact the environment experienced by organisms. While past studies and reviews have defined winter using combinations of biological timing (e.g. spawning) and environmental conditions (e.g. photoperiod) (Cunjak and Power, 1986; Biro *et al*., 2004; Brown *et al*., 2011), I took a more physical approach to defining winter, basing study start and end dates on local ice conditions. This approach allowed me to establish the times when winter conditions were present within each stream to investigate local variability within the winter period.

Temperature strongly regulates in-stream winter conditions, particularly during rapid cooling and warming events around the freezing point (Brown *et al*., 2001). Dynamic temperature events during the winter, whether warming or cooling, play an important role in creating conditions needed for the presence of anchor and frazil ice (Brown, 2011). Ice formation is responsible for substantial habitat alteration, including depth and velocity change (Whalen *et al*., 1999). Because of the ability of ice to cover stream environments, it can, by itself or with snow cover, significantly affect fish behavior by decreasing light availability and allowing nocturnal activities to occur throughout the day (Linnansaari *et al*., 2008; Heggenes *et al*., 1993; Jakober *et al*., 1998; Johnson and Douglas, 2009). Affected behaviors include feeding (Linnansaari *et al*., 2009; Heggenes *et al*., 2003) and predator avoidance (Johnson and Douglass, 2009;

Linnansaari *et al*., 2008) where winter cover increases the probability of overwintering survival.

Previous winter work has emphasized the importance of stable in-stream winter environments (Brown *et al.,* 2001; Cunjak and Power, 1986; Huusko *et al.,* 2007) and, while none have characterized all the conditions that comprise these environments, temperature thresholds seem to be one of the most important indicators of stability in streams (Linnansaari *et al.,* 2009). It has been proposed that stability within streams is best achieved by maintaining an ice-free environment year round or by freezing over once and maintaining this stability for the remainder of the winter (Brown *et al.,* 2011). These two sets of conditions can be present within many streams with limited additional groundwater inputs, along with the addition of a third intermediate dynamic section of stream separating the two (Brown *et al.,* 2011).

My study focused upon stream sections in 13 streams in Marquette and Alger Counties within the Upper Peninsula of Michigan. Streams in a small geographical area were chosen to minimize variation due to latitudinal conditions, such as photoperiod. Many in-stream winter conditions are driven by temperature (Brown, 2001) so the importance of understanding how changing localized climate patterns may affect the condition of fish communities is of paramount importance.

While studies have been done on how increased temperatures in streams have affected salmonids during the summer months (Hari *et al*., 2006), research into how this affects the condition of fish communities at a local level in winter are lacking. My study addresses this lack of research, by classifying local streams based upon winter conditions and relating them to biological indicators (e.g. species richness, diversity, and change in fish condition). Using our stream classifications, predictions may be made about how reaches will react to warming or cooling trends.

METHODS

Study site setup

Study streams (13) were selected throughout Marquette and Alger counties within the Upper Peninsula of Michigan to represent a variety of local stream habitats, including different amounts of groundwater input and substrate types. Other criteria for selection of study streams included winter accessibility, landowner-permitted access, and adequate stream size to allow for efficient electrofishing.

For the winter of 2011-12, the start of winter condition measurements and beginning of winter electrofishing were placed as close as possible, but before, the onset of major ice formation events on any of the study reaches. During the winter of 2012-13, the start of winter measurement was matched as closely as possible to the 2011-12 winter to minimize differences in photoperiod and other daylight driven conditions. The end of winter sampling for both years occurred on the first weekend when all 13 streams were ice-free enough to allow for electrofishing (approximate 50% uncovered).

In each stream, a 100 m study reach was selected and then divided into ten 10 m sections to allow for repetition in habitat measurements. Surface area was calculated at the start of winter 2011-12 by measuring stream width perpendicular to the flow for each 10m section, and compiled to estimate overall reach surface area. Pebble counts were made in ten locations perpendicular to the flow at 30m, 60m and 90m within each reach with recovered substrate being classified as either sand (<2mm), gravel/cobble (2-

256mm), boulders (256-4096mm), or bedrock (>4096mm). Each reach was then classified by its substrate type.

At the approximate center of each reach in areas of similar flow (0.20 ± 0.017m/s) and depth (0.26±0.007m), temperature data loggers (DS1921G Thermochron® ibutton, Maxim Integrated, San Jose, CA) were placed in waterproof housings, submerged, and anchored to stakes driven into the streambed. Depths were measured from the streambed to the surface of the water, and velocities were measured from the approximate center of the data logger housing after its installation. A second data logger was placed in a similar housing streamside at each location to record air temperature. Temperature was measured hourly throughout the winter season (Dec-Apr) for both winters, and during the summer of 2012 between study winters.

To assess vertical streambed movement during the 2012-13 season, three stakes of varying lengths were placed at equally spaced intervals along a cross section of each river (except Le Vasseur River due to its predominately bedrock substrate) perpendicular to the direction of primary stream flow in the fall. Stakes were marked and driven into the substrate; a washer with an outside diameter of ~57mm was dropped onto the stake which was then marked along the top of the washer. In the spring (within two days of electroshocking) the washer was dropped back onto each stake, the stake remarked at its new level, and then removed. Differences between marks on the stakes were recorded.

To evaluate substrate movement within four study streams that were dominated by gravel or cobble substrate, a study of in-stream rock movement was undertaken in winter 2012-2013 similar to (Edwards and Cunjak, 2006). Within each subject stream, 100 rocks were collected; 50 were <65mm (range=30-59mm) and 50 were >65mm (range=78-110mm) across their longest axis. Rocks of each size were divided into three nearly equal groups and painted red, yellow, or blue with nontoxic spray paint. Painted rocks were returned to their stream of origin and each group of the same color was equally spaced on one of three lines spaced 1m apart and oriented perpendicular to the current. Rocks were placed immediately after electroshocking in the fall, and were collected immediately after spring electroshocking, before large scale spring runoff, to best evaluate substrate movement within the winter period. Movements were recorded as downstream distance moved from initial location.

Ice Methods

Ice formation can be one of the most obvious physical changes evident in a stream during the winter months; however, it can also be one of the most challenging to quantify. The differences in ice among my study streams were assessed using photos and observations that were made at predetermined locations on a weekly basis during both study winters. During weekly visits to each study site, a visual estimation of surface ice (defined as ice in contact with the water and covering its surface) within the reach was determined as 0, 25, 50, 75, or 100% total coverage. A photo was also taken in a similar location each week for additional analysis. In cases where more than one observation was made per week, the observations were averaged and recorded as the weekly ice cover. In rare cases (4 in 2011-2012 and 7 in 2012-2013) when an ice observation was not made during a week, the weekly means from the preceding and following weeks were averaged to replace the missing week.

During 2012-13, winter ice coverage was divided into two groups: surface ice (as defined previously) and cover ice, which was defined as ice providing cover by virtue of its opacity or snow load. Cover ice included hanging ice and snow bridges that had no physical contact with the water itself, but provide thermal and visual cover, as well as surface ice which was opaque or snow covered. To allow for comparisons between years despite their different winter lengths (2011-12 consisting of 15 weeks, and 2012-13 lasting 19 weeks), average surface ice (for 2011-12 and 2012-2013) and ice cover (2012-13) also had their yearly averages calculated.

Biological Sampling

During the beginning of each winter study period, within a three day period, all study streams were sampled with single pass electrofishing using a Badger® model electrofishing unit (ETS Electrofishing LLC, Verona, WI) with a duty cycle of 10% and a voltage range 270-280V. Number of nets used varied between 2 and 3 depending upon the size of the stream and the available open water. All fish captured were placed in aerated holding containers. Fish were measured for length, weight, and identified to species, before being returned to their stream. Mottled (*Cottus bairdii*) and slimy (*Cottus cognatus*) sculpin were batched together as *Cottus* spp. due to difficulties in determining species of small specimens ~40mm in cold conditions.

Streams were electrofished using the same methods during the first weekend in the spring that all streams were ice-free enough (~50% ice free) to allow for electrofishing; they were fished using identical protocols to beginning of winter electrofishing. When ice was present within a stream, all open water and edges of ice were fished leading to varying areas of stream being sampled. Due to these varying ice conditions, and the focus upon capturing suitable numbers of fish, no attempt to control effort or measure catch per unit effort for reaches was made.

Data analysis and statistical tests

Using both winters temperature data, hourly water temperatures were graphed as a function of hourly air temperature to determine if air temperature alone was the source of variation in stream water temperatures. Summer temperature data was also graphed to show differences in stream temperature variation between seasons. Mean daily water and air temperature in each stream during winter were also determined for each stream.

To generate a quantitative method of comparing streams according to important temperature thresholds, freeze days and warm days were calculated. Freeze days are number of days with water temperatures dropping under 0.5^{o} C, calculated to give an approximate number of days icing events were possible, and warm days are defined as the number of days where the average daily temperature reached above 4^{0}C, the approximate temperature of local ground water.

Due to inter-annual variation within our study region, spring breakup was delayed a month between our first and second study years leading to winters of different lengths. To better compare the two years, our two temperature pattern metrics (freeze days and warm days) were calculated as the proportion of total days throughout the winter for each reach.

Winter based values collected for both study years were compared and pooled, due to lack of statistical difference, for analysis via K-means cluster analysis. Due to the winter basis of this study, and significance of the differences between them, only winter data rather than general stream habitat data, was used in clusters. Vertical streambed movement was the only exception as it was considered a winter-based data set, but differences in movement between streams were not significant so it was removed from the cluster analysis data set.

All fish species captured were organized by the number of streams in which they were present, as well as their mean size, range of sizes, and how many were captured per sampling period. Stream communities were compared using species richness (number of fish species present) calculated as the number of species captured during all of the four samplings within each study reach. These total values were placed into their cluster groups and tested against stream cluster groups to determine any significant differences in richness due to cluster membership.

Due to our small sample area (100m) within each stream, I assessed whether the fish captured were representative of the actual fish community present. This assessment was made by comparing species richness data against previously collected data from other sampling efforts by state and federal agencies during the summer months within the past three years (Michigan DNR, unpublished data). The seven streams for which species richness data was available were compared to our study streams to evaluate differences.

To assess diversity within study streams I calculated Simpson's diversity index for each reach, using the total numbers of each species captured within each stream for all sampling periods. Total diversity values from this analysis were then compared among stream clusters.

Two common species brook trout (*Salvelinus fontinalis*) and sculpin (*Cottus* spp.) whose presence spanned all three stream clusters, were evaluated for Fulton's condition factor (Fulton, 1904), a method of evaluating fish condition (Froese, 2006) each winter. I split both species into two size classes: <100mm and >100mm for brook trout and <60mm and >60mm for sculpin. Lack of a significant difference between years allowed us to evaluate sculpin condition data on a stream by stream basis. Using stream data cluster, groups were assessed and results showed whether cluster groups differed in change in condition over the winter. All statistical testing was done for this study was performed using SigmaPlot for Windows version 11, with the exception of K-means cluster analysis which was done using SPSS version 21.

RESULTS

Study reaches (13) were spread across ~55km of coastline on the southern shore of Lake Superior, between the latitudes of N46 42.004 and N46 22.563 representing a variety of local stream systems, sizes (mean surface area=507.6±106.3m^2), and habitat characteristics (Table 1). Winter start dates for 2011-12 and 2012-13 winters were closely matched (12/5/11 and 12/3/12, respectively). However, winter end dates for the two years differed by 30 days.

Mean winter air temperatures did not vary between years (Mann-Whitney p=0.891). Air temperatures varied (Kruskal-Wallis H=157.745, 12df, p=0.001) between streams; the range of mean temperatures was slight (range= 1.068°C), with a mean temperature of -4.088°C ±0.0217 across all streams. This slight variation is consistent with the expected range over a small geographical area. Like air temperature, water temperature did not vary between years (mean=1.14°C ± 0.278, Mann-Whitney p=0.858), but did vary between streams (Kruskal-Wallis H=56766.328, 12df, p=<0.001) with a larger range than air temperatures (range=3.90 °C).

Mean vertical substrate movements within streams varied (mean=-2mm ± 4.726 to 56 ± 8.145), but did not differ between streams (Kruskal-Wallis H=0.865, 11df, p=0.583. In streams with predominantly gravel or cobble substrate, small rocks moved (mean=0.18m ± 0.02) farther than larger rocks (mean=0.08m ± 0.01) (Mann-Whitney p<0.001) and the differences in movement between rock sizes was significant (Kruskal-Wallis H=19.156, 3df, p<0.001) (Figure 1).

Yearly percent total surface ice coverage means (2011-12 and 2012-13) were similar (Mann-Whitney p=0.918). Among streams there were large variations in both mean yearly surface ice (Range: 0-93% total winter coverage) and ice cover (Range: 0-95% total winter coverage) (Figure 2). Freeze days and warm days compared between years showed no significant differences between years for freeze days (t-test p=0.535) or warm days (t-test p=0.531).

Biological sampling resulted in a total of 1,526 fish captured representing 16 different species (Table 2). Fish communities varied in species richness and diversity from the most simple with only one species present, to the most species rich (in our sample) with 10 species. Overall species diversity varied significantly between streams (one-sample t-test t=8.60, 12df, p>0.001) with a mean of 2.4 ± 0.28. Species richness within streams also showed significant differences between streams (one-sample t-test t=5.966, 12df, p>0.001) with a mean of 4.46 ±0.75. Additional analysis comparing species richness data against (7) streams where previous biological sampling had occurred showed no difference in richness among data sets (Chi squared= 21, 16df, p=0.179).

Cluster Analysis

K-means cluster analysis, using mean composite values of winter data, (Table 3) created clusters (Table 4) that differed (Kruskal-Wallis) in average temperature (H=51821, 2df, p=<0.001), surface ice (H=105.688, 1df, p=<0.001), ice cover (H=28.562, 1df, p=0.001) , and freeze days (H=10.413, 2df, p=<0.001). Warm days however, didn’t vary significantly between clusters (H=6.741, 2df, p=0.066) (Figure 3). Three was chosen as the number of groups, to represent the three sets of conditions found within streams that experience freezing events (Brown *et al.,* 2011)

Clusters were named according to the type of stream they represented: Air Driven, Winter Dynamic, and Thermally Stabilized. Air Driven streams had water temperatures close to freezing, a high percentage of freeze days, no warm days, and high incidence of ice. Thermally Stabilized streams had warm (for winter) water temperatures, a low percentage of freeze days, a high percentage of warm days, and low incidence of ice cover. Winter Dynamic streams were intermediate between Thermally Stabilized and Air Driven streams and showed traits common to both (Table 5).

Air temperatures varied slightly by stream type (Table 5), (Kruskal-Wallis H=17.492, 2df, p = <0.001), with the highest temperatures found in the Winter Dynamic cluster streams. Regression lines generated when air temperatures were plotted against water temperature showed thermally stabilized streams differing the most compared to air temperatures (Figure 5A), with the opposite being true during the summer months (Figure 5B). Additional pair-wise comparison (Dunn’s) showed that the Air Driven cluster’s air temperature was significantly different from the Winter Dynamic and

Thermally Stabilized clusters ($p<0.05$), but Winter Dynamic and Thermally Stabilized clusters did not differ ($p>0.05$).

Biological cluster comparisons

Species richness was similar between clusters (ANOVA F=2.310, 2df, p=0.150). Despite the lack of difference (Figure 6), average richness for streams in both Air Driven (mean=6.00 ± 1.18) and Thermally Stabilized (mean=3.50 ± 0.87) clusters showed a trend toward being greater than the winter dynamic cluster (mean=2.67±1.20).

Diversity values across stream clusters showed no significant difference between clusters (ANOVA F=1.145, 2df, p=0.357). However, average diversity for streams in both Air Driven (mean=2.84±0.36) and Thermally Stabilized (mean=2.11±0.38) showed a trend toward higher values than the Winter Dynamic cluster (mean=1.89±0.85) (Figure 7).

For small size brook trout, ΔK was -0.048 for the one Air Driven stream where they were present, and mean ΔK was -0.012 ± 0.05 for the Thermally Stabilized streams where these fish were found. Both of these values showed a trend toward being greater than the one Winter Dynamic cluster stream ($\Delta K = -0.0954$) (Figure 8). For large brook trout, the trend was the similar for the one Air Driven stream where they were found ($\Delta K = 0.003$) and for Thermally Stabilized streams (mean $\Delta K = -0.042 \pm 0.04$), while the Winter Dynamic cluster streams had a value of mean=-0.099±0.12 (Figure 8).

Sculpin were present in the largest number of streams (11), but were only captured in sufficient numbers to compare ΔK across nine locations. ΔK for sculpin was compared between years (t-test, p=0.429) as well as among stream clusters (Kruskal-Wallis H=10.912; 8df; p = 0.207) with no significant differences found. Large sculpin

(>60mm) mean ΔK's for both Air Driven (mean=0.11±0.032) and Thermally Stabilized streams (mean=0.10±0.051) showed a trend toward being greater than for the Winter Dynamic stream (ΔK = 0.065) (Figure 9). However, ΔK for small sculpin had the lowest value for the Air Driven cluster (mean=-0.16±0.12) (Figure 9).

DISCUSSION

Winters are complex combinations of conditions with which fish communities must contend (Brown *et al.*, 2011; Whalen *et al.*, 1999; Quinn and Peterson, 1999; Linnansaari *et al.,* 2008; Johnson and Douglas, 2009). Most global and regional climate change models predict broad regional changes in fish distribution as a result of changes in temperature and frequency of extreme events (e.g. flooding) (Jensen *et al.,* 2008; Hari *et al.,* 2006; Isaak *et al.,* 2012; Rahel *et al.,* 1996). Because of this focus on broad trends and changes, most of these models gloss over local variability within their models (Hari *et al.,* 2006) and yet management must often operate at these smaller scales. The goal of this study was to compare streams within a small spatial area to characterize current local winter variation, and in turn examine how this variation affects overall stream communities and fish condition.

To determine if streams exhibited local variability, despite experiencing similar conditions, I first compared the climate conditions surrounding each stream. The best way of comparing climate conditions at each stream was through air temperature data collected streamside, due to the tendency of stream temperatures to follow air temperatures (Mohseni *et al.,* 2003; Hari *et al.,* 2006). My large number of temperature readings (>5000 per stream) allowed me to detect small differences between sample sites. However, mean temperatures were as expected from streams within a small geographical area and allowed me to study local conditions not seen on regional temperature models (Isaak *et al.,* 2012). The mean values varied less than water temperatures suggesting that, while these temperatures did affect water temperatures, local water temperature differences were due to more than just air temperature.

While some studies have compared winter conditions within streams to see if any individual factor affected fish within a single system (Roussel *et al.,* 2004; Johnson and Douglas; Linnansaari *et al.,* 2008), none have looked at combined winter condition effects. These combined conditions were used to group streams with similar sets of winter characteristics, which I then compared to see if these groupings were related to community makeup or condition. Among our 13 study streams average water temperature differed by more than 3^0 C between cluster groups. This resulted in a group of streams that spent nearly the entire winter under a solid cover of ice (Air Driven), a group that experienced multiple freezing and thawing events (Winter Dynamic), and a group that rarely experienced a single icing event (Thermally Stabilized). Both Thermally Stabilized and Air Driven streams exhibited relatively stable in-stream winter environments. Air Driven conditions were closely associated with air temperature (usually below freezing during the study), while Thermally Stabilized conditions did not closely associate with air temperature. Winter Dynamic streams, with their frequent crossing of the freezing point and presence of both warm and freeze days, exhibited a dynamic environment that has been shown to be detrimental to fish condition (Brown *et al.,* 2011). With a premium placed on stable winter environments (Whalen *et al.,* 1999; Brown *et al.,* 2011), it is not surprising that I saw trends toward higher condition values, in our two stable stream clusters. This stability could, however, result from very different conditions suggesting that winter dynamism in streams is a more important parameter to monitor than absolute temperature when considering winter impacts on fishes.

Aside from air temperature, one of the most important influences upon stream temperatures is the influence of groundwater inputs (Brown *et al*, 2011; Isaak *et al.,* 2012). All my study streams originated from groundwater inputs above the selected study reaches. The effect of ground water on in-stream temperatures (assuming no further inputs) is most prevalent nearest the source and decreases downstream as air temperature acts upon the water in the stream (Brown, 2011). Fish often aggregate within ice-free areas near enough to a source of groundwater for the stream to remain open throughout the winter (Cunjak and Power, 1986). I was unable to directly link groundwater to the temperature variation I saw within my study; however, it was likely responsible for that variation. Groundwater's relative wintertime warming (Brown *et al.,* 2011) influence was likely responsible for the higher average water temperatures and lack of ice cover in Thermally Stabilized streams, and probably contributed to the dynamic nature of Winter Dynamic streams.

The three reach classifications (Thermally Stabilized, Winter Dynamic, and Air Driven) used in this study may all be present within groundwater sourced streams with a progression from Thermally Stabilized at the groundwater source to predominantly Air Driven farther downstream from groundwater inputs (Brown *et al.,* 2011). This likely progression, and the possibility of additional downstream groundwater inputs, are important and affect winter conditions within a stream. Habitat differences present within each stream system are not necessarily taken advantage of by fish due to limited mid-winter fish movements (e.g. in salmonids) (Linnansaari *et al.,* 2008). These limited winter movements, combined with high site fidelity year round for some species (e.g. sculpin) (Edwards and Cunjak, 2006), allow us to reasonably assume that fish present within study reaches spend the majority of the winter within those reaches or similar nearby habitats; however, we do not yet fully appreciate the role of shifting winter habitat characteristics in over-wintering success. This may be even more important to understand with the increasing impacts of climate change on these local conditions.

It is important to note that, in this study, I focused on winter conditions. While Thermally Stabilized streams are warmer and showed more difference in temperature in relation to air temperature, because of their unfrozen nature, during winter months, (Figure 8A), they are not usually warm during the rest of the year. Groundwater influence provides a stream base-flow that is relatively constant (Siitari *et al.,* 2011) and has a cooling influence during the summer in these systems. Most groundwater influenced (e.g. Thermally Stabilized) reaches are what would be considered “cold water” streams by management agencies in our region and provide good summer temperatures for cold water species like salmonids and sculpins (Rahel *et al.,* 1996; Edwards and Cunjak, 2006). In my study the temperature data for the summer of 2012 showed air temperatures having the least relationship to water temperatures in Thermally Stabilized streams, with temperature effects becoming more pronounced in Winter Dynamic streams, and even more linked in Air Driven streams (Figure 8B). This relationship is a confounding concept common in the management literature because coldwater streams are not actually the coldest in an area throughout the year.

Obtaining a representative sample of the species present within each study reach was an important part of this study. I compared my findings with other sampling efforts (e.g. Michigan Department of Natural Resources, Troy Zorn, personal communication) at nearby locations within the same streams. In streams that had been previously sampled in other studies, there were slight differences in species richness; however, the differences were not significant. These additional sampling efforts occurred during the summer months; however, leading to possible discrepancies stemming from the tendency for some fish to undergo seasonal movements (Jakober *et al.,* 1998; Whalen *et al.,* 1999). Due to differing sampling protocols between study sampling, species richness was the only community metric I was able to compare. It would be advisable to increase the amount of sampling done in different seasons to increase our understanding of community dynamics in streams.

Using the stream groups, I evaluated change in fish condition (ΔK) over the winter as well as indices of community structure (richness and diversity). While my research failed to statistically show that these variables were linked to cluster membership, it did suggest a tendency in nearly all mean values for most cases for Winter Dynamic streams to have lower values for fish condition, species richness, and community diversity. With more samples, we would be able to evaluate these trends more thoroughly, but they are suggestive of a potential relationship between dynamism of winter conditions and fish biology. Potential variables that may also have influenced richness and diversity within stream reaches include each stream's connectivity to other water bodies as well as other distinguishing characteristics such as overall watershed size and land use. Disturbance events, and more importantly the frequency of disturbance events can also have impacts upon species richness and diversity; however, current research suggests these impacts vary greatly by species group and are difficult to quantify due to the many variables involved in riverine disturbances (Ward *et al.,* 2002).

Disturbance events in many environments can cause unpredictable changes in species richness, diversity, and community makeup (Ward *et al.,* 2002; Townsend *et al.,* 1997; Whittaker *et al.,* 2001); however, some of these changes are thought to be partially explained by intermediate disturbance levels that lead to the greatest levels of species richness (Connell, 1978). This is likely due to the ability of disturbance to limit competitive exclusion in environments that would otherwise have become dominated by a few species (Townsend *et al.,* 1997). While infrequent disturbance events can have a positive effect upon species richness, frequent events can decrease the number of species able to cope with disturbance (Townsend *et al.,* 1997; Ward *et al.,* 2002). Limited disturbance levels associated with spring breakup and associated high-velocity events may be occurring in our stabilized stream environments, while dynamic streams may be experiencing more frequent disturbance events which may be acting to limit their communities. Application of disturbance theory to this system would likely be beneficial in furthering our understanding of the mechanisms of winter's impact on fishes.

Sculpin were common in our streams and are usually considered a good indicator of coldwater fish communities. Slimy (*Cottus cognatus*) and mottled (*C. bairdi*) were combined in this analysis due to their similar life history traits and similar condition values (Kinziger, 1998). Our large (>60mm) sculpin were likely preparing to spawn during the spring sampling period (Edwards and Cunjak, 2006). This assumption is supported by the presence of spawning colors during spring sampling periods, and this pre-spawning status is likely the cause of the increase in sculpin condition in all study streams compared to fall. This increase in condition is unlike the overwinter change in condition found in other species observed in this study and others (Linnansaari *et al.,* 2008). In the case of small (non-reproductive) sculpin, whose biology is closely linked to substrate movements and have been shown to be more vulnerable to flood and scour events than large sculpin (Edwards and Cunjak, 2007), the large substrate movements present within the Little Garlic River study reach may have caused the lower condition values observed for that Air Driven stream.

Accurate stream classifications that predict fish condition, species richness and diversity may aid assessment of changes occurring within streams as the climate goes through global shifts. Because regional climate changes will be reasonably consistent across a small spatial area (Hari *e*t al., 2006), communities in streams at the margins between one winter stream group and another may be more affected by climate changes. For example, streams might pass into or out of the Winter Dynamic cluster group. This shift could presumably lead to changes in individual fish species status and community structure while systems that remain in the grouping might not be as adversely affected. The ability to identify streams that are close to this dynamic condition may allow managers to prioritize these systems for monitoring or restoration.

This study has laid groundwork for new methods of quantitatively assessing winter stream conditions (temperature variability and ice formation) and evaluated overwinter condition changes in multiple local species. Further work involving a larger number of stream reaches, as well as streams, and including groundwater input data should aid in clarifying the trends seen in this study. Multiple years of data collection spanning a variety of types of winters should also allow us to observe shifting of streams among winter condition clusters and any potential effects of these changes.

Table 1. Stream list with geographic location and basic physical stream characteristics present in data logger locations.

Stream	Location WGS 84	Brief Description	Study Area m^2	Substrate
Big Garlic River	Marquette County N46 40.963 W87 34.261	3th order independent drainage to Lake Superior	576	Sand
Cedar Creek	Marquette County N46 27.111 W87 22.225	Tributary to Chocolay River drainage system	626	Sand
Foster Creek	Marquette County N46 25.539 W87 15.894	Tributary to Chocolay River drainage system	433	Gravel
Johnson Creek	Marquette County N46 24.404 W87 14.213	2nd order tributary to Chocolay River drainage system	251	Sand
Laughing Whitefish River	Alger County N46 29.165 W87 02.834	2nd order independent drainage to Lake Superior	1542	Cobble
Le Vasseur Creek	Marquette County N46 27.834 W87 11.752	2nd order tributary to Chocolay River drainage system	851	Bedrock
Little Garlic River	Marquette County N46 40.429 W87 32.472	3rd order independent drainage to Lake Superior	517	Gravel
Nelson Creek	Marquette County N46 22.563 W87 14.153	Tributary to Chocolay River drainage system	724	Cobble
Nordwald Creek	Marquette County N46 32.987 W87 29.075	1st order tributary to Dead River drainage system	164	Sand
Orianna Creek	Marquette County N46 31.765 W87 25.076	2nd order independent drainage to Lake Superior	173	Sand
Sawmill Creek	Marquette County N46 42.004 W87 35.257	2nd order tributary to Big Garlic River Drainage system	235	Sand
Silver Creek	Marquette County N46 28.358 W87 23.867	Tributary to Chocolay River drainage system	291	Sand
Whetstone	Marquette County N46 32.701 W87 26.278	2nd order independent drainage to Lake Superior	216	Sand

Table 2. Summary of all fish species found in any study reach, with distribution and abundance information.

Common Name	Species	# of streams found	Average size (mm)	Size Range (mm)	Average # caught per sampling in streams with species present	Total # caught
Brook Trout	*Salvelinus fontinalis*	10	94	25-244	12.28	491
Sculpin	*Cottus* spp.	11	70	31-131	9.5	418
Rainbow Trout	*Oncorhynchus mykiss*	7	95	44-355	8.11	227
Brown Trout	*Salmo trutta*	5	120	51-280	10.25	205
Coho Salmon	*Oncorhynchus kisutch*	5	88	68-120	2.25	45
Creek Chub	*Semotilus atromaculatus*	3	107	42-208	1.42	17
Blacknose Dace	*Rhinichthys atratulus*	3	74	34-104	6.83	82
Longnose Dace	*Rhinichthys cataractae*	3	83	51-129	1.33	16
Redbelly Dace	*Chrosomus eos*	1	60	41-88	1.25	5
Iowa Darter	*Etheostoma exile*	1	49	49	0.5	2
Silver Redhorse	*Moxostoma anisurum*	2	107	93-120	0.25	2
Golden Redhorse	*Moxostoma erythrurum*	1	143	90-196	0.5	2
Common Shiner	*Luxilus cornutus*	1	78	60-91	1.75	7
Eastern Golden Shiner	*Notemigonus crysoleucas*	2	98	68-117	0.63	5
Emerald Shiner	*Notropis atherinoides*	1	92	92	0.25	1
Common mudminnow	*Umbra krameri*	1	90	90	0.25	1
Total # Caught						1526

Table 3. Components of winter based data used in cluster analysis.

Stream	Winter composite temperature	Surface ice composite	Warm days composite	Freeze days composite	Ice Cover 2012-13
Big Garlic	0.15	0.79	0	0.89	0.78
Cedar	3.20	0.033	0.26	0.02	0.28
Foster	0.52	0.19	0	0.57	0.26
Johnson	-0.38	0.90	0	0.97	0.87
Laughing Whitefish	0.05	0.84	0	0.96	0.88
Le Vasseur	0.002	0.81	0	1	0.84
Little Garlic	0.046	0.58	0	0.96	0.60
Nelson	-0.20	0.93	0	0.99	0.95
Nordwald	3.45	0	0.16	0	0
Orianna	0.78	0.08	0.004	0.52	0.05
Sawmill	2.40	0	0	0	0
Silver	3.23	0	0.23	0.007	0
Whetstone	1.60	0.16	0.007	0.16	0.5

Table 4. Stream cluster assignments- derived via K-means cluster analysis using winter driven conditions.

Stream	Winter based cluster membership
Big Garlic River	1
Cedar River	2
Foster Creek	3
Johnson Creek	1
Laughing Whitefish River	1
Le Vasseur River	1
Nelson Creek	1
Nordwald Creek	2
Orianna Brook	3
Sawmill Creek	2
Silver Creek	2
Whetstone Brook	3

Table 5. Summary comparison between winter based clusters

Cluster	Mean Temperature ^0C	% Total Surface Ice	Warm Days %	Freeze Days %	% Total Ice Cover
Air Driven	-0.056	80.8	0	96.2	81.9
Winter Dynamic	0.97	14.3	0.4	41.9	27.2
Thermally Stabilized	3.06	0.8	16.5	0.6	6.9

Table 6. Average air temperatures by cluster membership

Cluster membership	Mean Temperature ^0C	S.E.
Air Driven	-4.02	0.031
Winter Dynamic	-4.26	0.044
Thermally Stabilized	-4.05	0.043
Total Average Temperature	-4.09	0.022

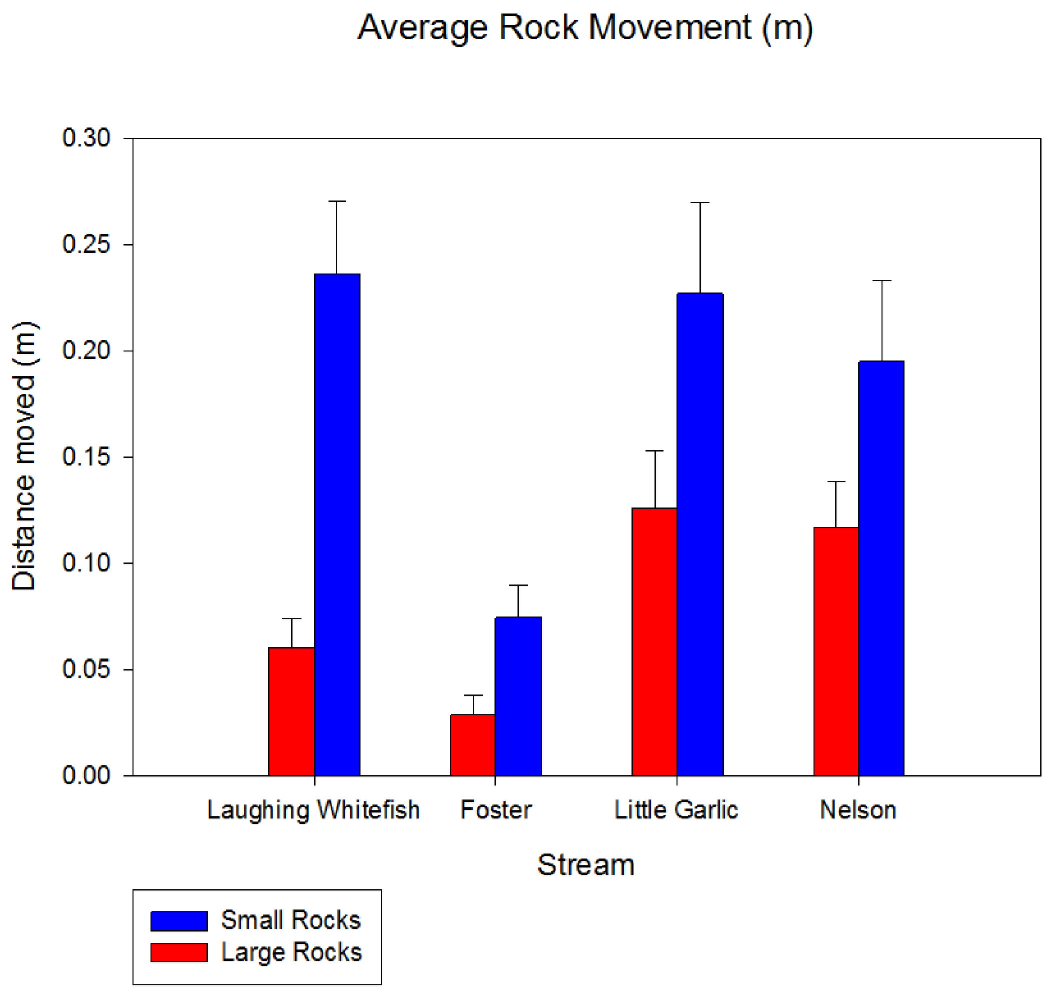

Figure 1: Average streambed movement observed by different size classes of rocks in four gravel/cobble dominated streams.

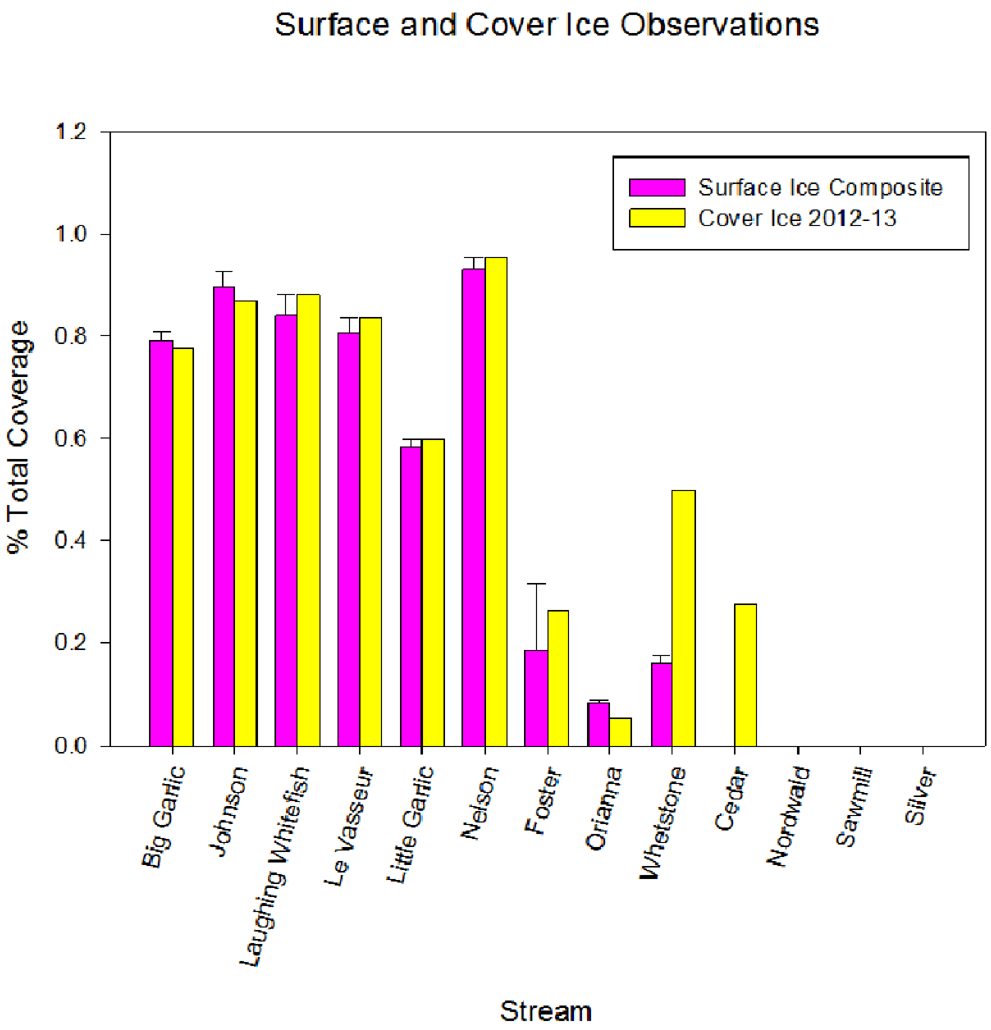

Figure 2: % total coverage for surface ice composite and cover ice (2012-13) by stream.

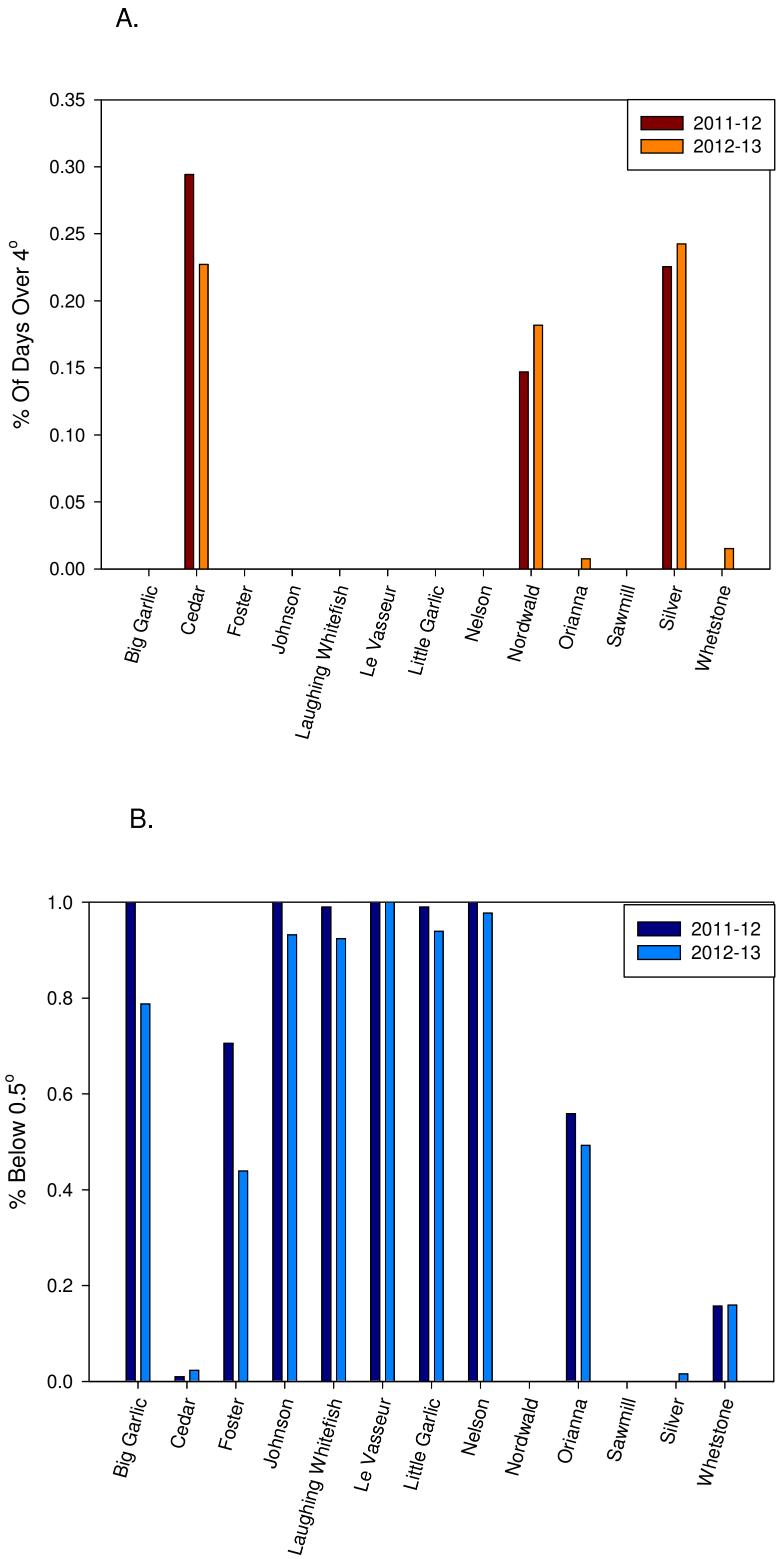

Figure 3: % Warm days and Freeze days by stream- A. % of days over 4ºC. B. % of days under 0.5ºC.

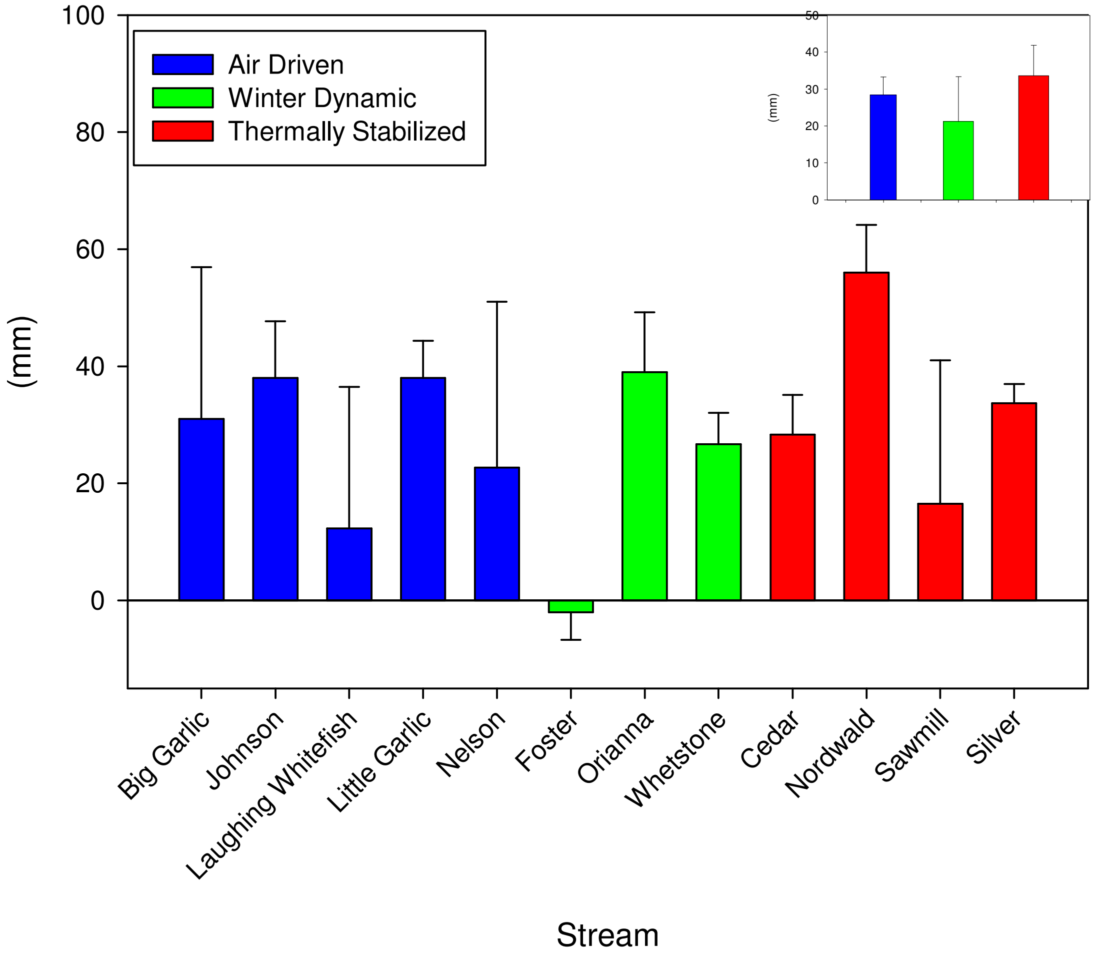

Figure 4: Vertical streambed movement by stream and cluster membership- insert shows cluster composite.

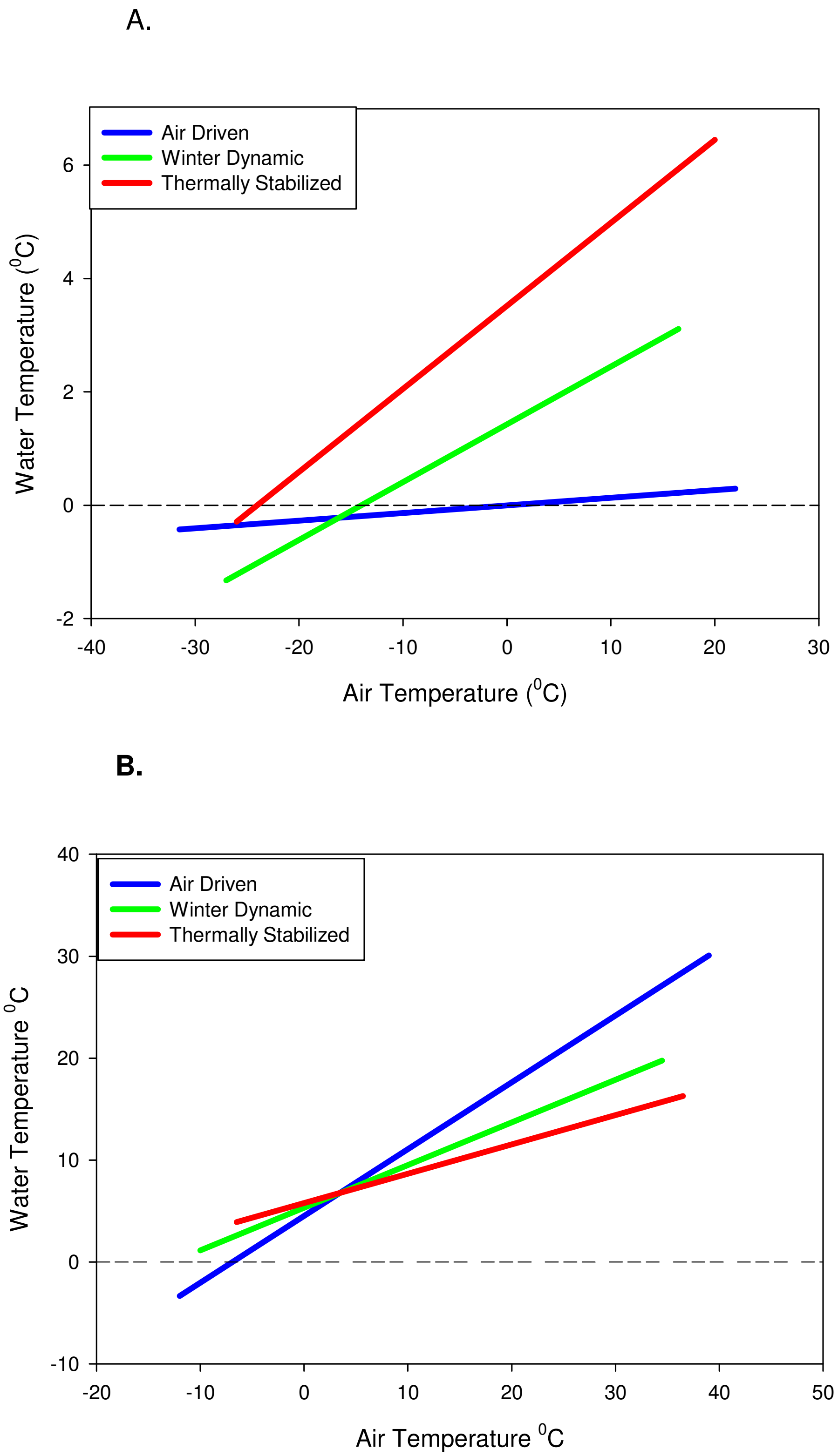

Figure 5: Air vs. water regressions by cluster- A. air temperature vs. water temperature during winters (2011-12 and 2012-13); B. air temperature vs. water temperature for summer (3/30/12-12/2/12) between study winters.

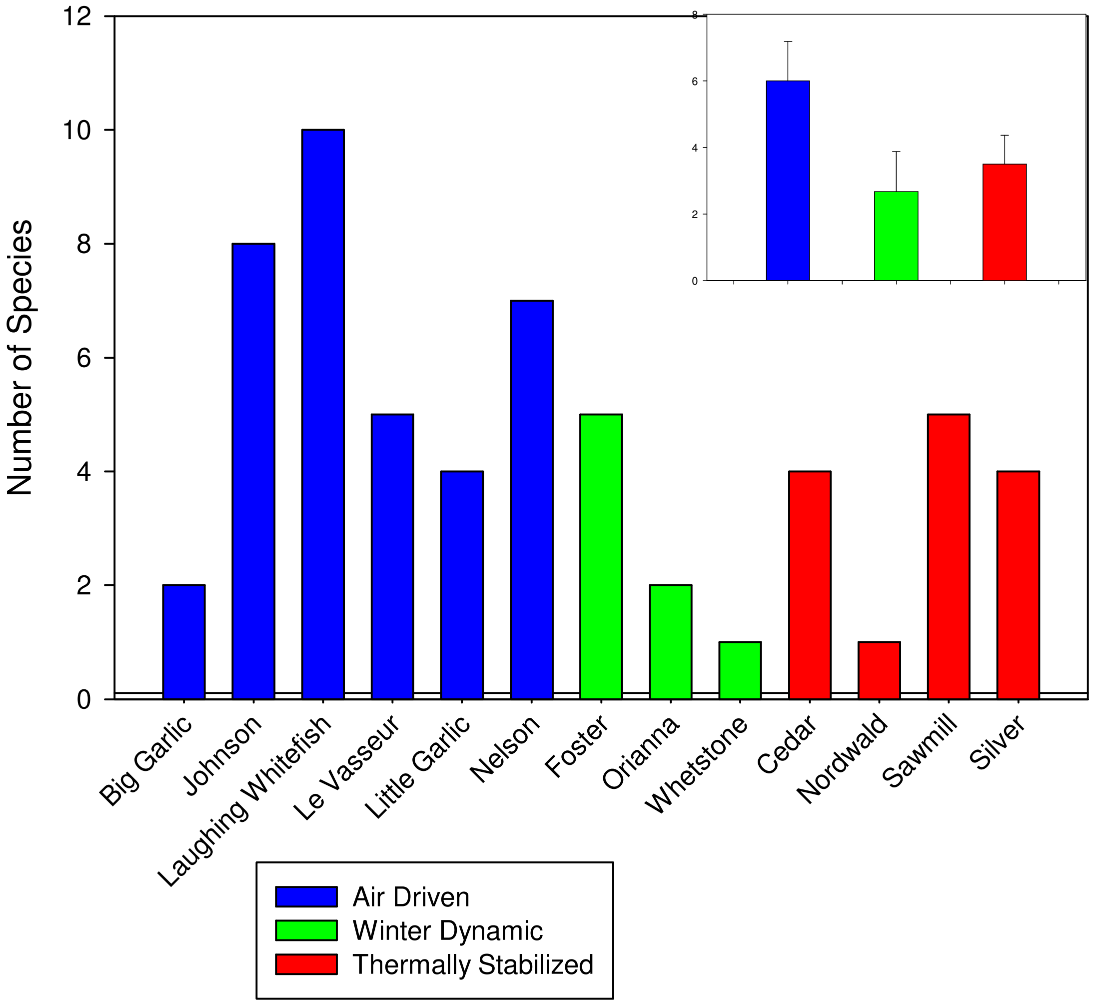

Figure 6: Species richness data by stream and cluster membership- insert shows composite cluster data.

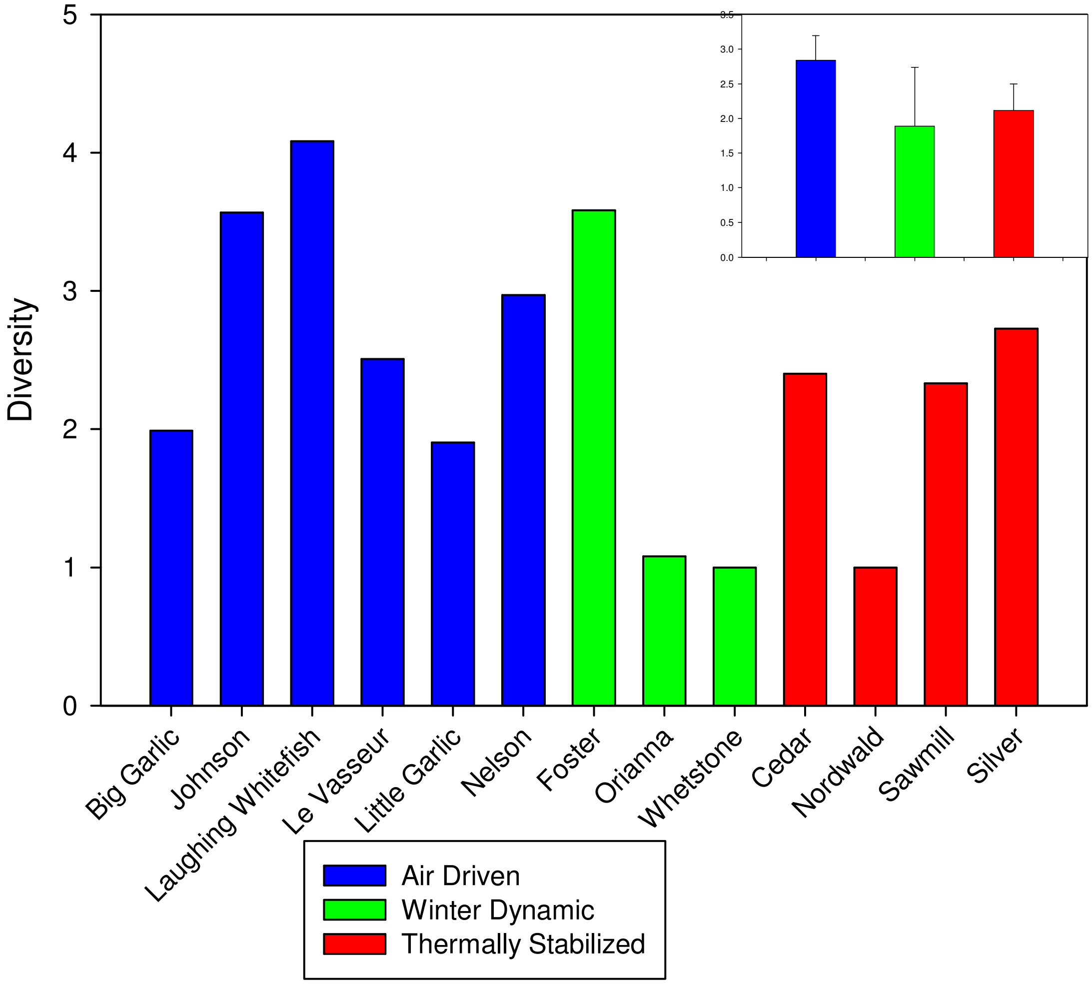

Figure 7: Species diversity data by stream and cluster membership- insert shows composite cluster data.

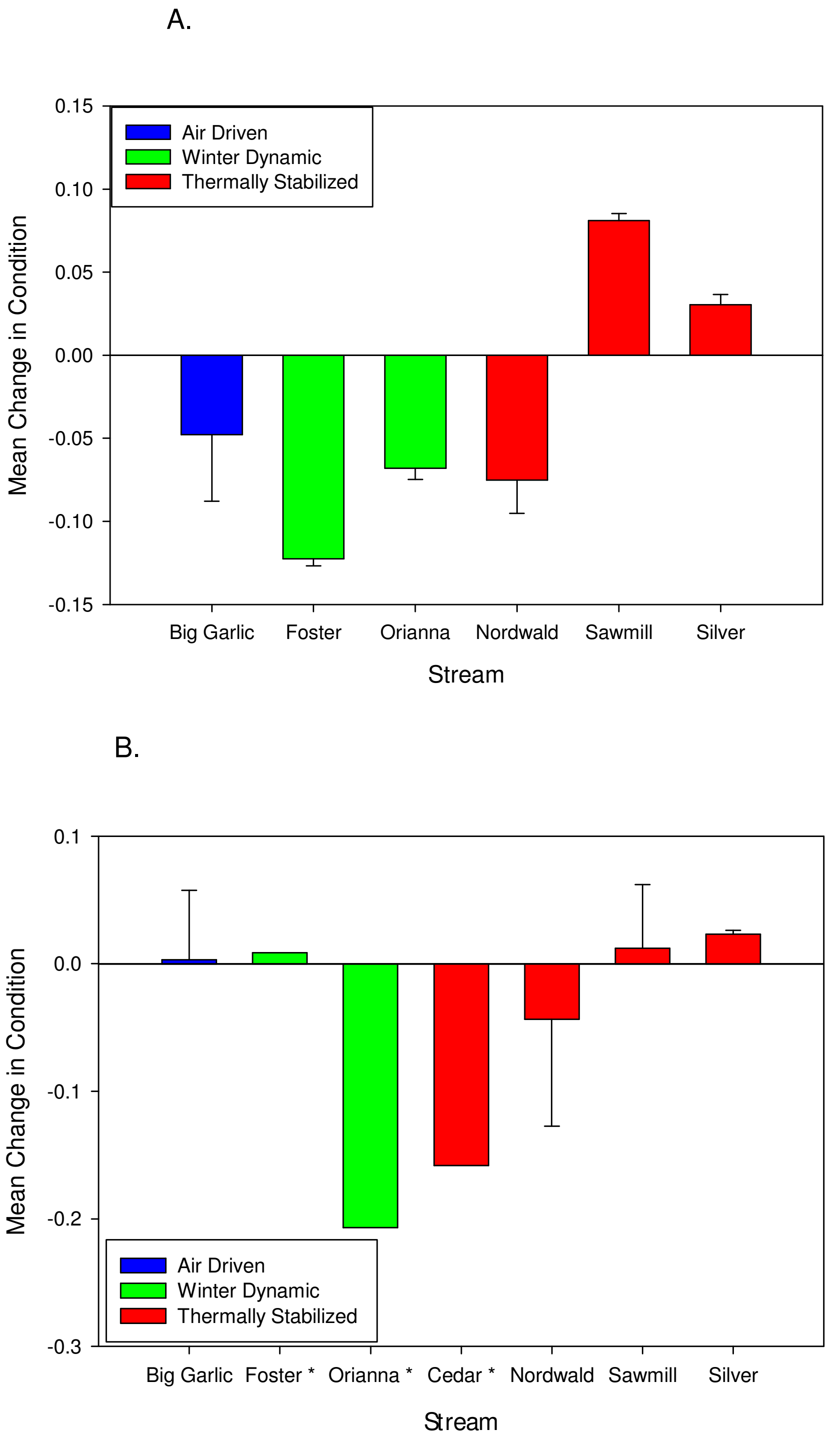

Figure 8: ΔK of brook trout by size class and cluster membership- (A) ΔK of brook trout <100mm by stream and winter based cluster; insert shows cluster composite. (B) ΔK of brook trout >100mm by stream and winter based cluster; insert shows cluster composite.

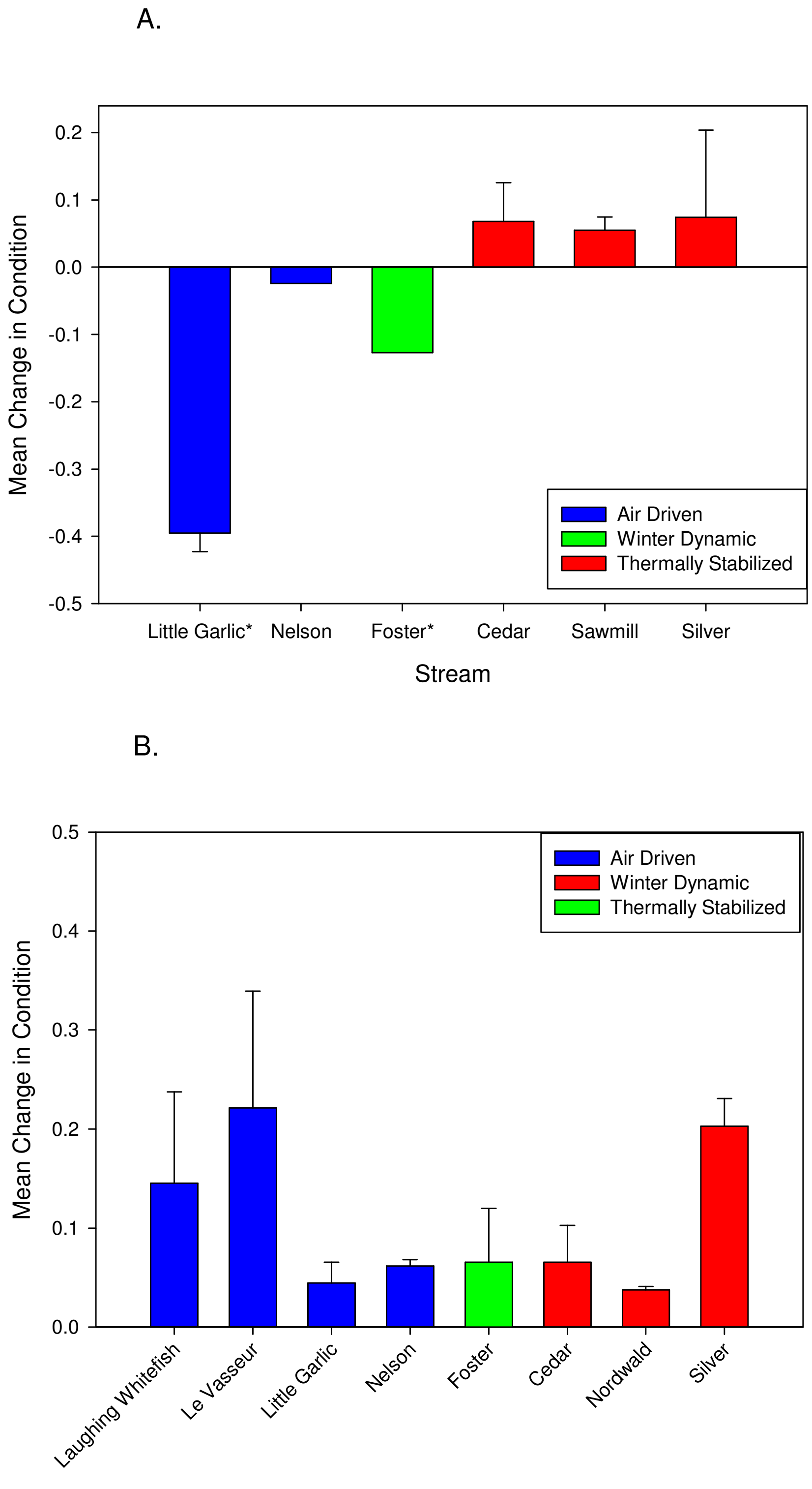

Figure 9. ΔK of sculpin by size class and cluster membership- (A) ΔK of sculpin <60mm by stream and winter based cluster; insert shows cluster composite. (B) ΔK of sculpin <60mm by stream and winter based cluster; insert shows cluster composite.

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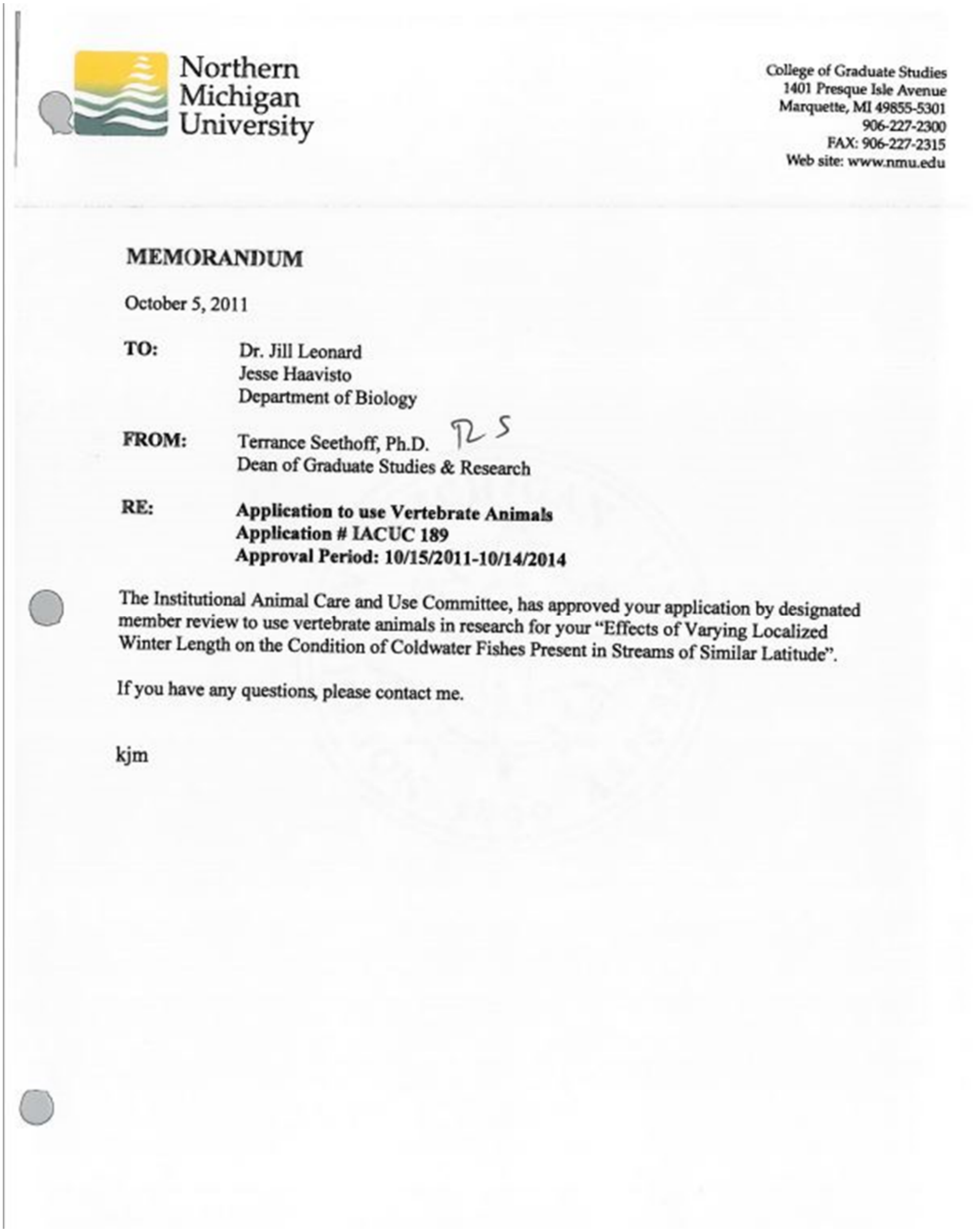
APENDEX A

IACUC Form



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MEMORANDUM

October 5, 2011

TO: Dr. Jill Leonard
Jesse Haavisto
Department of Biology

FROM: Terrance Seethoff, Ph.D.
Dean of Graduate Studies & Research

RE: **Application to use Vertebrate Animals**
Application # IACUC 189
Approval Period: 10/15/2011-10/14/2014

The Institutional Animal Care and Use Committee, has approved your application by designated member review to use vertebrate animals in research for your "Effects of Varying Localized Winter Length on the Condition of Coldwater Fishes Present in Streams of Similar Latitude".

If you have any questions, please contact me.

kjm