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Modern Distribution of Freshwater Ostracodes in the Southwest Yukon Territory and Northern British Columbia, Canada

A thesis submitted to the
Faculty of Graduate and Postgraduate Studies
in partial fulfillment of the requirements for the
Master of Science degree in Geography

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Abstract

This biogeographical study documents the modern distribution of ostracodes in the southwest Yukon Territory and northern British Columbia, Canada. The study tested the hypothesis that dissolved ion composition and concentrations of the lake water are the primary determinants of the distribution of modern ostracodes in this region. A total of 28 freshwater species representing 8 genera were identified in the 33 study lakes. Species common in the southwest Yukon are widely distributed throughout North America, and include *Cyclocypris ampla*, *Candona candida*, *Cypria turneri*, *Cypria ophtalmica*, and *Candona protzi*. Concentrations of ostracode valves were highest in four lakes with moderate conductivity values ranging between 330 and 397 µS/cm. Rarefaction estimated species richness was low (3 to 8), and the highest estimated species richness was found in four lakes, three of which were within 1 km of each other. Conductivities in these lakes ranged between 320 and 397 µS/cm. There is little geographic pattern in either species richness or in the distribution of common species. The dissolved ion composition is the primary control determining the species that will be present in a particular lake.

Résumé

Cette étude biogéographique documente la distribution des ostracodes dans le sud-ouest du Territoire du Yukon et dans le nord de la Colombie Britannique, Canada. Nous avons testé l'hypothèse selon laquelle la composition et la concentration des ions dissous dans les eaux lacustres sont les principaux déterminants de la distribution moderne des ostracodes dans la région d'étude. Un total de 28 espèces d'ostracodes d'eau douce représentant 8 genres ont été identifiés dans les lacs étudiés. Les espèces communes dans le sud du Yukon se retrouvent dans l'ensemble de l'Amérique du Nord et incluent *Cyclocypris ampla, Candona candida, Cypria turneri, Cypria ophtalmica* et *Candona protzi*. Les concentrations de valves d'ostracodes étaient les plus élevées dans quatre lacs dont la conductivité était moyenne, soit de l'ordre de 330 à 397 uS/cm. La richesse spécifique estimée par raréfaction était basse (3 à 8). La richesse spécifique estimée la plus élevée a été observé dans quatre lacs, dont trois étaient dans un rayon de 1 km. La conductivité dans ces lacs varie de 320 à 397 uS/cm. La richesse spécifique et la distribution des espèces communes montrent peu de patrons géographiques. La composition des ions dissous est le contrôle primaire qui détermine les espèces qui seront présentes dans un lac.

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TABLE OF CONTENTS

LIST OF TABLES

List of Figures

CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION

Most climate change scenarios suggest that arctic and subarctic regions will undergo the greatest and most rapid temperature increases (IPCC 2001). These may have large impacts on northern ecosystems that are susceptible to changes in climate. For example, warmer winter temperatures are expected to influence the amount and duration of ice cover. The growing season may lengthen, and warmer summer temperatures will alter the nutrient inputs to lakes, which will affect species abundance and composition (Rouse et al. 1997; Schindler 1997; Schindler 2001). Changes in precipitation amounts may also impact nutrient concentration in lakes due to dilution or evaporative concentration.

These changes must be understood in the context of natural climate variability. Studying the past may lend insight into how aquatic systems responded to past climate changes. Freshwater lake sediments preserve data about past lacustrine environments, and information derived from their study is useful in predicting the direction that an aquatic ecosystem may take in the future (Wetzel 2001). These sediments contain remains of organisms that provide information used in paleoenvironmental reconstructions.

Lake sediments are comprised of autochthonous organic and inorganic material generated within the lake, and allocthonous organic and inorganic material from the surrounding basin (Lowe and Walker 1997; Wetzel 2001). Through time, conditions within a lake can change in response to climatic and nonclimatic factors, which can alter the productivity within the lake. Aquatic organisms are sensitive to variations in their environment, and as the environment changes, species composition and abundance will be altered in response to these factors (Wetzel 2001).

The fossils of microscopic and macroscopic invertebrates comprise some of the organic material in the sediments, because many of them have parts that are effectively preserved. One group of particular interest is ostracodes. The calcified shell of an ostracode is well fossilized in marine and nonmarine sediments (Holmes 1992; Smith and Horne 2002) because the shell is largely unaffected by compaction and diagenesis of the sediments (Carbonel et al. 1988).

Ostracodes, as with any organism, have distinct environmental tolerances, and their abundance and distribution is affected by their environment. This includes the physical environment, aquatic vegetation, water chemistry, other organisms, and the local climate. Geographical distributions of ostracodes are limited by climatic patterns broadly associated with latitude (Whatley 1988), suggesting that air temperature influences their distribution (Delorme 1991; Holmes 2001). Water temperature and chemistry are coupled to the local climate (Hardie and Eugster 1970; Eugster and Jones 1979) and therefore influence the ostracode life cycle (Delorme et al. 1977; Forester et al. 1994). This link between climate, water temperature and water chemistry, and ostracodes makes the organism practical in paleoclimate reconstructions (Delorme 1969b; Holmes 1992; Lowe and Walker 1997; Smith and Horne 2002).

This is a biogeographical study that documents the modern distribution of ostracode fauna in the southwest Yukon Territory and northern British Columbia, Canada. Ostracodes found in modern lake sediments have been identified, and the ecological requirements of some species in this region have been established. This study will provide a better understanding of the connection between the ionic composition and concentration of lake water and species abundance and diversity. Although not part of this study, this is the first step in a paleoenvironmental reconstruction, where the present-day species in a region are used as modern analogs to infer environmental changes through time.

Hypothesis

Dissolved ion composition and concentration of the lake water are the primary determinants of the distribution of modern ostracodes in the southwest Yukon and northern B.C.

1.2 Ostracode Taxonomy

Ostracodes are members of the class Ostracoda, where generally accepted spellings of the common name in the literature include ostracode and ostracod. The literature suggests that the former is used in North America and France, and the latter is used in the rest of Europe and Australia (Holmes and Chivas 2002). Ostracode is the spelling chosen here and will be used throughout this study.

Marine ostracodes have been found in Cambrian sediments (Delorme 1991), while freshwater and brackish species are believed to have originated in the Palaeozoic and/or early Mesozoic (Whatley 1988). They are one of the most diverse groups of living crustaceans, and are believed to have the best fossil record of any arthropod (Horne et al. 2002). They are the primary calcareous microorganism and microfossil on the continents (Smith and Horne 2002).

The class Ostracoda is divided into two subclasses, one of which is exclusively marine and will not be discussed further. The subclass Podocopa has three orders, which are further divided into seven suborders, 10 superfamilies, and 40 families. Most freshwater species today are from the superfamily Cypridacea (Holmes 1992). In North America there are 54 genera of ostracodes with 420 species, 43 of which are found in Canada. At least 20 species are known to exist north of 60° (Delorme 1991).

1.3 Ostracode Biology

Ostracodes are small (0.4 to 7.7 mm) (Delorme 1969a; 1970a; 1970b; 1970c; 1970d; Delorme 1971), bivalved crustaceans with a carapace made of low-magnesium (< 5%) calcite (Forester 1986; Holmes and Chivas 2002). The two valves of the subclass Podocopa are generally not the same size, where the larger overlaps the smaller one along part or all of its margin. Enclosed within and attached to the carapace are the body and appendages. Ostracodes can possess up to 8 pairs of limbs (Holmes 1992), some of which have sensory functions, and others that are used for mobility (De Deckker 2002) or feeding (Pennak 1989; Delorme 1991).

Although there are a few planktonic species, most ostracodes are benthic swimmers or non-swimmers that prefer the sediment-water interface (Delorme 1991). Planktonic species are rare (Delorme 1991) and are less important for our purposes because they have a weakly calcified shell that does not fossilize well (Lowe & Walker 1997). Most ostracodes are detrivores, sustaining themselves on decaying vegetation and organisms (De Deckker 2002), as well as phytoplankton, including diatoms (Holmes 1992).

Freshwater ostracode populations are known to reproduce both sexually and parthenogenetically. Parthenogenesis is the development of an unfertilized egg into a complete organism that is always female and an exact replicate of the parent (Rudin 1997).

It is believed that parthenogens are better adapted to harsher conditions, such as northern climates, where as sexual populations tend to thrive under more optimal conditions (Horne and Martens 1999). Geographic parthenogenesis is common (Holmes 1992). This refers to species that have both sexual and asexual reproduction within part of the geographic range, yet the asexual species tend to have a wider distribution (Butlin and Menozzi 2000).

Ostracodes complete their life cycle between a few weeks and one to two years (Delorme 1991). Those with a shorter life cycle tend to exist in ephemeral habitats, where those with a longer life cycle inhabit large lakes (Porter et al. 1999). They moult their shell forming eight or nine instars prior to reaching maturity (Engstrom & Nelson 1991; Holmes 1992). At each moult, depending on the species, both the body and the appendages develop further (De Deckker 2002), until reaching adulthood. Each shell therefore reflects the specific set of environmental conditions present within the lake at the time the carapace was formed (Carbonel et al. 1988; Engstrom & Nelson 1991; Xia et al. 1997), and is a useful tool for paleoenvironmental reconstructions (Holmes and Chivas 2002).

1.4 Ostracode Ecology

Lacustrine ostracodes are ubiquitous, occurring in lakes in nearly all latitudes and elevations (Forester 1986). They inhabit virtually all aquatic habitats, including freshwater lakes and ponds, ephemeral ponds, saltwater lakes, brackish and marine waters, (Holmes 1992), springs, seeps, and groundwater (Forester 1991). Some species are even known to live in terrestrial environments, such as damp leaf litter (Horne, et al. 2002), and organic mats of fens and bogs (Delorme 1991).

Ostracodes are found in lakes from the arctic to the tropics, and from desert to alpine regions (Forester 1987). They are present in dilute to highly saline waters (Forester 1987) and alkaline to slightly acidic waters (Holmes and Chivas 2002). However, they cannot tolerate acidic waters, which cause their calcium carbonate valves to dissolve (Delorme 1990; De Deckker 2002). From a biogeographical perspective, Pennak (1989) describes several species as cosmopolitan (existing globally) or Holarctic (in the northern hemisphere).

Ostracodes quickly colonize ponds, closed basin lakes and temporary pools because their eggs are tolerant of both desiccation and freezing, and can be easily transported by wind, waterfowl, and other animals (Delorme 1969b; De Deckker 2002). Fish do not inhabit these small, closed systems, so ostracodes are able to thrive in the absence of their main predator. Some larger species of ostracodes are themselves predators that feed on chironomid larvae or copepods (De Deckker 2002).

A wide range of factors control ostracode presence and abundance within the aquatic environment. These include size, depth, energy level and turbidity of the water body, as well as predation, food supply, nature of the substrate (Holmes 1992; Holmes and Chivas 2002), aquatic plants (Holmes 2001), and the presence of oxygen (Forester 1986). Also important with respect to water chemistry are temperature, pH, salinity and ionic composition (Holmes 2001).

Delorme et al. (1977; 1978) found that ostracode abundance was highly influenced by water temperature. Subsequent studies suggest that solute composition is an important factor affecting species presence or absence (Forester 1983; Carbonel et al. 1988; Delorme 1991). Also important is the solute concentration (Forester 1983; Forester 1986); as salinity increases, the species diversity decreases (Delorme 1990). De Deckker and Forester (1988) reached this same conclusion, but also found that as the salinity increased, so did species abundance.

Different species of ostracodes have specific environmental tolerances (Delorme 1969b; Holmes 1992; Curry 1999). Some species are tolerant of large temperature ranges, while others of large variations in dissolved ion content (Forester 1983). There are also species that have very narrow tolerances to dissolved ion concentrations (Holmes 1992) and pH (Delorme 1990). Delorme (1991) found that those species with a smaller tolerance range tend to be more limited in their geographic range as well.

1.5 Chemistry of Freshwater

The dissolved ion composition (solutes), and dissolved ion concentrations (salinity), result from a combination of geologic and climatic processes. These relationships tend to be fairly complex, but are generally related to regional and local climates (temperature, precipitation, and evapotranspiration), and rock-water reactions (weathering) within the drainage basin that are dependent on the local geology (Forester 1987; Kalff 2002).

There are eight major ions present in freshwater. Cations are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}), and anions are bicarbonate (HCO_3^{-}), carbonate ($CO_3^{=}$), sulphate (SO_4^{-}), and chloride (Cl^{-}). Other ions include minor and trace elements such as iron (Fe^{3+}), copper (Cu^{2+}), and silicon (Si^{4+}), and nutrients such as phosphorus (P) and nitrogen (N). Globally, inland lakes are dominated by Ca, Mg, and HCO_3 with high or low concentrations of SO_4, Na, Cl and K (Wetzel 2001; Kalff 2002).

The relationship between precipitation and evaporation separates lakes into two different climatic classes. Where precipitation is greater than evaporation, Ca, Mg, and HCO_3 dominate and the water is considered fresh. However, if evaporation is greater than precipitation, ions become more concentrated within the lake increasing the salinity, and altering the dominant ions (De Deckker and Forester 1988).

The solute content and salinity of fresh water is dependent on rock type and surficial geology found in the catchment. Sedimentary rocks such as limestone are soft and easily weathered, whereas igneous rocks are harder and more resistant to weathering, so lakes in sedimentary basins are prone to higher ion concentrations. Generally, ion-rich fresh water is found in recently deglaciated regions that receive high amounts of precipitation, where ion-poor waters are found in basins containing insoluble igneous rock, or dominated by bogs that have a thick, organic mat preventing the weathering of the underlying bedrock (Kalff 2002).

Sources of carbon in a lake include precipitation falling directly on the water body or in the surrounding basin, biological activity or exchange with the air, and exchanges with the sediments, soil and water. As CO_2 dissolves in water, it forms a weak carbonic acid. The pH is lowered, and some minerals are more readily dissolved, which then results in an increase in pH and alkalinity (Wetzel and Likens 2000). This hard, or alkaline water occurs in regions underlain by large amounts of calcareous deposits (Wetzel 2001).

1.6 Solutes, Salinity and Ostracodes

Because ostracodes precipitate calcite from the host water to make their shell, solutes, salinity and carbonate are particularly important for ostracode ecology. De Deckker and Forester (1988) found a complex relationship between species diversity, abundance and the salinity of lake water. Generally speaking, below the calcite branchpoint (freshwater), species diversity and abundance increase with an increase in calcium concentrations. As the water becomes saturated with respect to calcite (above the calcite branchpoint), species diversity decreases, reaching low levels in saline lakes. Species abundance, however continues to rise.

Delorme (1991) divides chemical water types into 4 classes based on the most predominant anion or oxyanion. These are bicarbonate, sulphate, chloride and carbonate waters, and the water type is largely responsible for the ostracode genera found there. Mourguiart and Carbonel (1994) identified the Mg/Ca ratio as the controlling factor over presence/absence of individual taxa.

Smith (1993) determined that ostracodes could be used to identify changes in the ionic composition and ionic concentrations of water. She established relationships between ostracode species and 3 different water types. Waters dominated by SO_4 had different ostracode species in them depending on whether they were enriched or depleted in HCO_3, except for one species that was found in both water types. These two water types were located on the prairies. Altogether different species were found in freshwater lakes located in forested catchments.

1.7 Ostracodes as Paleoenvironmental Indicators

Ostracode research began in the late 1800's and was limited to systematics, morphologic, and stratigraphic studies until the early 1960's. At that time, major research projects began that focused on the ecology and paleoecology of different species. Since the early 1980's an interdisciplinary approach to the subject has evolved, and fossil ostracodes are studied by chemists, hydrologists, and sedimentologists, in an effort to better understand the environments in which they lived (Carbonel et al 1988).

Much of the work on ostracodes prior to the early 1990's focused on marine ostracodes and their use in paleoceanography (Holmes 1992; Whatley 1988). Studies of fossilized non-marine ostracodes from lake sediments have become increasingly important in the past few decades (Holmes 1992, 2001; Horne et al. 2002). Delorme (1969b) recognized that ostracodes could be used for quantitative paleoenvironmental reconstructions because their ecology and biogeography are so habitat-specific (Forester 1987). This makes them useful in providing an interpretation of the physical and chemical environments in which they lived (Delorme 1991; Forester 1991).

Changes in the species abundance ratios of ostracodes have been used to identify lake level changes based on the salinity of the lake, which in turn is reflected in the ostracode assemblages (Forester et al. 1994). Bridgwater et al. (1999) inferred oscillating wet and dry periods over the last 3,500 years in central Mexico from ostracode assemblages and stable isotopes of their valves. A similar study was conducted by Miller et al. (2000) in Wisconsin, where the assemblages and oxygen isotopes of ostracodes and molluscs were used to determine the controls of lake level fluctuations over the past 6,000 years.

In east-central Wisconsin, Smith (1997) used ostracodes to establish past temperature and hydrochemical changes in Lake Winnebago. Curry (1996) used ostracodes as a paleochemical indicator and concluded that dissolved ionic composition and concentrations over the past 11,000 years had changed significantly in Lakes Agassiz and Manitoba. Porter et al. (1999) conducted a similar study that focused on the past 9,200 years in southwest Saskatchewan. These 3 studies inferred temperature, hydrochemistry and climate using regional modern analogs.

1.8 Northern Paleolimnological Studies

Many paleolimnological studies have been conducted in northern regions. Several subarctic examples are listed here, but this is not meant to be an inclusive review. Larocque et al. (2001) used chironomids as an indicator of climate change in Swedish Lapland, and Davydova et al. (2001) used pollen and diatoms to reconstruct the vegetation history and development of three lakes in Russia. Korhola et al. (2002) used a multi-proxy (diatoms, cladoceran and chrysophytes) approach to understand the changes in productivity in a subarctic lake in Finnish Lapland since the Little Ice Age. A study in Sweden compared mollusc assemblages to stable isotopes to reconstruct the environment and the climate from the last glacial (Hammarlund and Keen 1994).

In Canada there has been research on aquatic organisms in northern Quebec. Ponader et al. (2002) undertook a study on diatoms in a lake at tree-line on the eastern shore of Hudson Bay; Swadling et al. (2001) studied the biogeography of copepods in lakes and ponds of subarctic Quebec, and zooplankton communities in the Yukon and Northwest Territories and their relationship to water chemistry (Swadling et al. 2000). Moser et al. (2000) used diatoms to infer lake level changes on the Alberta-Northwest Territories boundary, and northwest Finland.

Two separate studies in Great Slave Lake looked at the bottom ostracode fauna (Rawson 1953), and documented the ostracode species diversity (Tressler 1957). At the time, ostracode species were virtually unknown in northern Canada. Delorme (1968) performed a paleoecological study on Pleistocene ostracodes near Old Crow in the northwest Yukon. This study revealed 30 species of freshwater ostracodes, two of which were previously unknown. Delorme et al. (1977, 1978) also used ostracodes as one of two paleoclimate indicators from four sites in the northwest corner of the Northwest Territories. This study addressed changes in temperature, precipitation, and the growing season during the period 14410–6820 BP.

Paleolimnological studies in the southwest Yukon include work on present-day distribution of diatoms (Wilson and Gajewski 2002) and chironomids (Wilson and Gajewski submitted). Lacourse and Gajewski (2000) conducted a paleoecological reconstruction using pollen. Older studies are referenced in these papers.

CHAPTER TWO: STUDY AREA

2.1 SOUTHWEST YUKON AND NORTHERN BRITISH COLUMBIA, CANADA

The study area is located between 135°–140°W and 59°–62°N in the southwest portion of the Yukon Territory, and the northwest corner of British Columbia, Canada (Figure 1). Many sites are located along the Alaska Highway from Whitehorse to Beaver Creek, with a large concentration in the Kluane Lake region. Other sites are located to the south along the Haines Road, and northeast on the Aishihik Road. Logistical constraints played a role in lake selection.

The study lakes vary in surface area, depth, and elevation, and provide a wide range of environmental variables. Many are closed basin and fed mainly by groundwater. Those along the eastern shore of Kluane Lake are highly influenced by the lake's water level, which increases as the summer progresses.

The study area lies in the rainshadow of the St. Elias Mountains, which results in a semi-arid climate (Table 1). Given that the mean annual daily temperature is below 0°C, discontinuous permafrost occurs in the region (National Atlas Information Service 1995).

Table 1: Canadian Climate Normals - 1971-2000 (Environment Canada 2000)

	Burwash 61°22'N, 139°03'W	Otter Falls 61°02'N, 137°03'W	Whitehorse 60°42'N, 135°04'W
Mean temperature (°C)			
Daily	-3.8	-1.4	-0.7
January	-22	-16.4	-17.7
July	12.8	13.1	14.1
Total precipitation (mm)	279.7	297.3	267.4
Rain (mm)	192.1	189.9	163.1
Snow (cm)	106.4	107.4	145

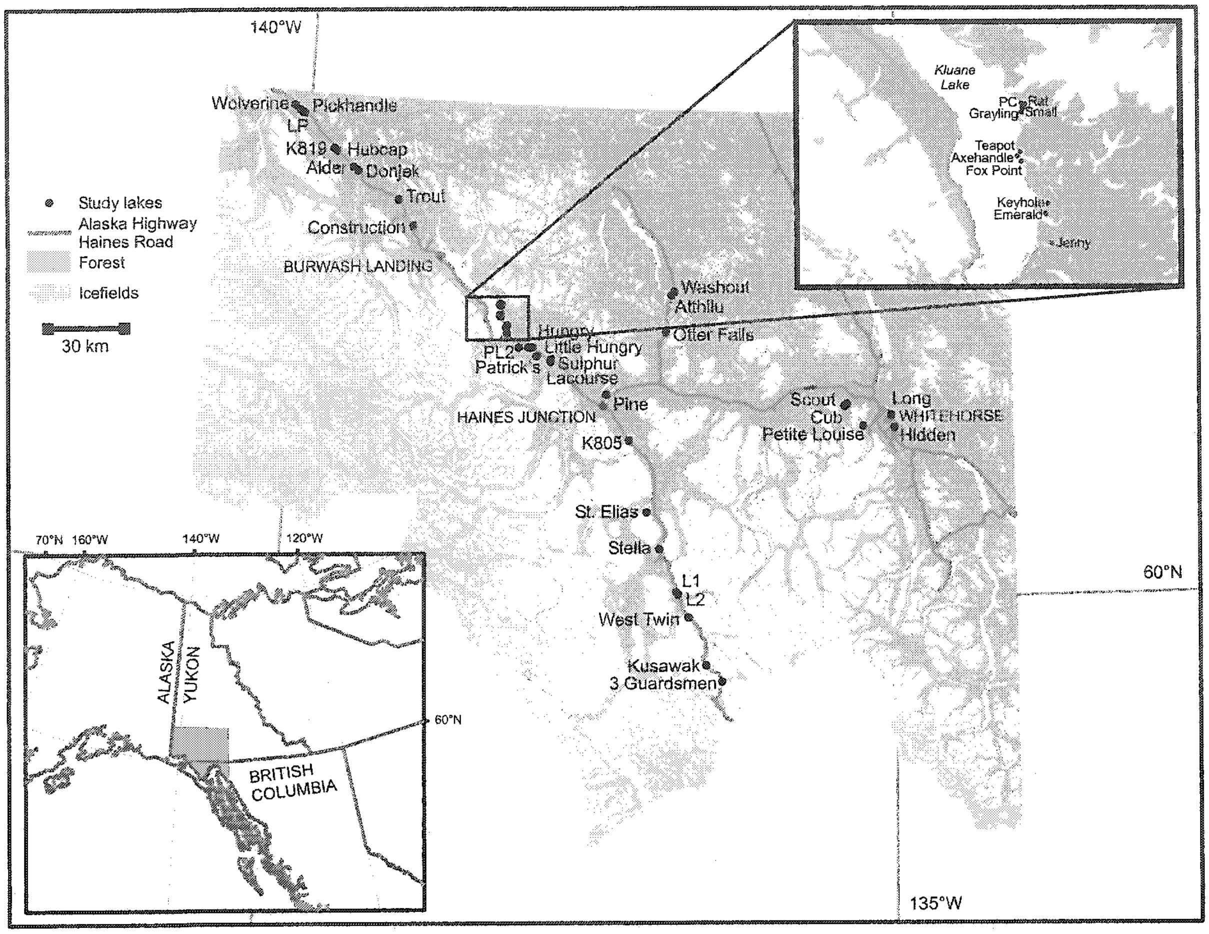


Figure 1: Location of the 42 study lakes in the southwest Yukon and northern British Columbia. Extract of the topographic datsets 104 M, 105 D & E, 114 I & P, 115 A-C, F-H at 1:250,000 scale © Her Majesty the Queen in Right of Canada. Reproduced with permission of Natural Resources Canada.

Johnson and Raup (1964) characterize the forest in the Shakwak Trench as simple in structure and species composition. In this part of the boreal forest the dominant species are white spruce (*Picea glauca*), balsam poplar (*Populus balsamifera*), and trembling aspen (*Populus tremuloides*). Natural grasslands are interspersed with open forest stands in the southwest Yukon, generally on warm, dry, south facing slopes (Vetter 2000). These are found adjacent to several of the study lakes along the southeast shore of Kluane Lake. In the eastern and southern portions of the study area the forest is more diverse, and includes paper birch (*Betula papyrifera*) and pine (*Pinus* spp.). Sites in northern B.C. are in lichen-heath tundra, and some of the sites to the north are situated in bogs that are more characteristic of boreal forest.

The geology of the region is complex, underlain with a combination of metamorphic, sedimentary, and igneous rocks. The study lakes are situated on a variety of bedrock types including large intrusive bodies composed of granodiorite and quartz diorite, and quartz monozite and granite. Gneiss and volcanic rock are also present throughout the region (Figure 2a and b) (Gabrielese et al. 1977; Wheeler et al. 1997). The bedrock is overlain with combinations of thick, continuous and thin, discontinuous till, on which several of the study lakes are located (Figure 2c) (Fulton 1995).

Previous research in the Yukon indicates that lakes are slightly alkaline (pH 7 to 9); and oligotrophic to mesotrophic (Shortreed and Stockner 1986; Pienitz et al. 1997; Wilson and Gajewski 2002). In the southwest Yukon, Wilson and Gajewski (2002) found that both alkalinity and specific conductance values were higher in comparison to other boreal and subarctic lakes. They attribute this to the absence of weathering-resistant Precambrian bedrock in the southwest Yukon, and the presence of glacial till.

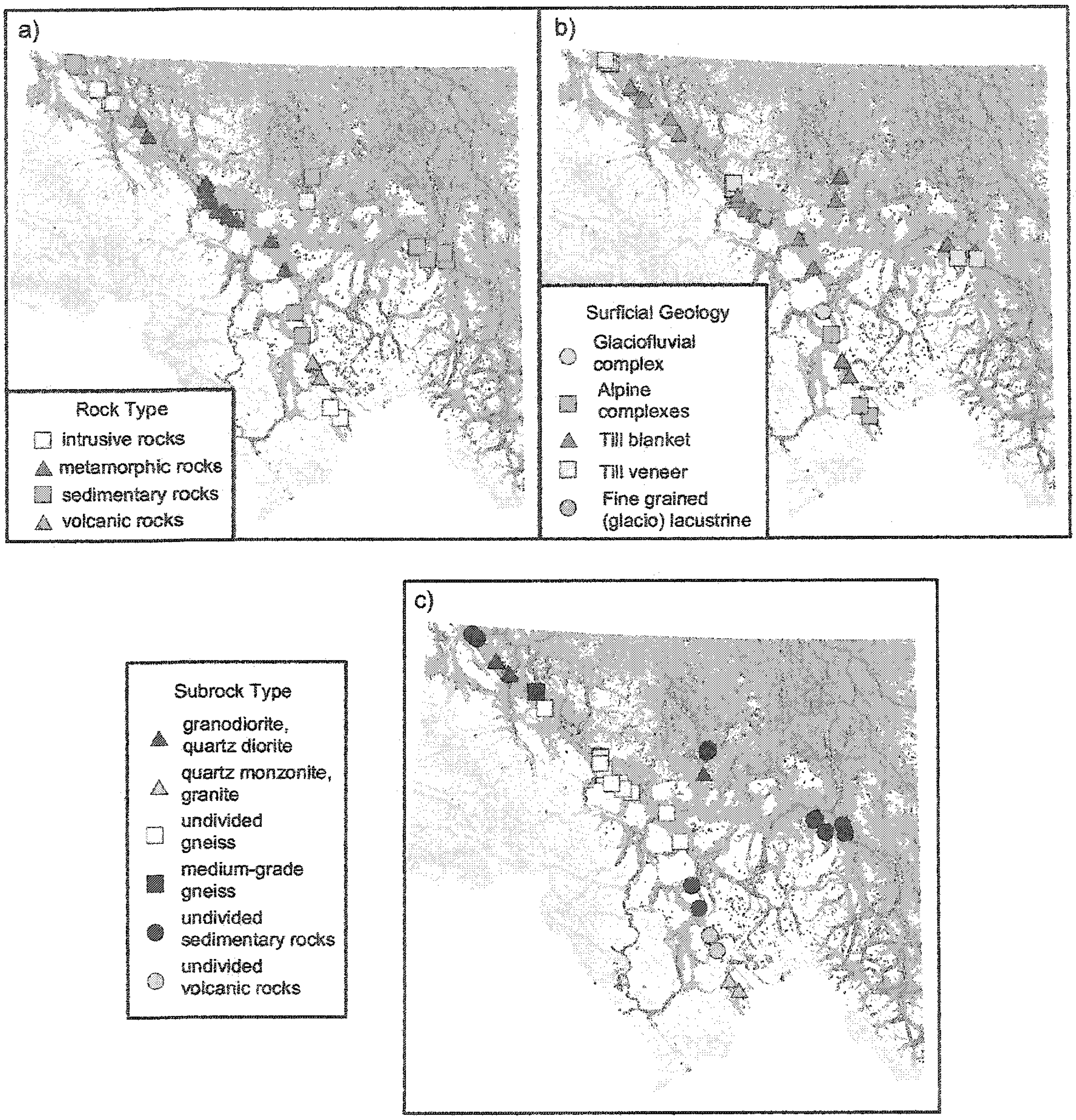


Figure 2: Geology of the 42 study lakes in the southwest Yukon and northern B.C. a) rock type, b) surficial geology and c) subrock type. Geology data was extracted from Wheeler et al. (1997) and Fulton (1996). Scale is 1:5,000,000.

Chapter Three: Methods and Techniques

3.1 Sample Collection

Water chemistry and sediment samples were collected from 38 lakes between June 4 and June 18, 2002. The remaining 4 lakes were sampled in early August 1998. In 2002, profiles of temperature (Temp), dissolved oxygen (DO), conductivity (Cond), specific conductance, pH, and total dissolved solids (TDS) were measured at 1 metre increments with a YSI 556 MPS (multi probe system). Either one or two additional pH measurements were taken at the surface with Oakton portable handheld pH meters. An additional specific conductance measurement was also taken at the surface with an Oakton TDSTestr 3 handheld meter. All instruments were calibrated regularly.

In 1998 temperature and conductivity were recorded using a YSI model 33 SCT meter. Dissolved oxygen was measured using a YSI model 51B oxygen meter, and pH was recorded with an Oakton portable handheld meter. In all years, water clarity was determined using a standard 22 cm Secchi disk.

Water samples were collected at 0.5 metre ("elbow depth") depth for total phosphorus (TP), total Kjeldahl nitrogen (TKN), filtered phosphorus (TPF), filtered Kjeldahl nitrogen (TKNF), dissolved organic carbon (DOC), alkalinity (Alk), major ions, trace metals, and chlorophyll *a*.

Sediment samples were collected with an Ekman dredge and/or a Glew maxi corer (Glew 1991). With the Ekman dredge the upper 1-2 cm was carefully removed from the chamber and kept for analysis. Sediment collected with the Glew maxi corer was extruded in the field in 0.5 cm increments.

3.2 Water Sample Preparation and Analysis

Environment Canada (1994) protocols were followed in preparing equipment for the field, collecting water samples in the field, and preparing the samples for storage and shipping prior to analysis. All water samples were collected in 1L plastic Nalgene bottles that were rinsed with lake water prior to collection. In the laboratory at the end of the day, 200 ml of lake water was transferred to 300 ml polyethylene teresphalate (PET) sterilized bottles provided by the City of Ottawa for the analysis of total phosphorus, total nitrogen, dissolved organic carbon, alkalinity, major ions and trace metals. Phosphorus and nitrogen samples were filtered on the day of collection through Whatman cellulose acetate filters (47 mm diameter, 0.45 μm pore size) with the exception of the 1998 water samples (Appendix 1).

All phosphorus and nitrogen water samples were preserved with 0.3 ml 30% H_2SO_4, and all samples for trace metals were preserved with 0.3 ml HNO_3 (metals grade). Samples were kept cool until analysis. All samples were processed at the Region of Ottawa-Carleton/City of Ottawa Laboratory with the exception of trace metals and cations from 1998, which were analyzed at the ICP-ES, University of Ottawa Analytical Chemistry Laboratory.

Dissolved inorganic carbon (DIC) was calculated from alkalinity measured by the City of Ottawa (Wetzel & Likens 2000), and bicarbonate (HCO_3) was calculated from DIC (Appendix 2).

3.2.1. Chlorophyll *a*

One-litre of lake water was collected in a plastic Nalgene bottle for analysis of chlorophyll *a* (Chla). The bottle was rinsed once with lake water prior to collection. Depending on the primary production of the lake, between 500 ml and 1 litre was filtered in the field using a filtering apparatus with a Whatman GF/C glass microfibre filter (42.5 mm diameter, 0.45 um pore size). The filter was immediately frozen and returned to Ottawa at the end of the season for analysis using the Modified Dimethyl Sulfoxide (DMSO) Extraction Method (Burnison 1979). This was done in the Biology department at the University of Ottawa.

The method resulted in spectrophotometer readings (extinction values), which were converted to estimates of chlorophyll *a* using the following equation:

$$\text{chlorophyll } a = 11.85\ E_{664} - 1.54\ E_{647} - 0.08\ E_{630}$$

where E_x is the extinction value at the given wavelength (Jeffrey and Humphrey 1975). All chlorophyll *a* values are uncorrected for pheophytin.

3.3 Loss-on-ignition: Sediment Organic and Carbonate Content

Organic content of the sediment (LOI) may be a rough measure of the food available for the organisms, and carbonate content (Carb) of the sediment reflects the carbonate concentration in the lake, which is an important variable for ostracodes considering their shell chemistry. One cm^3 of sediment was subsampled from the modern sediment to determine the sediment organic and carbonate content of each lake. Dried sediment was ignited for 4 hours at 550°C to obtain the organic content and ignited for 2 hours at 950°C to obtain the carbonate content (Heiri et al. 2001).

3.4 Environmental Data

Thirty variables associated with the physical, chemical and biological properties of lake water were retained for the analysis of the study lakes. Missing data was dealt with on an individual basis, and is described below. The detection limit was used for variables that had values less than the minimum detection limit. Surface area (Area) of the lakes was calculated manually from 1:50,000 topographic maps. Temperature and dissolved oxygen are surface measurements. TKNF and TKN values were comparable, so TKNF was removed from the dataset. Values from 2000 were substituted for pH, sulphate (SO_4), and alkalinity for Grayling Lake, loss-on-ignition (sediment carbonate content) for Long Lake, and dissolved oxygen values for Emerald, Jenny, and Keyhole Lakes. For explanations, see Appendix 3.

Conductivity and alkalinity were measured in the field and by the City of Ottawa. The City of Ottawa values were used for both variables because there were no missing data. The correlation between City of Ottawa conductivity and field conductivity was 0.98, and the correlation between City of Ottawa alkalinity and field alkalinity was 0.96 (Appendix 4).

A Principal Components Analysis (PCA) was performed to summarize the environment in the study lakes. To perform a PCA, a data matrix containing several variables and several cases must exist, so it can be difficult to identify the important gradients in the data. A PCA simplifies the analysis by combining variables together into separate components (Davies 1984), where the first component summarizes the main direction of variation in the data, and the second component summarizes the main direction of variation that is completely uncorrelated to the first component (Insightful 2001). All variables were included except TDS, DIC and alkalinity. With the exception of temperature, dissolved oxygen, pH, LOI and carbonate, all variables were log transformed. The exploratory data analysis revealed that these variables were not normally distributed therefore transformation was necessary. The mean was substituted for missing data.

3.5 Ostracode Preparation and Identification

3.5.1 Ostracode subsampling and preparation

Between 5 and 10 cm^3 of sediment was subsampled at a time using a 10 cm^3 syringe with an aperture of 1.5 mm. The sediment was then carefully sieved through 50 μm nitrex mesh under a gentle stream of tap water. Remaining sediment and ostracodes were rinsed with deionized water and transferred to a petri dish where valves were picked with a 0/5 brush using a 16x stereoscope. This method is modified from Danielopol et al. (2002). If insufficient valves were obtained, this procedure was repeated until a sum of at least 50 valves was reached, see below. Picked valves were mounted on micropaleontological slides with water soluble gum tragacanth (Delorme 1967). All unbroken adult valves in a processed sediment sample were picked.

3.5.2 Species acquisition curves

The number of valves per sample was determined by preparing a species acquisition curve for each lake. The cumulative number of valves was plotted against the cumulative number of species. Counting would be terminated when the richness curve leveled off (modified from Henderson & Walker 1986). Examples of species acquisition curves are shown in Appendix 5.

This method was used because the ostracode concentrations per gram of sediment can vary substantially (<1 to >6,000), depending on location (Griffiths and Holmes 2000). Heiri and Lotter (2001) and Quinlan and Smol (2001) have determined that 50 chironomid head capsules per sample are needed to statistically estimate the population. Since the richness of ostracodes per lake is comparable to that of chironomids, this number should be applicable.

Of the 42 lakes analyzed, only 33 contained a sufficient amount of valves for analysis. All species in the 33 lakes analyzed were found in the other 9 lakes except for one, *Limnocythere inopinata*, which was found in Little Hungry Lake, but no other (Table 2). The ostracodes in these 9 lakes will not be discussed further, other than to comment on ostracode presence or absence.

Table 2: Raw counts of species found in 9 lakes. These ostracodes were not included in the analysis.

	Sediment subsampled (cm^3)	5	5	5	5	10	10	5	5	5	5
	Number of specimens	16	17	0	2	0	19	7	6	0	0
Species list	**Authority**	Construction	Cub	Hippie	Kusawak	Lance	Little Hungry	Otter Falls	Petite Louise	Stella	TT
Candona candida	(Müller), 1776						4				
Candona protzi	Hartwig, 1898						1				
Cyclocypris ampla	Furtos, 1933						2	2			
Cypria turneri	Hoff, 1942		12								
Limnocythere inopinata	(Baird), 1843						12				
Cypria sp.	Zenker, 1854		5								
Cyclocypris sp.	Brady & Norman, 1889	16			2			2	6		
	Total species	1	2	0	2	0	4	2	6	0	0

3.5.3 Ostracode identifications

Adult ostracode valves were identified with a stereomicroscope under 80x magnification. Taxonomy follows Delorme (1968; 1969a,b; 1970a,b,c,d; 1971) and other resources, including Furtos (1933), Tressler (1959), Gutentag and Benson (1962), Benson & MacDonald (1963), Swain (1963); Nuttall (1969), Bronshtein (1988), and Henderson (1990). Where possible, specimens in this study were compared to those in L.D. Delorme's reference collection deposited at the Canadian Museum of Nature. The valves identified in this study are deposited at the Laboratory for Paleoclimatology and Climatology, Department of Geography, University of Ottawa.

Stratigraphic diagrams displaying raw counts, percentages, and concentrations of ostracode valves per lake were prepared using C2 version 1.3 (Juggins 2003). The data can be found in Appendix 6.

3.5.4 Taxonomic Notes

Identification of the following species requires explanation.

Cyclocypris ampla

It was difficult differentiating between *Cyclocypris ampla* and *Cyclocypris serena* as both species have very similar size, shape, colour, and sculpturing. A distinguishing characteristic of *C. serena* is that the carapace is lopsided when viewed from the end, where *C. ampla* is symmetrical (Delorme 1970b). This was seen in the reference collection, and where available, the carapace was viewed from the end. In all instances, the carapace had a symmetrical appearance, and was identified as *C. ampla*. Individual valves were not as obvious and sizes fell within the size overlap between the two species. Given the presence of *C. ampla* over *C. serena* when identifying carapaces, individual valves were also identified as *C. ampla*.

Cypridopsis vidua

The specimens identified in this study ranged between 0.643 and 0.738 mm in length and 0.405 and 0.452 mm in height. Generally, they were smaller than specimens identified by Delorme (1970b), but fell in the size range of Furtos (1933), Tressler (1957), and Nuttall (1969), and matched the appearance of specimens found in the reference collection.

Candona sp. 1

These specimens were found in 3 different lakes, all of which were > 7 m deep. Both males and females were encountered, and they were the largest specimens in the study (Table 3). They were unlike anything in the taxonomic references and the reference collection. Females had a prominent posterodorsum hinge flap on the left valve, a steeply sloped posterodorsum (almost concave) that met the venter at an acute angle. Males lacked the steep posterodorsum, rather they had a broadly arched dorsum, and an anteroventral notch.

Table 3: Length and height of *Candona* sp. 1

	Length (mm)		Height (mm)	
	Min	Max	Min	Max
Male	1.406	1.572	0.69	0.786
Female	1.238	1.477	0.595	0.738

Candona sp. 2

One specimen, believed to be female, was found in one lake. It was large (length = 1.477 mm, height = 0.714 mm) and similar in shape to *Candona ohioensis* and *Candona eriensis*, but has a broader posterior in the lateral view. It is smaller than *C. ohioensis* and larger than *C. eriensis*.

Candona cf. *distincta*

These specimens lacked prominent posterodorsal and anterodorsal concavities that give the dorsum a characteristic humped appearance (Furtos 1933; Hoff 1942; Delorme 1970c). These concavities were present, although not as prominent and the specimens otherwise matched in size, antereoventral notch (♂), sinuate venter and subtruncate posterior.

Candona cf. *subtriangulata*

These specimens were larger than the taxonomic literature, but otherwise resembled *C. subtriangulata*.

3.5.5 Dissolution of valves

There was evidence of the dissolution of low-calcite valves in a number of lakes, and as a consequence, these valves could only be identified to genus. In these cases, they were identified as *Cyclocypris* sp., *Cypria* sp., *Cypridopsis* sp., or *Limnocythere* sp. where the use of sp. indicates generic identification only. These valves may or may not be a separate species from other valves identified within the genus (eg. *Cyclocypris ampla, Cypria ophtalmica*), but have been treated as a separate species in the computation of estimated species richness.

3.6 Estimated Species Richness

Species richness was estimated using rarefaction (Birks and Line 1992). The species richness (number of species in the lake) is not only a function of the actual population, but also the sample size. Rarefaction accounts for the difference in sample size by standardizing all count sizes to the smallest count in the population to estimate the richness of the sample in a comparable manner. Estimated species richness was calculated using Analytic Rarefaction 3.1 (Steven M. Holland, www.uga.edu/~strata/software).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 PHYSICAL, CHEMICAL, AND BIOLOGICAL ENVIRONMENT

Morphometry, chemical composition and productivity vary widely among the study lakes (Table 4). Surface area ranges between 0.1 and 597.5 ha, and depth between 0.75 and 17 m. Lakes are oligotrophic to eutrophic, (TP between 6 and 63 μg/L) (Wetzel 2001), with sediment organic content ranging between 8 and 76%. Alkalinity is moderate (pH 7.3 to 8.9), and the lake water is dominated by either Ca or Mg and enriched in HCO_3. Fox Point and St. Elias are the only exceptions, where SO_4 is the dominant anion. Conductivity ranges between 40 and 1100 μS/cm, reflecting both high and low ion concentrations. TDS values (where available) are low, between 0.021 and 0.652 g/L, indicating freshwater lakes. Five lakes (Keyhole, Emerald, Jenny, Fox Point, and Sulphur) have conductivity > 600 μS/cm, and TDS > 0.350 g/L. Lakes at higher elevations have conductivity and TDS values well below the mean (< 100 μS/cm and < 0.1 mg/L).

A principal components analysis summarizes the environmental conditions within the lakes. All 42 lakes were included in the analysis, even those for which ostracode assemblages were not obtained due to dissolution. It needed to be seen if some factor explained the low ostracode numbers in these lakes, as well as to define the major gradients that might explain the general distribution of ostracodes in the region.

The first two axes explained 47.8% of the variation and each axis had comparable eigenvalues (Figure 3). Ions are highly correlated with axis 1 (Cond, HCO_3, Mg, Na, SO_4, and Ca), and nutrient measurements (TPF, TP, Chla, and TKN), Depth and Fe are highly correlated with axis 2. Dissolved ion concentrations are greatest in lakes on the right of the

Table 4: Environmental variables of the 42 study lakes. Alkalinity is in mg/L as $CaCO_3$. Minimum detection limit values are indicated by <. NA is no data.

Lake	Year	Latitude (°N)	Longitude (°W)	Elev (m)	Area (ha)	Temp (°C)	DO (mg/L)	pH	Depth (m)	Cond (µS/cm)	TDS (g/L)	Ca (mg/L)	K (mg/L)
3 Guardsmen	2002	60.23	-136.45	940	17.23	10.7	10.37	7.5	9.5	40	0.021	5.40	2.60
Alder	2002	61.70	-139.80	777	4.80	16.5	7.77	8.0	1.0	300	0.175	50.00	0.94
Atthilu	2002	61.23	-136.95	942	36.43	16.4	9.74	8.7	1.3	176	0.1	29.00	5.60
Axehandle	2002	61.12	-138.44	787	1.00	13.9	8.54	8.5	5.0	420	0.244	28.00	3.90
Construction	2002	61.47	-139.25	823	1.38	13.5	5.23	7.5	1.0	280	0.167	37.00	3.80
Cub	2002	60.78	-135.44	880	6.70	16.5	9.22	8.5	5.0	330	0.194	38.00	3.10
Donjek	2002	61.00	-139.76	732	0.63	16.0	8.83	8.0	6.0	300	0.178	41.00	4.10
Emerald	2002	61.07	-138.37	820	8.38	13.7	8.9	8.5	7.0	700	0.409	14.50	6.20
Fox Point	2002	61.12	-138.43	790	3.75	12.6	9.14	8.4	10.0	1100	0.652	39.00	11.10
Grayling	2002	61.16	-138.43	790	4.91	11.9	9.5	8.5	11.0	397	0.213	21.90	6.49
Hidden	2002	60.69	-135.01	680	6.89	15.8	8.7	8.3	14.0	200	0.118	25.00	1.38
Hubcap	2002	61.76	-139.96	732	0.79	15.7	7.8	8.0	1.1	380	0.225	53.00	4.50
Hungry	1998	60.99	-138.18	920	44.69	15.0	8.5	8.7	6.5	350	NA	21.75	2.33
Jenny	2002	61.04	-138.36	817	19.90	15.3	10.4	8.4	2.6	680	0.403	33.00	8.50
K805	1998	61.77	-139.99	732	47.31	NA	NA	8.8	1.5	240	NA	28.66	0.66
K819	2002	61.08	-138.37	730	79.69	15.6	8.78	8.3	0.8	310	0.18	51.00	2.10
Keyhole	2002	59.69	-136.58	826	4.06	14.3	8.6	8.4	4.2	600	0.348	22.00	5.00
Kusawak	2002	60.93	-137.98	1000	6.13	17.7	8.3	8.0	1.5	69	0.039	10.10	0.20
L1	2002	60.99	-138.14	838	1.50	13.6	9.64	8.1	1.9	82	0.046	13.20	0.67
L2	2002	59.98	-136.83	878	3.00	13.3	9.49	8.1	2.5	138	0.078	24.00	0.43
Lacourse	2002	59.99	-136.85	838	1.00	15.2	3.58	7.3	1.2	183	0.107	17.70	8.60
Little Hungry	2002	60.74	-135.04	990	6.00	15.7	8.28	8.9	1.2	570	0.321	38.00	3.20
Long	2002	61.91	-140.27	680	15.94	15.0	8.79	8.7	16.0	560	0.324	23.00	4.40
LP	2002	60.62	-137.27	686	1.50	18.0	7.59	8.1	1.8	340	0.319	83.00	4.80
Otter Falls	2002	61.68	-136.99	899	13.53	14.5	8.8	7.9	0.8	120	0.068	18.20	1.08
Patrick's	2002	60.96	-138.10	950	7.69	13.0	9	8.2	1.2	430	0.249	43.00	2.60
PC	2002	61.17	-138.43	799	2.00	13.0	8.03	8.3	17.0	340	0.201	32.00	4.60
Petite Louise	1998	60.70	-135.28	1021	9.56	14.5	NA	8.6	5.0	200	NA	20.96	0.88
Pickhandle	2002	61.92	-140.29	747	162.05	16.3	9.61	8.6	2.0	250	0.147	28.00	2.40
Pine	2002	60.81	-137.48	671	597.50	12.7	9.84	8.3	13.0	290	0.169	36.00	2.40
PL2	2002	60.99	-138.26	980	2.50	12.1	7.26	8.3	2.0	330	0.196	50.00	1.62
Rat	2002	61.17	-138.42	790	5.75	10.6	9.78	8.5	5.0	320	0.19	36.00	4.00
Scout	2002	60.79	-135.42	880	23.56	14.2	8.87	8.5	9.0	330	0.193	24.00	4.50
Small	2002	61.16	-138.43	799	0.63	13.5	10.12	8.8	4.0	440	0.239	30.00	8.30
St. Elias	1998	60.32	-137.11	890	17.50	NA	NA	8.3	7.0	510	NA	64.83	0.19
Stella	2002	60.17	-137.00	787	23.56	11.4	10.06	8.4	6.0	175	0.101	33.00	0.33
Sulphur	2002	60.95	-137.98	854	142.56	13.4	8.51	8.5	10.0	750	0.437	31.00	8.80
Teapot	2002	61.12	-138.43	808	0.65	13.2	9.02	8.3	12.0	510	0.301	73.00	6.00
Trout	2002	61.58	-139.39	727	55.53	13.6	7.91	7.9	2.0	300	0.16	32.00	3.50
Washout	2002	61.25	-136.93	991	0.10	15.5	10.03	8.1	2.5	330	0.197	57.00	3.40
West Twin	2002	59.89	-136.74	914	8.13	9.4	9.56	7.9	3.8	270	0.158	39.00	0.94
Wolverine	2002	61.94	-140.36	686	29.81	15.4	8.57	8.4	10.0	270	0.159	41.00	1.53
Minimum				671	0.10	9.4	3.58	7.3	0.8	40	0.021	5.40	0.19
Maximum				1021	597.50	18.0	10.40	8.9	17.0	1100	0.652	83.00	11.10
Mean				825	33.96	14.2	8.73	8.3	5.4	355	0.211	34.20	3.61
Std Deviation				100	95.53	1.9	1.30	0.4	4.5	205	0.126	16.18	2.70

Table 4: Environmental variables of the 42 study lakes. Alkalinity is in mg/L as $CaCO_3$. Minimum detection limit values are indicated by <. NA is no data.

Lake	Mg (mg/L)	Na (mg/L)	Cl (mg/L)	SO_4 (mg/L)	HCO_3 (mg/L)	DIC (mg/L)	Alkalinity (mg/L)	DOC (mg/L)	TKN (mg/L)	TP (µg/L)	TPF (µg/L)	Chla (µg/L)
3 Guardsmen	0.26	1.82	0.39	1.42	21.1	4.2	16	0.7	0.08	<5	<5	1.16
Alder	10.60	2.10	8.29	1.43	180.3	35.5	142	28.0	1.14	24	18	3.35
Atthilu	4.10	2.70	0.44	4.02	106.1	20.9	87	8.8	0.53	21	10	4.09
Axehandle	38.00	3.60	1.37	23.45	243.8	48.0	200	2.4	0.28	12	<5	1.75
Construction	13.20	5.10	10.04	12.39	159.8	31.5	121	29.1	1.19	40	25	4.67
Cub	14.50	10.70	1.54	20.28	187.8	37.0	154	9.4	0.86	12	6	2.83
Donjek	15.00	1.82	6.83	3.62	185.4	36.5	146	15.3	0.66	13	10	1.07
Emerald	88.00	15.30	2.69	62.21	414.5	81.6	340	5.6	0.62	8	6	1.16
Fox Point	44.00	4.60	3.80	458.37	234.1	46.1	192	2.8	0.30	20	6	1.35
Grayling	35.50	7.52	1.30	16.80	256.0	50.4	191	2.2	0.20	8	6	1.22
Hidden	9.70	1.98	0.48	12.37	113.4	22.3	93	3.9	0.45	17	10	1.44
Hubcap	14.30	7.00	3.34	17.02	231.1	45.5	182	11.5	0.66	44	22	1.85
Hungry	26.25	4.72	0.60	29.00	187.8	37.0	154	NA	0.32	14	7	1.54
Jenny	72.00	11.10	1.91	174.74	243.8	48.0	200	18.0	1.84	9	6	1.78
K805	7.16	2.74	0.40	32.00	100.0	19.7	82	NA	0.33	15	10	1.46
K819	9.90	2.90	0.87	34.71	157.3	31.0	129	8.5	0.51	21	10	4.11
Keyhole	69.00	6.70	1.51	66.90	329.2	64.8	270	4.8	0.51	15	<5	0.90
Kusawak	1.33	1.46	0.94	2.87	36.6	7.2	30	1.4	0.16	7	<5	0.94
L1	1.65	0.61	0.57	0.69	48.8	9.6	40	9.9	0.64	22	7	2.91
L2	2.80	1.23	0.78	1.43	84.1	16.6	69	14.4	0.70	15	6	1.99
Lacourse	7.30	3.10	7.21	1.21	109.7	21.6	80	19.3	1.42	63	31	5.26
Little Hungry	57.00	5.20	9.17	18.29	338.8	66.7	290	20.8	1.15	34	13	2.78
Long	54.00	16.30	2.45	77.24	280.4	55.2	230	5.8	0.54	6	<5	2.16
LP	19.50	6.30	5.21	114.84	193.9	38.2	159	19.8	0.97	32	21	7.90
Otter Falls	2.70	1.95	0.51	3.66	69.9	13.8	55	5.6	0.32	9	7	2.66
Patrick's	33.00	3.70	1.24	25.09	256.0	50.4	210	6.8	0.48	21	8	3.00
PC	23.00	5.00	1.30	18.86	202.4	39.8	166	2.2	0.25	6	<5	0.88
Petite Louise	5.07	2.67	1.80	12.40	98.8	19.4	81	6.5	0.22	<5	<5	1.08
Pickhandle	12.10	5.10	4.27	20.74	124.4	24.5	102	8.9	0.54	16	8	2.27
Pine	14.70	3.50	0.58	7.81	180.4	35.5	148	3.7	0.34	10	7	0.90
PL2	14.90	1.26	1.07	8.60	209.7	41.3	172	9.7	0.44	12	7	2.63
Rat	19.30	4.80	1.34	11.45	201.2	39.6	165	5.0	0.47	27	11	3.69
Scout	21.00	14.30	1.92	5.43	208.5	41.0	171	6.5	0.54	6	6	0.70
Small	34.00	5.20	2.02	50.40	189.0	37.2	155	5.1	0.63	29	13	5.49
St. Elias	16.06	5.98	0.50	164.00	126.8	25.0	104	NA	0.17	<5	<5	0.85
Stella	2.80	1.78	0.69	2.46	108.5	21.4	89	4.6	0.41	9	8	1.89
Sulphur	79.00	19.20	3.46	75.93	426.7	84.0	350	16.5	0.97	21	<5	4.07
Teapot	114.00	12.20	1.45	111.19	202.4	39.8	166	2.1	0.28	16	6	2.01
Trout	11.00	14.40	2.97	10.06	182.9	36.0	144	20.8	1.15	22	8	2.67
Washout	6.70	2.20	0.42	57.29	135.3	26.6	111	12.8	1.00	27	15	2.96
West Twin	10.50	2.90	0.58	30.82	110.5	21.8	110	2.0	0.16	9	<5	2.02
Wolverine	9.50	2.10	7.62	27.24	123.1	24.2	101	15.3	0.68	20	9	2.72
Minimum	0.26	0.61	0.39	0.69	21.1	4.2	16	0.7	0.08	<5	<5	0.70
Maximum	114.00	19.20	10.04	458.37	426.7	84.0	350	29.1	1.84	63	31	7.90
Mean	24.87	5.59	2.52	43.59	181.0	35.6	148	9.7	0.60	19	11	2.43
Std Deviation	26.56	4.69	2.64	77.80	90.6	17.8	75	7.4	0.38	12	6	1.51

Table 4: Environmental variables of the 42 study lakes. Alkalinity is in mg/L as $CaCO_3$. Minimum detection limit values are indicated by <. NA is no data.

Lake	Si (mg/L)	Al (mg/L)	Ba (mg/L)	Fe (mg/L)	Mn (mg/L)	Sr (mg/L)	LOI (%)	Carbonate (%)	Mg/Ca	Species richness	Concentrations (valves/cm3)
3 Guardsmen	1.41	0.05	0.0127	0.042	0.0137	0.054	20.68	1.56	0.05	3	7.9
Alder	2.3	0.035	0.032	0.61	0.044	0.104	28.26	7.62	0.21	5	4.9
Atthilu	2.2	0.051	0.037	0.088	0.011	0.123	26.36	15.39	0.14	5	5.1
Axehandle	4.8	0.029	0.055	0.029	0.015	0.143	19.84	18.42	1.36	5	5.1
Construction	5.2	0.031	0.03	0.24	0.023	0.111	48.61	1.39	0.36	NA	NA
Cub	2.9	0.027	0.053	0.006	0.0119	0.280	35.85	14.15	0.38	NA	NA
Donjek	2.2	0.03	0.038	0.025	0.0036	0.116	10.47	7.01	0.37	3	5.3
Emerald	9.6	0.026	0.0049	0.009	0.0023	0.069	26.50	21.49	6.07	5	1.9
Fox Point	3.1	0.043	0.033	0.071	0.051	0.290	13.41	10.55	1.13	6	1.7
Grayling	4.4	0.026	0.024	0.013	0.038	0.085	8.65	4.45	1.62	8	29.0
Hidden	0.087	0.031	0.023	0.016	0.002	0.178	30.67	4.47	0.39	3	3.1
Hubcap	1.98	0.027	0.054	0.39	0.043	0.220	23.83	6.28	0.27	5	9.6
Hungry	2.38	<0.01	<0.005	<0.01	0.0074	0.110	23.72	12.47	1.21	7	31.2
Jenny	4.6	0.005	0.02	0.057	0.0158	0.128	27.15	20.07	2.18	4	2.9
K805	1.38	<0.01	<0.005	0.0368	<0.005	0.227	21.80	4.58	0.25	5	2.4
K819	1.73	0.037	0.034	0.097	0.032	0.174	12.10	13.43	0.19	6	3.2
Keyhole	9.3	0.024	0.0064	0.009	0.0039	0.093	23.31	25.97	3.14	4	6.6
Kusawak	1.66	0.044	0.0068	0.02	0.0018	0.025	59.46	1.72	0.13	NA	NA
L1	0.48	0.037	0.0182	0.09	0.0065	0.048	76.32	2.63	0.13	NA	NA
L2	3.5	0.027	0.044	0.05	0.0165	0.090	50.39	0.00	0.12	NA	NA
Lacourse	0.41	0.069	0.0097	0.29	0.08	0.070	59.24	2.76	0.41	3	3.8
Little Hungry	0.27	0.061	0.036	0.035	0.0073	0.250	36.53	8.17	1.50	NA	NA
Long	5.9	0.03	0.0148	0.007	0.0027	0.220	20.91	11.00	2.35	6	3.4
LP	1.11	0.042	0.046	0.106	0.053	0.180	25.66	2.72	0.23	4	5.3
Otter Falls	2.7	0.098	0.022	0.124	0.0114	0.082	24.15	1.74	0.15	NA	NA
Patrick's	3.6	0.041	0.041	0.112	0.014	0.270	30.43	14.70	0.77	7	11.0
PC	4.4	0.025	0.046	0.006	0.035	0.210	18.58	10.07	0.72	8	21.3
Petite Louise	3.21	<0.01	0.006	<0.01	<0.005	0.130	11.83	0.91	0.24	NA	NA
Pickhandle	0.024	0.028	0.03	0.014	0.0138	0.126	29.22	16.23	0.43	6	10.6
Pine	4.1	0.035	0.0195	0.008	0.0024	0.181	10.60	1.80	0.41	6	3.4
PL2	4.3	0.029	0.053	0.28	0.0109	0.137	28.79	2.51	0.30	4	10.3
Rat	1.11	0.032	0.046	0.047	0.0122	0.220	12.73	18.27	0.54	8	5.0
Scout	2.4	0.056	0.037	0.004	0.0026	0.240	37.71	10.20	0.88	8	29.8
Small	1.58	0.032	0.027	0.03	0.065	0.127	28.12	8.21	1.13	7	3.4
St. Elias	1.60	<0.01	<0.005	<0.01	<0.005	0.708	19.16	28.08	0.25	6	6.1
Stella	1.82	0.027	0.0159	0.01	0.027	0.250	62.26	1.95	0.08	NA	NA
Sulphur	7.9	0.033	0.0152	0.026	0.0169	0.144	54.86	10.58	2.55	3	1.5
Teapot	3.5	0.039	0.024	0.047	0.04	0.510	12.01	22.22	1.56	5	8.9
Trout	5.1	0.034	0.05	0.22	0.081	0.142	15.42	9.65	0.34	5	10.0
Washout	0.29	0.033	0.056	0.054	0.0039	0.195	43.30	13.20	0.12	4	5.3
West Twin	2.3	0.028	0.056	0.35	0.0126	0.111	34.72	5.28	0.27	5	1.6
Wolverine	1.01	0.032	0.024	0.021	0.0076	0.130	28.55	3.01	0.23	3	3.3
Minimum	0.0	0.005	0.005	0.004	0.0018	0.025	8.65	0.00	0.05	3	1.5
Maximum	9.6	0.098	0.056	0.610	0.0810	0.708	76.32	28.08	6.07	8	31.2
Mean	2.9	0.036	0.031	0.095	0.0216	0.174	29.34	9.45	0.84	5	8.0
Std Deviation	2.3	0.015	0.016	0.132	0.0214	0.121	15.92	7.39	1.12	2	8.1

biplot, where the dominant cation for lakes in the upper quadrant is Ca, and in the lower quadrant is Mg. Jenny, Fox Point and Teapot have high values of SO_4 and Na, where Emerald, Keyhole and Long exhibit high pH. Sulphur has high values of a number of ions, reflected also in the high conductivity. Hungry, Grayling, Scout, and PC are positively correlated with depth and dissolved oxygen, negatively correlated with nutrients, and have very similar scores in the PCA suggesting comparable water chemistry.

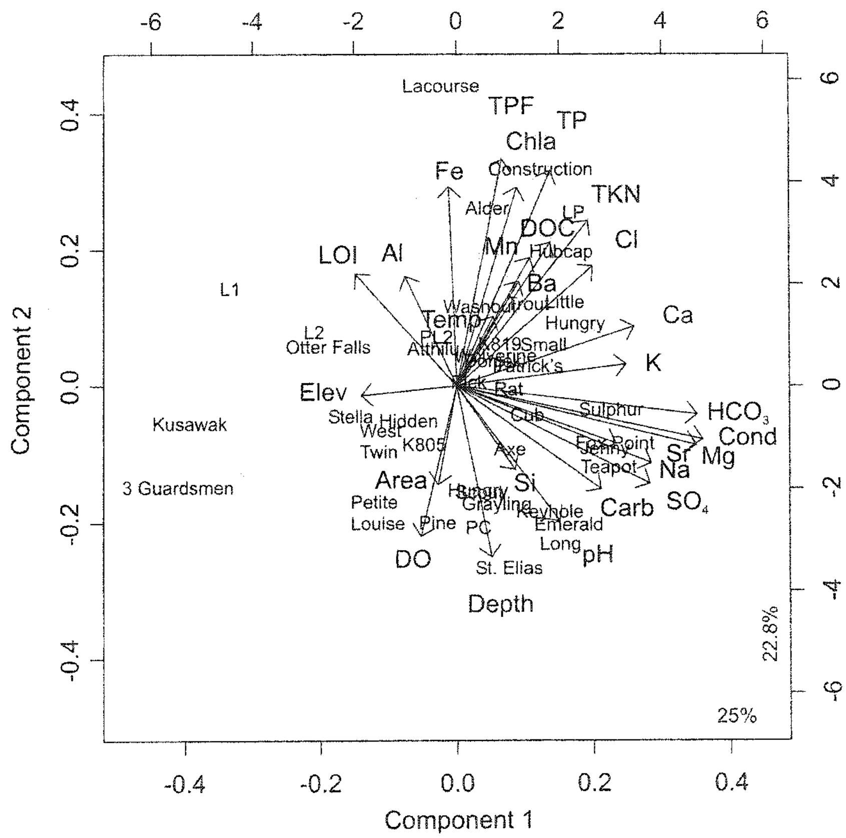


Figure 3: Principal components biplot of environmental variables for lakes in the southwest Yukon and northern B.C. The analysis was based on 42 cases of 27 variables using a correlation matrix. The following variables have not been identified in the text: aluminum (Al), barium (Ba), iron (Fe), manganese (Mn), strontium (Sr), and silica (Si).

In contrast, lakes on the left side of the diagram have low concentrations of dissolved ions. Kusawak and 3 Guardsmen are negatively correlated with ions and nutrients. Lakes L1, L2, Otter Falls, Kusawak, Stella and Petite Louise, all of which had an insufficient number of valves to include in the analysis, contained low concentrations of dissolved ions. A number of lakes are found in the upper right quadrant and have high nutrients. LOI is negatively correlated with ions, and poorly correlated with the rest of the variables.

4.1.1 Dissolution of valves

Sulphur, Fox Point, Jenny, Teapot, Keyhole, Emerald and Long had little or no dissolution of ostracode valves (< 1%). Lakes with higher pH, located in the bottom right quadrant of the biplot, exhibited a low abundance of deteriorated valves compared to lakes on the rest of the biplot. In comparison, over 70% of the valves of Cyclocyprids or Cyprids exhibited dissolution in West Twin, 3 Guardsmen, K805 and Lacourse Lakes. With the exception of K805, these lakes had a pH < 8.3.

Ostracodes require a source of $CaCO_3$ to make their shell, and neutral to alkaline waters to preserve it (pH between 7 and 9.2). Generally, Cyclocyprids, Cyprids, and Cypridopsids have thinner, low-calcite valves, and species of these genera can exist in environments with lower pH (Delorme 1991). Valves that experience dissolution were found in lakes poorly correlated with both HCO_3 and pH, and although the solute concentrations were sufficient to support the ostracodes while they were alive, the valves were not well preserved after death due to poorly buffered water (Delorme 1990; De Deckker 2002).

4.2 Distribution and Abundance of Ostracodes in the Southwest Yukon and Northern B.C.

A total of 28 freshwater species representing 8 genera were found in the 33 lakes (Figure 4). Common species (present in > 10 lakes) include *Cyclocypris ampla* (25 lakes), *Candona candida* (19 lakes), *Cypria turneri* (16 lakes), *Cypria ophtalmica* (14 lakes), and *Candona protzi* (11 lakes). These are widely distributed throughout North America (Henderson 1990; Curry and Delorme 2003). Abundances of *Cyclocypris ampla* ranged from < 1% to 69% of the individuals, and *Candona candida* between < 1% and 45%. Common species are widespread throughout the study area (Figure 5).

Rare species (present in ≤ 2 lakes) include *Candona compressa*, *Candona* cf. *distincta*, *Candona ikpikpukensis*, *Candona paraohioensis*, *Candona rawsoni*, *Candona* cf. *subtriangulata*, *Candona* sp. 2, and *Cypria palustera*. All other species were present in 3 to 8 lakes, and most have been found north of 60°N (Delorme 1968; Delorme et al. 1977; Delorme and Zoltai 1984). *Cypria palustera* has not previously been identified in the north, but have been found elsewhere in North America (Delorme 1970b). *Cyclocypris sharpei* has been found in present-day lakes only in Canada (Curry and Delorme 2003), and *Candona ikpikpukensis* is only found in arctic regions (Delorme 1968).

4.3 Ostracode Autoecology

The range of environmental conditions of species present in 3 or more lakes is presented in Table 5. The data here suggests that *Cypria turneri* can tolerate a broad range of ionic concentrations and compositions. *Candona candida* and *Cyclocypris ampla* have a broad pH range and inhabit a variety of aquatic environments occurring in lakes, ponds and

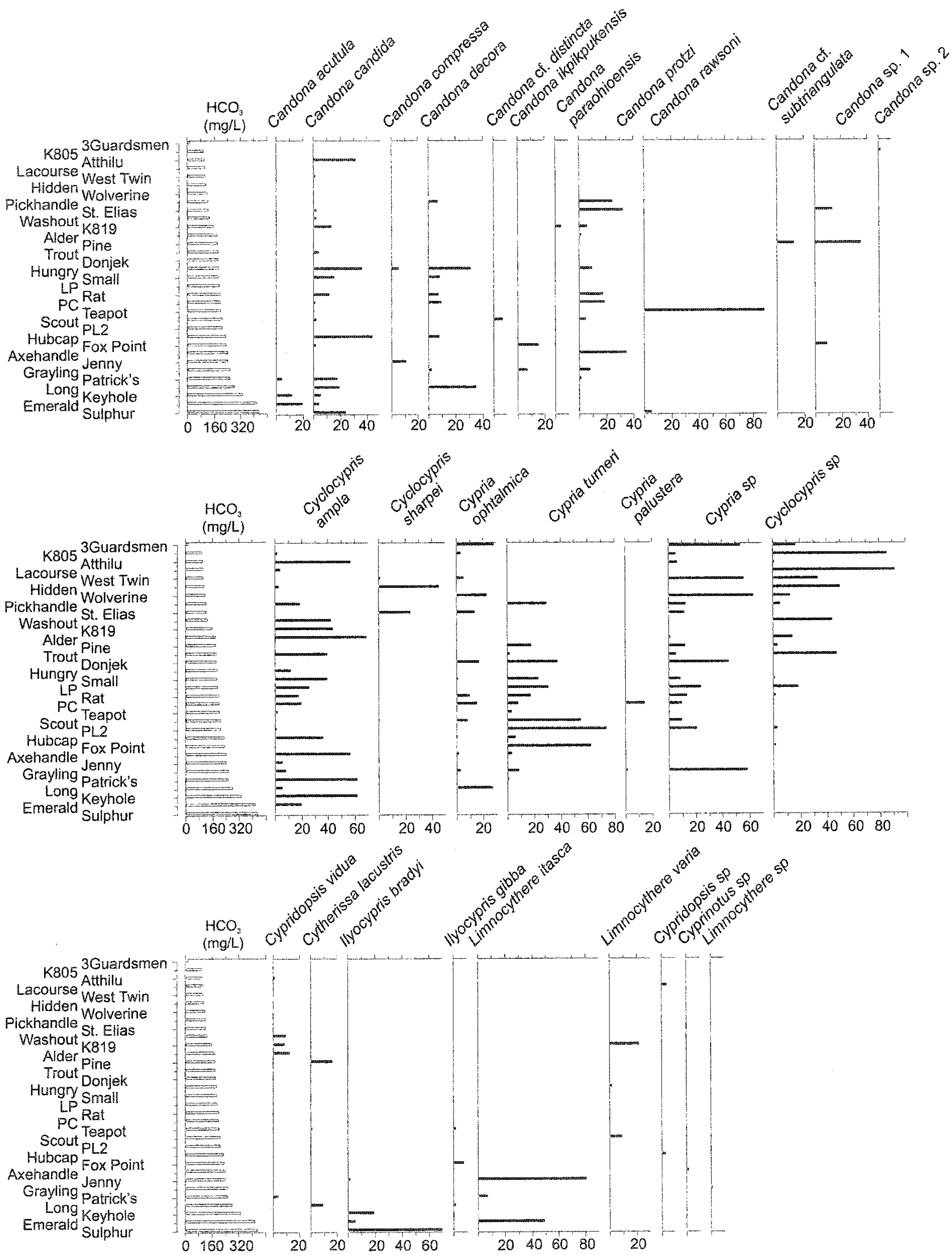


Figure 4: Percentage abundance of ostracode valves from 33 study lakes in the southwest Yukon and northern B.C, organized by increasing values of HCO_3. Note varying scales.

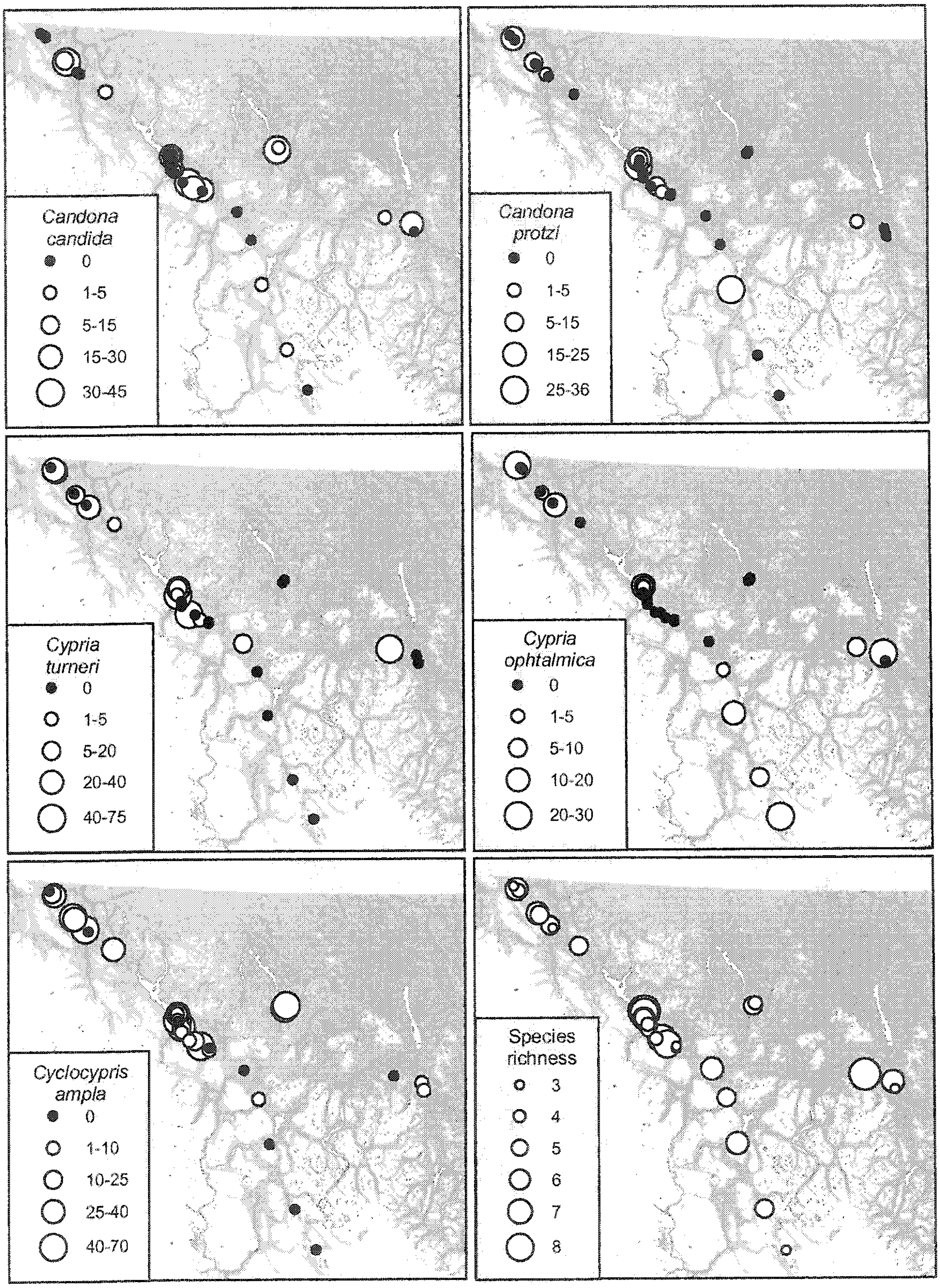


Figure 5: Modern distribution of common ostracode species (percent abundance) and estimated species richnss in the southwest Yukon and northern B.C. Scale is 1:4,000,000.

Table 5: Autoecological data of selected species. Note that these ranges apply only to the study lakes and actual range of the species may be greater. N represents the number of lakes.

		Depth (m)		pH		Cond (µS/cm)		TDS (g/L)		Ca (mg/L)		Mg (mg/L)		K (mg/L)		Na (mg/L)		SO_4 (mg/L)		HCO_3 (mg/L)		Mg/Ca	
Species	N	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Candona acutula	3	1.2	7.0	8.2	8.5	430	700	0.249	0.409	14.5	43.0	33.0	88.0	2.6	6.2	3.7	15.3	25.1	66.9	256.0	414.5	0.14	6.07
Candona candida	19	0.8	17.0	7.9	8.8	176	1100	0.100	0.652	14.5	73.0	4.1	114.0	0.2	11.1	2.2	19.2	4.0	458.4	106.1	426.7	0.12	6.07
Candona decora	8	1.1	17.0	8.0	8.8	250	560	0.147	0.324	21.8	53.0	12.1	54.0	2.3	8.3	4.7	16.3	11.5	77.2	124.4	280.4	0.27	2.35
Candona protzi	11	0.8	17.0	8.0	8.7	250	510	0.147	0.249	21.8	64.8	9.9	38.0	0.2	6.5	2.1	14.3	1.4	164.0	124.4	256.0	0.19	1.62
Candona sp 1	3	7.0	13.0	8.3	8.4	290	1100	0.169	0.652	36.0	64.8	14.7	44.0	0.2	11.1	3.5	6.0	7.8	458.4	126.8	234.1	0.25	1.13
Cyclocypris ampla	25	0.8	17.0	7.3	8.8	176	700	0.100	0.409	14.5	83.0	4.1	114.0	0.7	8.6	1.3	16.3	1.2	174.7	100.0	414.5	0.12	6.07
Cyclocypris sharpei	4	3.8	14.0	7.9	8.5	200	510	0.118	0.193	24.0	64.8	9.7	21.0	0.2	4.5	2.0	14.3	5.4	164.0	110.5	208.5	0.25	0.88
Cypria ophtalmica	14	1.1	17.0	7.5	8.8	40	560	0.021	0.324	5.4	64.8	0.3	54.0	0.2	8.3	1.8	16.3	1.4	164.0	21.1	280.4	0.05	2.35
Cypria turneri	16	1.1	17.0	7.9	8.8	250	1100	0.147	0.652	21.9	83.0	11.0	114.0	1.6	11.1	1.3	14.4	3.6	458.4	124.4	256.0	0.23	1.62
Cypridopsis vidua	6	0.8	6.5	8.0	8.7	176	430	0.100	0.249	21.8	57.0	4.1	33.0	0.9	5.6	2.1	4.7	1.4	57.3	106.1	256.0	0.12	1.21
Cytherissa lacustris	3	12.0	16.0	8.3	8.7	290	560	0.169	0.324	23.0	73.0	14.7	114.0	2.4	6.0	3.5	16.3	7.8	111.2	180.4	280.4	0.41	2.35
Ilyocypris bradyi	4	2.6	10.0	8.4	8.5	600	750	0.348	0.437	14.5	33.0	69.0	88.0	5.0	8.8	6.7	19.2	62.2	174.7	243.8	426.7	2.18	6.07
Limnocythere itasca	3	1.2	7.0	8.2	8.5	430	700	0.249	0.409	14.5	43.0	33.0	88.0	2.6	8.5	3.7	15.3	25.1	174.7	243.8	414.5	0.77	6.07

streams (Delorme 1991; Henderson 1990). They are able to live in a broad range of HCO_3, ion concentrations, and depth. The cosmopolitan species *Cypridopsis vidua* endures various habitats with different water chemistry (Delorme 1968; Curry 1999; Mezquita, et al. 1999), and occurred here in waters with high and low Mg/Ca ratio and HCO_3, but more moderate ion concentrations (Figure 6).

Candona decora and *Candona protzi* were present in lakes with mid to high HCO_3 and Mg/Ca ratios, and low SO_4 concentrations. Both species prefer dilute lakes (Delorme 1991; Porter et al. 1999). *Cyclocypris* sp. and *Cypridopsis* sp. decreased in abundance with an increase in HCO_3, and were only found in lakes with Mg/Ca ratio < 1. *Cypria* sp. also decreased in abundance with an increase in HCO_3 concentrations, with one obvious exception (Grayling Lake). Lakes with Mg/Ca < 1 hosted *Cyclocypris sharpei*, where *Ilyocypris bradyi* only occurred in lakes with a ratio > 2. Mourguiart et al. (1994) consider the Mg/Ca ratio the principal control over a species to be present at a site.

Cypria ophtalmica is commonly found in lakes with low conductivity and low salinity (Curry 1999), whereas *Ilyocypris gibba* is found in high sulphate waters (Mezquita et al 1999). *Candona distincta* prefers permanent lacustrine environments (Miller et al. 2000 and references therein).

Candona acutula, *Ilyocypris bradyi*, and *Limnocythere itasca* were found in a narrower range of HCO_3 and ion concentrations, but at higher values. *C. acutula* was only found in low abundance (< 20%), whereas *I. bradyi* (2% and 70%) and *L. itasca* (8% to 81%) could be either rare or abundant. *Cytherissa lacustris* is restricted to cold, deep freshwater lakes (Delorme 1970; Delorme and Zoltai 1984; Danielopol et al. 1993), and occurred at a minimum depth of 12 metres.

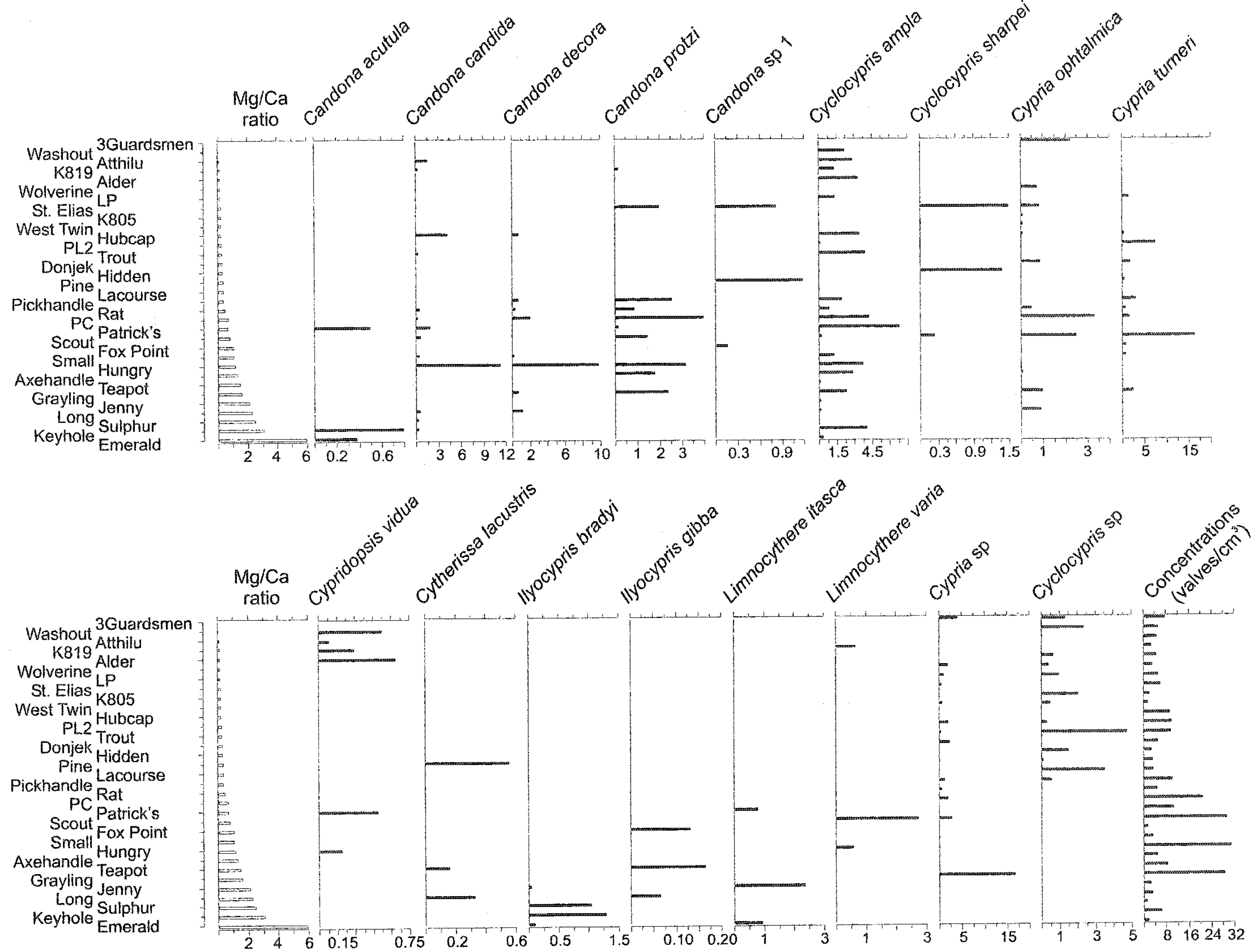


Figure 6: Concentration abundance of ostracode valves from 33 study lakes in the southwest Yukon and northern B.C., Organized by increasing values of Mg/Ca ratio. Species present in 3 or more lakes are shown. Note varying scales.

4.4 Species Abundance

Four lakes (Teapot, Jenny, PL2 and Sulphur) each supported one dominant species - *Candona rawsoni* (89%), *Limnocythere itasca* (81%), *Cypria turneri* (74%) and *Ilyocypris bradyi* (70%), respectively. *Cypria turneri* also comprised 63% of the individuals in Fox Point. With the exception of lake PL2, SO_4 concentrations in these lakes are well above the mean. Smith (2002) suggests *C. rawsoni* and *L. itasca* are more abundant in waters with high SO_4.

Candona rawsoni is a eurytopic species tolerant of a wide range of physical and chemical conditions (Smith 1993; Smith 1997; Curry 1999), and is common in environments that are characterized by high variability and low predictability (Forester et al. 1994). Teapot Lake undergoes wide fluctuations in nutrients and chemistry throughout the summer months. It is a small, deep, closed-basin kettle lake adjacent to glacier-fed Kluane Lake, which experiences an increase in water levels as the season progresses. In 2001, the level of Teapot increased by 3 meters between the end of May and the beginning of August (personal observation). Teapot Lake routinely develops a metalimnetic oxygen maxima which increases dissolved oxygen and phosphorus concentrations significantly in the metalimnion, and depletes oxygen in the hypolimnion, thereby impacting the organisms in the lake. *C. rawsoni* is able to tolerate these changing conditions.

4.5 Valve Concentrations and Species Richness

The highest concentrations of ostracodes are found in Hungry, Grayling, Scout and PC Lakes where the conductivity ranges between 330 and 397 μS/cm (Figure 7). These lakes have moderate to low nutrients (TP < 15 μg/L) and sediment organic matter (9% to

38%). All 4 lakes are deep (> 6 m), and two have a large surface area (> 20 ha). Typically, shallow lakes have higher nutrients, which result in more organic matter in the sediment, yet it is the deep, less productive lakes that provide a variety of habitats to support different species requirements (Mourguiart et al. 1986; Mourguiart and Carbonel 1994; Mourguiart and Montenegro 2002).

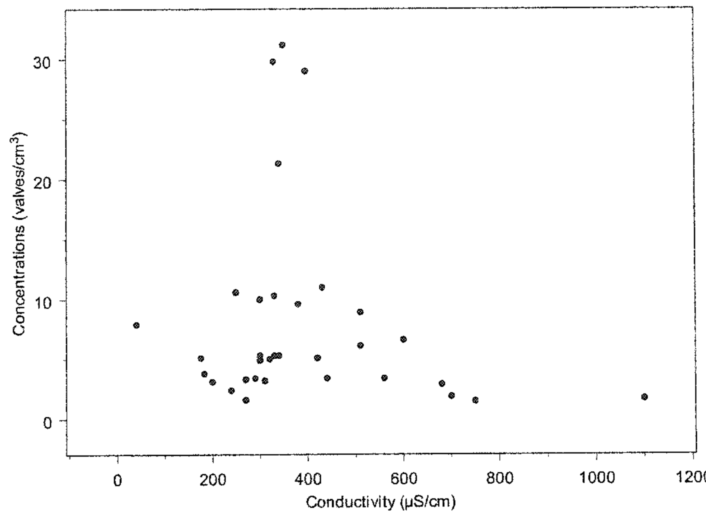


Figure 7: Conductivity and total ostracode valve concentrations in 33 lakes in the southwest Yukon and northern B.C.

PC, Grayling, Rat and Scout Lakes have the highest estimated species richness. PC, Grayling and Rat Lakes are within 1 km of one another, and all 4 lakes are either oligotrophic (PC, Grayling and Scout) or mesotrophic (Rat), and have mid to low values of LOI (9% to 40%). This suggests that productivity and sediment organic matter are not positively correlated with species richness. A study in the northern mid-west United States found that highest species richness occurred between 350 and 450 µS/cm (Smith 1993a), which is comparable to the conductivities encountered in the southwest Yukon (Figure 8).

Not surprisingly, high values of estimated species richness are generally found in lakes with high concentrations of valves (Figure 9). One exception is Fox Point Lake, which has the highest conductivity (1100 µs/cm) and SO_4 (458 mg/L) values among the study lakes, and an estimated species richness of 6. This lake is on the same bedrock type as PC, Grayling, and Rat, and is likely influenced by groundwater that is Mg-Ca-SO_4 dominant (Smith 2002). Fox Point Lake contains one species that represents 63% of the individuals, suggesting the influence of high values of sulphate on species abundance.

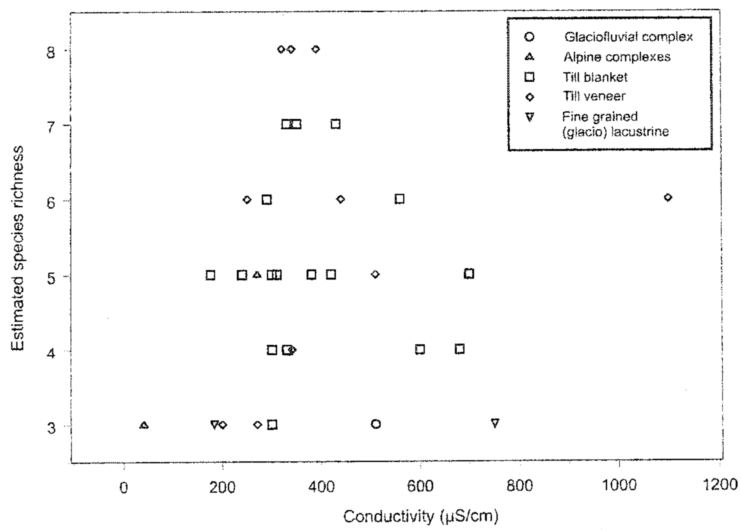


Figure 8: Conductivity and estimated species richness of ostracodes in 33 lakes in the southwest Yukon and northern B.C., displayed by surficial geology

Of the 11 species present in the 3 lakes with the highest species richness, 6 species are found in all 3 lakes. These are *Candona decora*, *Candona protzi*, *Cyclocypris ampla*, *Cypria ophtalmica*, *Cypria turneri* and *Cypria* sp. Four of these species are common in this study (Figure 5).

Overall, the estimated species richness is low (3 to 8). There is little geographical pattern to the species richness, high and low values can be found across the study area

(Figure 5). The species richness is similar to that found in other freshwater lakes, which is typically between 1 and 5 species (De Deckker and Forester 1988).

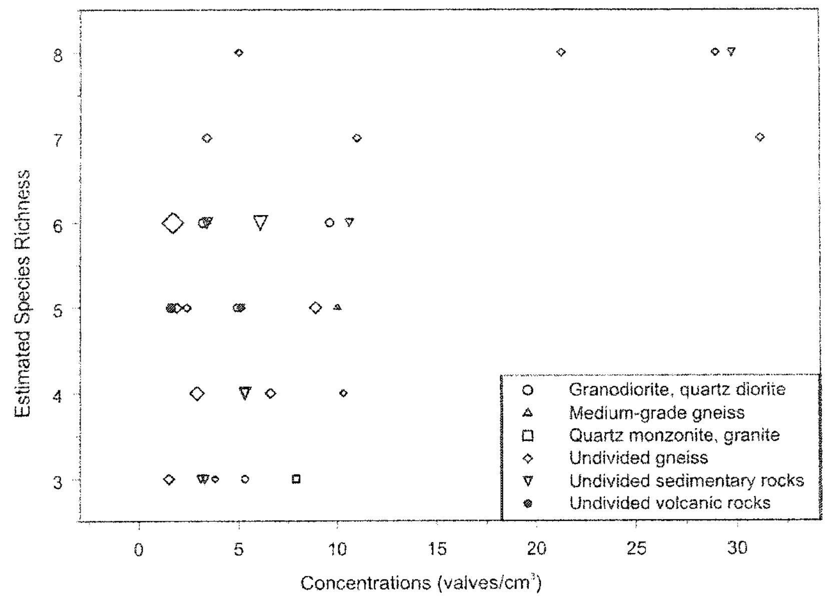


Figure 9: Total ostracode valve concentrations and estimated ostracode species richness in 33 lakes in the southwest Yukon and northern B.C., displayed by subrock type. Symbol size represents low, medium and high values of SO_4.

4.6 Ostracodes and the Chemical Environment

High concentrations of ostracode valves appear to depend on the ionic concentration of the lake water, where moderate values of the various ions result in the most valves per cm^3 of sediment. This occurs because many species can tolerate these intermediate values. Higher ion concentrations are often the result of one dominant cation or anion (Gorham et al. 1983), which can decrease species richness as fewer species can tolerate high values (Smith 1993a).

The Mg/Ca ratio is an important determinant of ostracode presence. For example, higher concentrations of Mg relative to Ca favoured *I. bradyi*, and lower concentrations, *C. sharpei*. In comparison, species abundance was affected by sulphate, where higher values could result in a dominant species not common in other lakes. In both of these cases, it appears it was the higher or lower value of an anion or cation that was responsible for the presence of these species.

CHAPTER FIVE: CONCLUSION

5.1 CONCLUSION

The impact of nutrients and sediment organic matter on ostracode abundance and distribution could not be identified in this study, as these parameters were variable or low in lakes with high concentrations and high estimated species richness. Generally, common species and estimated species richness show little geographic pattern. The lack of spatial pattern in the distribution of the common species suggests dissolved ion concentrations and composition is a factor that ultimately determines the species found in any lake.

The hypothesis that dissolved ion concentrations and composition of the lake water are the primary determinants of the modern ostracode distribution in the southwest Yukon and northern B.C. is supported by this study. Intermediate values of dissolved ion concentrations of the water support the highest species richness. In the southwest Yukon and northern B.C., the range of dissolved ion concentrations is generally low, but this range provides an environment for a wide range of species to exist. In contrast, different ionic compositions control individual species presence.

REFERENCES

Birks, H.J.B. and J.M. Line. 1992. The use of rarefaction analysis for estimating palynological richness from Quaternary pollen-analytical data. *Holocene*. 2(1): 1-10.

Benson, R.H. and H.C. MacDonald. 1963. Postglacial (Holocene) ostracodes from Lake Erie. University of Kansas Paleontological Contributions, Article 4: 1-26.

Bridgwater, N.D., T.H.E. Heaton and S.L. O'Hara. 1999. A late Holocene palaeolimnological record from central Mexico, based on faunal and stable-isotope analysis of ostracod shells. *Journal of Paleolimnology*. 22: 383-397.

Bronshtein, Z.S. 1988. *Fresh-water Ostracoda*. Rotterdam: A.A. Balkema. 470 pp.

Burnison, B.K. 1980. Modified Dimethyl Sulfoxide (DMSO) Extraction for Chlorophyll Analysis of Phytoplankton. *Canadian Journal of Fisheries and Aquatic Sciences*. 37: 729-733.

Butlin, R.K., P. Menozzi. 2000. Open questions in evolutionary ecology: do ostracods have the answers? *Hydrobiologia*. 419: 1-14.

Carbonel, P., J.-P. Colin, D.L. Danielopol, H. Löffler and I. Neustrueva. 1988. Paleoecology of Limnic Ostracodes: A Review of Some Major Topics. In Gray, J. (ed.), *Paleolimnology: Aspects of freshwater paleoecology and biogeography*. New York: Elsevier Science, pp. 413-475.

Curry, B.B. 1996. Paleochemistry of Lakes Agassiz and Manitoba based on ostracodes. *Canadian Journal of Earth Sciences*. 34: 699-708.

Curry, B.B. 1999. An environmental tolerance index for ostracodes as indicators of physical and chemical factors in aquatic habitats. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 148: 51-63.

Curry, B.B. and D. Delorme. 2003. Ostracode-based reconstruction from 23,300 to about 20,250 cal yr BP of climate, and paleohydrology of a groundwater-fed pond near St. Louis, Missouri. *Journal of Paleolimnology*. 29: 199-207.

Danielopol, D.L., E. Ito, G. Wansard, T. Kamiya, T.M. Cronin, and A. Baltanás. 2002. Techniques for Collection and Study of Ostracoda. In Holmes, J.A. and A.R. Chivas (eds.), *The Ostracoda: Applications in Quaternary Research.* Washington: American Geophysical Union, pp. 65-97.

Danielopol, D.L., M. Handl and Y. Yin. 1993. Benthic ostracods in the pre-alpine deep lake Mondsee. Notes on their origin and distribution. In McKenzie, K.G. and P.J. Jones, *Ostracoda in the Earth and Life Sciences, 11th International Symposium on Ostracoda*. Rotterdam: Balkema Publishers. 465-480.

Davies, W.K.D. 1984. *Factorial Ecology*. Aldershot, Hants: Gower, 409 pp.

Davydova, N.N., D.A. Subetto, V.I. Khomutova and T.V. Sapelko. 2001. Late Pleistocene-Holocene paleolimnology of three northwestern Russian lakes. *Journal of Paleolimnology*. 26: 37-51.

De Deckker, P. 2002. Ostracod Palaeoecology. In Holmes, J.A. and A.R. Chivas (eds.), *The Ostracoda: Applications in Quaternary Research.* Washington: American Geophysical Union, pp. 121-134.

De Deckker, P. and R.M. Forester. 1988. The use of ostracods to reconstruct continental palaeoenvironmental records. In De Deckker, P., J.P. Colin, and J.P. Peypouquet (eds.), *Ostracoda in the Earth Sciences*. New York: Elsevier, pp. 175-199.

Delorme, L.D. 1967. Field Key and Methods of Collecting Freshwater Ostracodes in Canada. *Canadian Journal of Zoology*. 45: 1275-1280.

Delorme, L.D. 1968. Pleistocene freshwater Ostracoda from Yukon, Canada. *Canadian Journal of Zoology*. 46: 859-876.

Delorme, L.D. 1969a. On the identity of the ostracode genera Cypriconcha and Megalocypris. *Canadian Journal of Zoology* 47: 271-281.

Delorme, L.D. 1969b. Ostracodes as Quaternary paleoecological indicators. *Canadian Journal of Earth Sciences*. 6: 1471-1476.

Delorme, L.D. 1970a. Freshwater ostracodes of Canada. Part I. Subfamily Cypridinae. *Canadian Journal of Zoology*. 48:153-168.

Delorme, L.D. 1970b. Freshwater ostracodes of Canada. Part II. Subfamily Cypridopsinae and Herpetocypridinae and family Cyclocyprididae. *Canadian Journal of Zoology*. 48:253-266.

Delorme, L.D. 1970c. Freshwater ostracodes of Canada. Part III. Family Candonidae. *Canadian Journal of Zoology*. 48:1099-1127.

Delorme, L.D. 1970d. Freshwater ostracodes of Canada. Part IV. Families Ilyocyprididae, Notodromadidae, Darwinulidae, Cytherideidae, and Entocytheridae. *Canadian Journal of Zoology*. 48:1251-1259.

Delorme, L.D. 1971. Freshwater ostracodes of Canada. Part V. Families Limnocytheridae, Loxoconchidae. *Canadian Journal of Zoology*. 49:43-64.

Delorme, L.D. 1990. Freshwater Ostracodes. In Warner, B.G. (ed.), *Methods in Quaternary Ecology*, Reprint Series 5. Geosciences Canada, pp. 93-100.

Delorme, L.D. 1991. Ostracoda. In Thorp, J.H. and A.P. Covich (eds.), *North American Freshwater Invertebrates*. Toronto: Academic Press, pp. 691-717.

Delorme, L.D. and S.C. Zoltai. 1984. Distribution of an arctic ostracode fauna in space and time. *Quaternary Research*. 21:65-73.

Delorme, L.D., S.C. Zoltai and L.L. Kalas. 1977. Freshwater shelled invertebrate indicators of paleoclimate in Northwestern Canada during the late glacial. *Canadian Journal of Earth Sciences*. 15: 462-463.

Delorme, L.D., S.C. Zoltai and L.L. Kalas. 1978. Freshwater shelled invertebrate indicators of paleoclimate in Northwestern Canada during late glacial times; reply. *Canadian Journal of Earth Sciences*. 14: 2029-2046.

Emsley, J. 1998. *The Elements* (3rd ed.). Oxford: Clarendon Press, 292 pp.

Engstrom, D.R. and Nelson, S.R. 1991. Paleosalinity from trace metals in fossil ostracodes compared with observational records at Devils Lake, North Dakota. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 83: 295-312.

Environment Canada. 2000. Canadian Climate Normals. Ottawa: Environment Canada. Available: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/

Environment Canada. 1994. Manual of Analytical Methods: Major Ions and Nutrients, v. 1. Burlington: National Laboratory for Environmental Testing.

Eugster, H.P. and B.F. Jones. 1979. Behavior of major solutes during closed-basin brine evolution. *American Journal of Science*. 279: 609-631.

Forester, R.M. 1983. Relationship of two lacustrine ostracode species to solute composition and salinity: Implications for paleohydrochemistry. *Geology*. 11: 435-438.

Forester, R.M. 1986. Determination of the dissolved anion composition of ancient lakes from fossil ostracodes. *Geology*. 14: 796-798.

Forester, R.M. 1987. Late Quaternary paleoclimate records from lacustrine ostracodes. In Ruddiman, W.F. and H.E. Wright (eds.), *North America and adjacent oceans during the last deglaciation stage, The Geology of North America*, v. K-3. Boulder: Geological Society of America, pp. 261-276.

Forester, R.M. 1991. Ostracode Assemblages from Springs in the Western United States: Implications for Paleohydrology. *Memoirs of the Entomological Society of Canada No. 155,* pp. 181-209.

Forester, R.M., S.M. Colman, R.L. Reynolds and L.D. Keigwin. 1994. Lake Michigan's late Quaternary limnological and climate history from ostracode, oxygen isotope, and magnetic susceptibility. *Journal of Great Lakes Research.* 20: 93-107.

Fulton, R.J. (Compiler). 1995. Surficial materials of Canada. Geological Survey of Canada Map 1880A, scale 1:5,000,000. Cd-rom.

Furtos, N.C. 1933. *The Ostracoda of Ohio.* Ohio Biological Survey Bulletin 29, 5(6): 413-524.

Gabrielese, H., D.J. Tempelman-Kluit, S.L. Blusson, and R.B. Campbell (Compilers). 1977. MacMillan River Yukon – District of Mackenzie – Alaska. Geological Survey of Canada Map 1398A, scale 1:1,000,000.

Glew, J.R. 1991. Miniature gravity corer for recovering short sediment cores. *Journal of Paleolimnology.* 5:285-287.

Gorham, E., W.E. Dean and J.E. Sanger. 1983. The chemical composition of lakes in the north-central United States. *Limnology and Oceanography.* 28(2): 287-301.

Griffiths, H.I. and J.A. Holmes. 2000. *Non-marine ostracods and Quaternary paleoenvironments.* Technical Guide No. 8. London: Quaternary Research Association, 188 pp.

Gutentag, E.D. and R.H. Benson. 1962. Neogene (Plio-Pleistocene) fresh-water ostracodes from the central high plains. Geological Survey of Kansas, Bulletin 157(4): 1-60.

Hammarlund, D. and D.H. Keen. 1994. A Late Weichselian stable isotope and molluscan stratigraphy from southern Sweden. *GFF.* 116: 235-248.

Hardie, L.A. and H.P. Eugster. 1970. The evolution of closed-basin brines. Mineralogical Society of America Special Paper 3, pp. 273-290.

Heiri, O.A.F. and G. Lotter. 2001. Effect of low sum counts on quantitative environmental reconstructions: an example using subfossil chironomids. *Journal of Paleolimnology.* 26: 343-350.

Heiri, O, A.F. Lotter, G. Lemcke. 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology.* 25: 101-110.

Henderson, P.A. 1990. *Freshwater Ostracods. Synopses of the British fauna (New Series) No. 42*. Oegsteest: Universal Book Services and Dr. W. Backhuys.

Henderson, P.A. and I. Walker. 1986. On the leaflitter community of the Amazonian blackwater stream Tarumazinho. *Journal of Tropical Ecology*. 2: 1-17.

Holmes, J.A. 1992. Nonmarine ostracodes as Quaternary palaeoenvironmental indicators. *Progress in Physical Geography*. 16(4): 405-431.

Holmes, J.A. and A.R. Chivas. 2002. Introduction. In Holmes, J.A. and A.R. Chivas (eds.), *The Ostracoda: Applications in Quaternary Research*. Washington: American Geophysical Union, pp. 1-4.

Holmes, J.A. 2001. Ostracoda. In Smol, J.P., H.J.B. Birks, and W.M. Last (eds.), *Tracking Environmental Change Using Lake Sediments: Zoological Indicators*, v. 4. Boston: Kluwer Academic Publishers, pp. 125-151.

Horne, D.J. and K. Martens. 1999. Geographical parthenogenesis in European non-marine ostracods: post-glacial invasion or Holocene stability? *Hydrobiologia*. 391: 1-7.

Horne, D.J., A.Cohen, and K. Martens. 2002. Taxonomy, Morphology and Biology of Quaternary and Living Ostracodes. In Holmes, J.A. and A.R. Chivas (eds.), *The Ostracoda: Applications in Quaternary Research*. Washington: American Geophysical Union, pp. 5-36.

Insightful Corporation. 2001. *S-Plus 6 for Windows Guide to Statistics, Volume 2*. Seattle: Insightful Corporation, 622 pp.

Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Third Assessment, McCarthy, J.J, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White (eds.). Cambridge University Press, 1032 pp.

Jeffrey, S.W. and G.F. Humphrey. 1975. New Spectrophotometric Equations for Determining Chlorophylls a, b, c_1 and c_2 in Higher Plants, Algae and Natural Phytoplankton. *Biochemie Physiologie Pflanzen*. 167: 191-194.

Johnson, F. and H.M. Raup. 1964. Investigations in Southwest Yukon: Geobotanical and Archaeological Reconnaisance. Papers of the Robert S. Peabody Foundation for Archaeology, v. 6, Andover, Massachusetts. pp. 81-123.

Kalff, J. 2002. Limnology: Inland water ecosystems. Upper Saddle River, N.J.: Prentice Hall. 592 pp.

Korhola, A., S. Sorvari, M. Rautio, P.G. Appleby, J.A. Dearing, Y. Hu, N. Rose, A. Lami, and N.G. Cameron. 2002. A multi-proxy analysis of climate impacts on the recent development of subarctic Lake Saanajärvi in Finnish Lapland. *Journal of Paleolimnology*. 28: 59-77.

Lacourse, T. and K. Gajewski. 2000. Late Quaternary Vegetation History of Sulphur Lake, Southwest Yukon Territory, Canada. *Arctic*. 53(1): 27-35.

Lerbekmo, J.F. and F.A. Campbell. 1969. Distribution, composition, and source of the White River Ash, Yukon Territory. *Canadian Journal of Earth Sciences*. 6: 109-116.

Larocque, I., R.I. Hall, and E. Grahn. 2001. Chironomids as indicators of climate change: a 100-lake training set from a subarctic region of northern Sweden (Lapland). *Journal of Paleolimnology*. 26: 307-322.

Löffler, H. 1986. Ostracod analysis. In Handbook of Holocene Palaeoecology and Palaeohydrology, Berglund, B.E. (ed.). Toronto: John Wiley & Sons, 869 pp.

Lowe, J.J. and M.J.C. Walker. 1997. *Restructuring Quaternary Environments* (2^{nd} ed.). Toronto: Prentice Hall, 446 pp.

Malmqvist, B., C. Meisch and A.N. Nilsson. 1997. Distribution patterns of freshwater Ostracoda (Crustacea) in the Canary Islands with regards to habitat use and biogeography. *Hydrobiologia*. 347: 159-170.

Mezquita, F. A. Sanz-Brau and G. Wansard. 2000. Habitat preferences and population dynamics of Ostracoda in a helocrene spring system. *Canadian Journal of Zoology*. 78: 840-847.

Miller, B.B., A.F. Schneider, A.J. Smith and D.F. Palmer. 2000. A 6000 year water level history of Europe Lake, Wisconsin, USA. *Journal of Paleolimnology*. 23: 175-183.

Moser, K.A., A. Korhola, J. Weckström, T. Blom, R. Pienitz, J.P. Smol, M.S.V. Douglas, and M.B. Hay. 2000. Paleohydrology inferred from diatoms in northern latitude regions. *Journal of Paleolimnology*. 24: 93-107.

Mourguiart, Ph., and P. Carbonel. 1994. A quantitative method of palaeolake-level reconstruction using ostracod assemblages: an example from the Bolivian Altiplano. *Hydrobiologia*. 288: 183-193.

Mourguiart, P. and M.E. Montenegro. 2002. Climate changes in the Lake Titicaca area: evidence from ostracod ecology. In Holmes, J.A. and A.R. Chivas (eds.), *The Ostracoda: Applications in Quaternary Research.* Washington: American Geophysical Union, pp. 151-165.

Mourguiart, P., P. Carbonel, J.-P. Peypouquet, D. Wirrmann, and C. Vargas. 1986. Late Quaternary palaeohydrology of Lake Huinaymarca (Bolivia). *Hydrobiologia*. 143: 191-197.

National Atlas Information Service. 1995. *Canada, Permafrost*. Map. 1:7,500,000. The National Atlas of Canada, 5th Edition, MCR 4177. Ottawa: Natural Resources Canada.

Nuttall, P.M. 1969. The taxonomy, ecology and distribution of the freshwater ostracods of Ontario. M.Sc. Thesis University of Waterloo, 134 pp.

Pennak, R.W. 1989. *Fresh-Water Invertebrates of the United States: Protozoa to Mollusca* (3rd ed.). Toronto: John Wiley & Sons, Inc., 628 pp.

Pienitz, R., J. P. Smol, and D.R.S. Lean. 1997. Physical and chemical limnology of 59 lakes located between the southern Yukon and Tuktoyaktuk Peninsula, Northwest Territories (Canada). *Can. J. Fish. Aquat. Sci.* 54: 330-346.

Ponader, K, R Pienitz, W. Vincent and K. Gajewski. 2002. Limnological conditions in a subarctic lake (northern Québec, Canada) during the late Holocene: analyses based on fossil diatoms. *Journal of Paleolimnology*. 27(3): 353-366.

Porter, S.C., D.J. Sauchyn and L.D. Delorme. 1999. The ostracode record from Harris Lake, southwestern Saskatchewan: 9200 years of local environmental change. *Journal of Paleolimnology*. 21: 35-44.

Quinlan, R. and J.P. Smol. 2001. Setting minimum head capsule abundance and taxa deletion criteria in chironomids-based inference models. *Journal of Paleolimnology*. 26:327-342.

Rawson, D.S. 1953. The bottom fauna of Great Slave Lake. *Journal of Fisheries Resources Board of Canada*. 10(8): 207-240.

Rudin, N. 1997. *Dictionary of Modern Biology*. New York: Barron's. 504 pp.

Rouse, W.R., M.S. Douglas, R.E. Hecky, A.E. Hershey, G. W. Kling, L. Lesack, P. Marsh, M. McDonald, B.J. Nicholson, N.T. Roulet and J.P. Smol. 1997. Effects of climate change on the freshwaters of Arctic and Subarctic North America. *Hydrological Processes*. 11: 873-902.

Schindler, D.W. 1997. Widespread effects of climatic warming on freshwater ecosystems in North America. *Hydrological Processes*. 11: 1043-1067.

Schindler, D.W. 2001. The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. *Canadian Journal of Fisheries and Aquatic Sciences*. 58: 18-29.

Shortreed, K.S. and J.G. Stockner. 1986. Trophic status of 19 subarctic lakes in the Yukon Territory. *Canadian Journal of Fisheries and Aquatic Sciences.* 43: 797-805.

Smith, A.J. 1993. Lacustrine ostracodes as hydrochemical indicators in lakes of the north-central United States. *Journal of Paleolimnology.* 8: 121-134.

Smith, A.J. 1993a. Lacustrine ostracode diversity and hydrochemistry in lakes of the northern Midwest of the United States. In McKenzie, K.G. and P.J. Jones, *Ostracoda in the Earth and Life Sciences, 11th International Symposium on Ostracoda.* Rotterdam: Balkema Publishers. 493-502.

Smith, A.J., J.J. Donovan, E. Ito, D.R. Engstrom and V.A. Panek. 2002. Climate-driven hydrologic transients in lake sediment records: multiproxy record of mid-Holocene drought. *Quaternary Science Reviews.* 21: 625-646.

Smith, G.L. 1997. Late Quaternary climates and limnology of the Lake Winnebago basin, Wisconsin, based on ostracodes. *Journal of Paleolimnology.* 18: 249-260.

Smith, A.J. and D.J. Horne. 2002. Ecology of Marine, Marginal Marine and Nonmarine Ostracodes. In Holmes, J.A. and A.R. Chivas (eds.), *The Ostracoda: Applications in Quaternary Research.* Washington: American Geophysical Union, pp. 37-64.

Swadling, K.M., R. Pienitz, and T. Nogrady. 2000. Zooplankton community composition of lakes in the Yukon and Northwest Territories (Canada) relationship to physical and chemcial limnology. *Hydrobiologia.* 431(2-3): 211-224.

Swadling, K.M., J.A.E. Gibson, R. Pienitz and W.F. Vincent. 2001. Biogeography of copepods in lakes and ponds of subarctic Québec, Canada. *Hydrobiologia.* 453/454: 341-350.

Swain, F.M. 1963. Pleistocene Ostracoda from the Gubik Formation, Arctic Coastal Plain, Alaska. *Journal of Paleontology.* 37(4): 798-834.

Tressler, W.L. 1957. The Ostracoda of Great Slave Lake. *Journal of the Washington Academy of Sciences.* 47:415-423.

Tressler, W.L. 1959. Ostracoda. In Edmonston, W.T. (ed.), *Fresh-water Biology.* New York: John Wiley & Sons, 657-734.

Vetter, M.A. 2000. Grasslands of the Aishihik-Sekulmun Lakes Area, Yukon Territory, Canada. *Arctic* 53 (2): 165-173.

Wetzel, R.G. 2001. *Limnology: Lake and River Ecosystems* (3rd ed.). New York: Academic Press, 1006 pp.

Wetzel, R.G. and G.E. Likens. 2000. *Limnological Analyses* (3rd ed.). New York: Springer, 429 pp.

Whatley, R.C. 1988. Ostracoda and Palaeogeography. pp. 103-123 *in* De Deckker, P., J.P. Colin, and J.P. Peypouquet (Eds.), *Ostracoda in the Earth Sciences*. New York; Elsevier, pp. 103-123.

Wheeler, J.O., P.F. Hoffman, K.D. Card, A. Davidson, B.V. Sanford, A.V. Okulitch, and W.R. Roest (Compilers). 1997. Geological Map of Canada. Geological Survey of Canada. Map D1860A, scale 1:5,000,000. Cd-rom.

Wilson, S.E. and K. Gajewski. 2002. Surface-sediment diatom assemblages and water chemistry from 42 subarctic lakes in the southwestern Yukon and north British Columbia, Canada. *Écoscience*. 9(2): 256-270.

Wilson, S.E. and K. Gajewski. Submitted. Modern chironomid assemblages and their relationship to physical and chemical variables in southwest Yukon and northern British Columbia lakes. *Arctic, Antarctic and Alpine Research.*

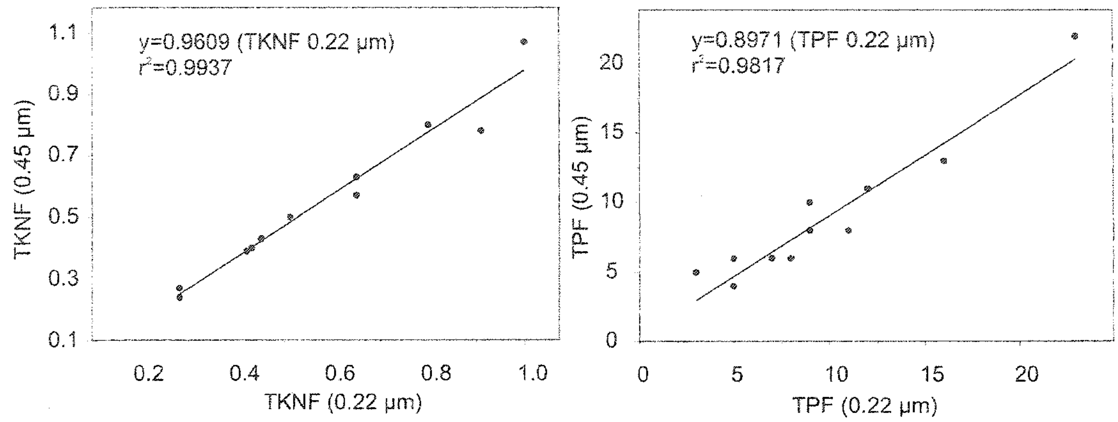
Xia, J. D.R. Engstrom and E. Ito. 1997. Geochemistry of ostracode calcite: Part 2. The effects of lake-water chemistry and seasonal temperature variation on *Candona rawsoni*. *Geochimica et Cosmochimica Acta*. 61: 383-391.

APPENDIX 1: FILTERED PHOSPHORUS AND NITROGEN

In 1998, 0.47 mm diameter, 0.22 μm filters were used to filter water samples for filtered phosphorus and nitrogen samples (TPF and TKNF) and in 2002, 0.47 mm diameter, 0.45 μm filters were used. Typically, samples filtered through the 0.22 μm filters exhibit slightly higher values. Therefore, a linear regression model was fit to the data to establish an equation to estimate 0.22 μm values from 1998 to the 0.45 μm equivalent.

In 2003, twelve lakes representing high, medium and low productivity were selected for the comparison. To ensure consistent results, the water samples measured for TPF/TKNF through the 0.45 μm filter, and TPF/TKNF through the 0.22 μm filter, were taken from the same 1L water sample that was collected in the field.

A linear regression model was chosen based on the data (Figure 1). TKNF (0.45 μm) and TPF (0.45 μm) were selected as the dependent variables. Both models were forced through 0 because when the value of either TKNF or TPF is 0 with one pore size filter, then it is expected that it would be 0 for the other pore size filter. Both models showed a strong positive correlation, and each model had a p-value statistic of 0, indicating the model as significant.



Appendix 1, Figure 1: Scatterplots, regressions and regression equations of TKNF(0.22 µm and 0.45 µm filters) and TPF (0.22 µm and 0.45 µm filters).

APPENDIX 2: CALCULATION OF DISSOLVED INORGANIC CARBON (DIC) AND BICARBONATE (HCO_3)

DIC = total alkalinity x pH factor

- pH factor is based on known dissociation constants of the carbonate complex at a given concentration of hydrogen ions and temperature (Wetzel & Likens 2000)

HCO_3 = DIC x 5.08 (wt H + wt C + 3 (wt O) / wt C = 5.08)

Where:
- H = hydrogen (1.00794)
- C = carbon (12.011)
- O = oxygen (15.9994)

DIC is effectively carbon, which is why carbon is used
Atomic weights of the elements are in brackets (Emsley 1998)

APPENDIX 3: EXPLANATION OF DATA SUBSTITUTION AND DELETION

Total Kjeldahl Nitrogen (particulate) and Filtered Total Kjeldahl Nitrogen (dissolved)

Once water has been filtered through the 0.45 µm filter, the nitrogen on the filter paper is bound to particles and is defined as being in particulate form. The water that has transferred through the filter is in dissolved form, and is unstable. This makes it difficult to accurately measure dissolved nitrogen in lake water. The unstable nitrogen is susceptible to change, and in 6 of the study lakes the dissolved nitrogen was actually greater than particulate nitrogen. This is problematic in these samples because most of the nitrogen is particulate, making the amounts comparable. Due to this inconsistency, the variable was removed from the dataset.

Surface area calculations

The lakes were measured from 1:50,000 topographic maps and the linear measurement converted to metres. Depending on the shape, the area in square metres was calculated using standard area calculations. Although few of the lakes had "perfect" shapes, the following approximations were used.

- Circle = $\pi(r^2)$
- Rectangle/square = l x w
- Oval = (l x w)0.8

This was converted to hectares by dividing the result by 10,000.

Substitution of other year's data

1) Grayling Lake

Based on field and City of Ottawa laboratory measurements taken over several years, a problem appeared with pH and alkalinity values measured from the 2002 Grayling Lake water samples. The following table outlines the differences.

	Field		City of Ottawa		
Year	pH	Alkalinity	pH	Alkalinity	Sulphate
1998	8.5	No data	8.66	210	16
2000	8.7	No data	8.52	210	16.8
2002	8.5	191	**6.6**	**49**	**78.51**
2003	8.5	173	8.21	210	16

Sulphuric acid is used to preserve water samples that are to be tested for phosphorus and nitrogen. The high value of sulphate for the year 2002, suggests that sulphuric acid was inadvertently added to the sample to be tested for pH, alkalinity, sulphate and other ions. This was supported by the discrepancy between the field pH and alkalinity values versus City of Ottawa pH and alkalinity values for the same year. For this reason, data from the year 2000 was substituted for these 3 variables in this lake.

2) Loss-on-Ignition

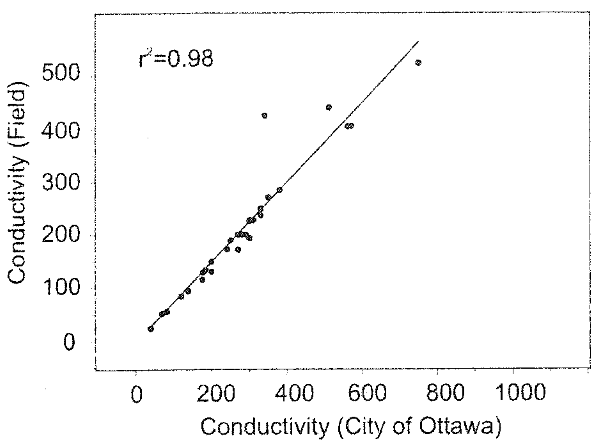
Loss-on-ignition laboratory procedures require that the sediment sample be weighed before drying, after drying, after the first ignition and after the second ignition. These weights are then used to compute the percentage of organic content and carbonate content of the sediment for each lake. The carbonate content for Long Lake was over 300%, which is not possible. Therefore, carbonate content measured in the year 2000 (Wilson and Gajewski submitted) was substituted.

3) Dissolved oxygen

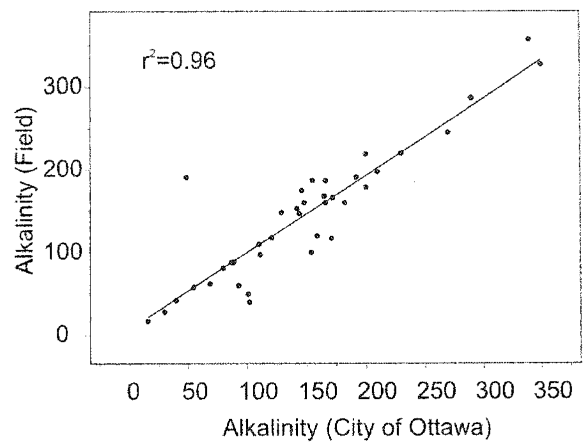
In 2002, dissolved oxygen was only measured in percentage for Emerald, Jenny and Keyhole Lakes, so values in mg/L were substituted from the year 2000.

Appendix 4: Conductivity and alkalinity regressions

Conductivity and alkalinity measurements were taken in the field and were also measured by the City of Ottawa. However, several field measurements were missing. The City of Ottawa conductivity and field conductivity showed a strong positive correlation (Figure 1), as did the City of Ottawa alkalinity and field alkalinity (Figure 2). Therefore, the City of Ottawa values were used in the analysis.



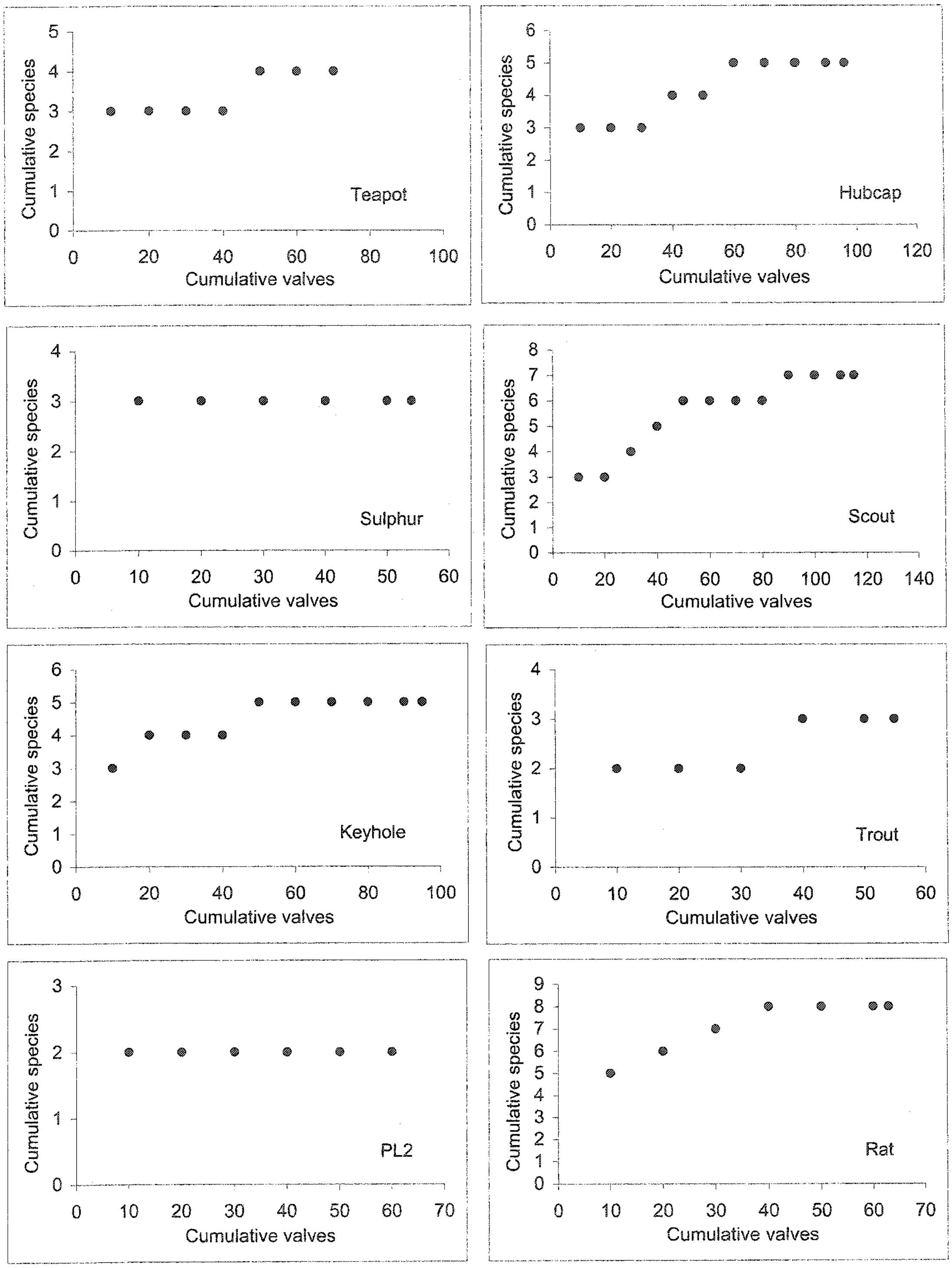
Appendix 4, Figure 1: Conductivity scatterplot



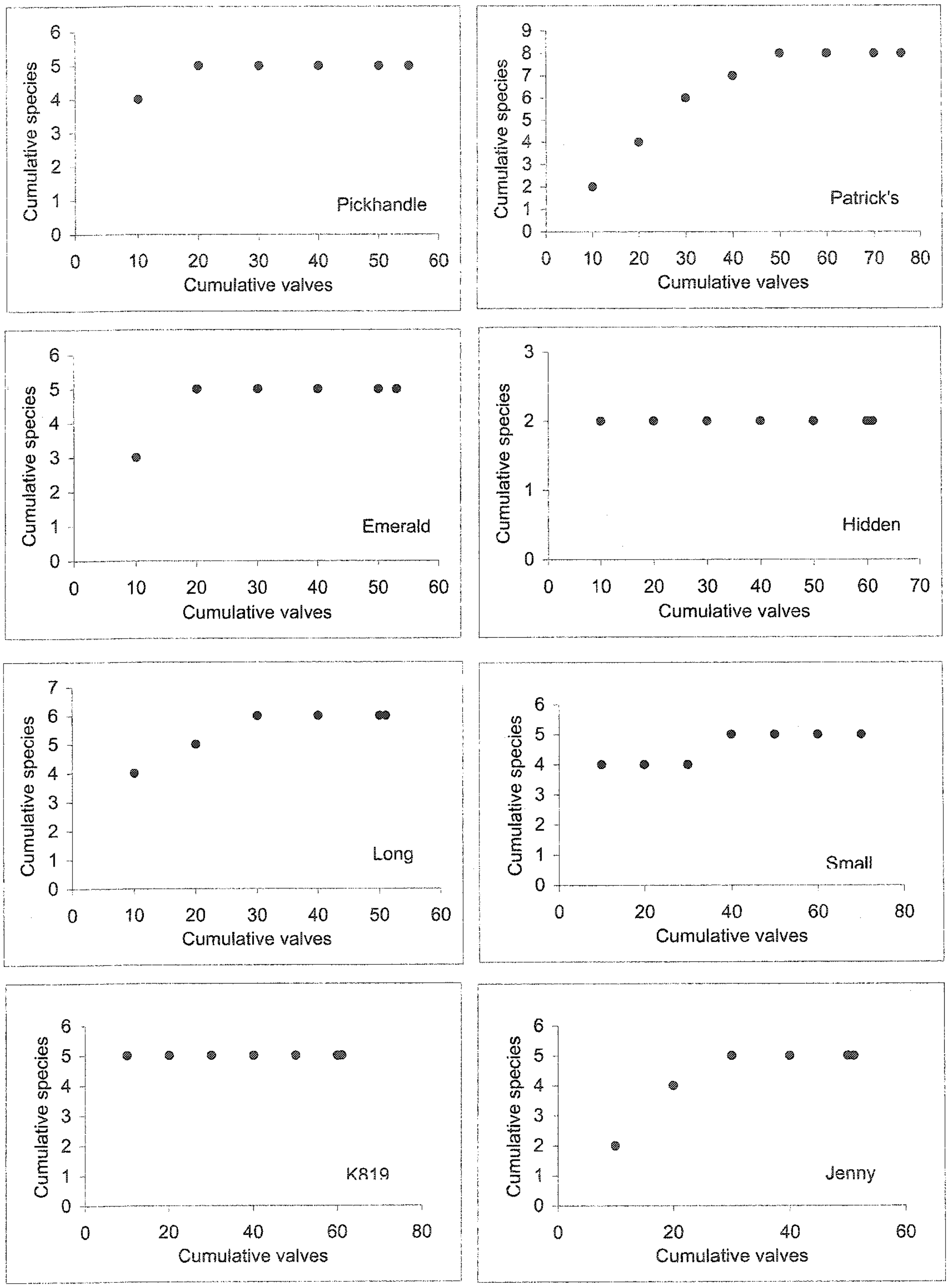
Appendix 4, Figure 2: Alkalinity scatterplot

Appendix 5: Species acquisition curves for samples

These curves were used to determine when a sufficient amount of sediment was analyzed to estimate the species richness and abundance of ostracodes in the lake. When the curve leveled off after sampling additional valves, no further sediment was analyzed.



Appendix 5: Species acquisition curves



Appendix 5: Species acquisition curves (continued)

APPENDIX 6: OSTRACODE DATA

Raw species counts per lake, and abundance of species in percentages and concentrations are presented here.

Appendix 6: Ostracode data - Raw counts

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
		Sediment subsampled (cm^3)	8	14	11	10	10	26	30	5	20	10	5	18	21	20	10	13	15	11	6	6	5	16	6	10	4	20	12	35	12	5	15	40	16
		Number of specimens	63	68	56	51	53	50	51	145	61	96	156	53	51	64	66	50	51	58	66	128	53	54	62	50	119	68	73	53	107	50	80	65	52
			Lakes																																
	Species list	Authority	3 Guardsmen	Alder	Atthilu	Axehandle	Donjek	Emerald	Fox Point	Grayling	Hidden	Hubcap	Hungry	Jenny	K805	K819	Keyhole	Lacourse	Long	LP	Patrick's	PC	Pickhandle	Pine	PL2	Rat	Scout	Small	St. Elias	Sulphur	Teapot	Trout	Washout	West Twin	Wolverine
1	*Candona acutula*	Delorme, 1967						10									8				3														
2	*Candona candida*	(Müller), 1776			18			2	1			43	57			9	4		10		12	2				6	3	11	2	13	1	2	2	1	
3	*Candona compressa*	(Koch), 1838											9	6																					
4	*Candona decora*	Furtos, 1933								4		8	49						18			13	4			4		6							
5	*Candona* cf. *distincta*	Furtos, 1933																									9								
6	*Candona ikpikpukensis*	(Swain), 1963							8	11																									
7	*Candona paraohioensis*	Staplin, 1963														3																			
8	*Candona protzi*	Hartwig, 1898		1		18				12			16			4					1	24	13			9	6		24						
9	*Candona rawsoni*	Tressler, 1957																												3	95				
10	*Candona* cf. *subtriangulata*	Benson & MacDonald, 1963																						7											
11	*Candona* sp. 1								5															19					10						
12	*Candona* sp. 2														1																				
13	*Cyclocypris ampla*	Furtos, 1933		47	32	29		10		12	2	35	19	3	1	28	41	2	3	15	41	26	10		1	9	1	27			2	20	34		
14	*Cyclocypris sharpei*	Furtos, 1933									28																1		18					1	
15	*Cypria ophtalmica*	(Jurine), 1820	18			1	9			5		1			2				14			20				5	10	1	10					4	12
16	*Cypria turneri*	Hoff, 1942				2	20		32	13		6								18	1	11	16	10	46	9	66	16			4	1			
17	*Cypria palustera*	Furtos, 1935								2												19													
18	*Cypridopsis vidua*	(Müller), 1776		9	1								1			6					3												8		
19	*Cytherissa lacustris*	(Sars), 1863																	5					9							2				
20	*Ilyocypris bradyi*	Sars, 1890						3						1			13													37					
21	*Ilyocypris gibba*	(Ramdohr), 1808							4										1												2				
22	*Limnocythere (Limnocytherina) itasca*	Cole, 1949						25						43							5														
23	*Limnocythere (Limnocytherina) varia*	Staplin, 1963											3			14											11								
24	*Cypria* sp	Zenker, 1854	34	1	4		24			85			2		3					14		13	7	7	13	7	12	6	9		1	3		37	33
25	*Cyclocypris* sp	Brady & Norman, 1889	11	10	1				1		31				44			46		11			3	2	2	1		1				24	36	22	7
26	*Cypridopsis* sp	Brady, 1868										3						2																	
27	*Cyprinotus* sp	Brady, 1886				1																													
28	*Limnocythere* sp	Brady, 1868								1																									

Appendix 6: Ostracode data - Percentages

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
		Sediment subsampled (cm^3)	8	14	11	10	10	26	30	5	20	10	5	18	21	20	10	13	15	11	6	6	5	16	6	10	4	20	12	35	12	5	15	40	16
		Number of specimens	63	68	56	51	53	50	51	145	61	96	156	53	51	64	66	50	51	58	66	128	53	54	62	50	119	68	73	53	107	50	80	65	52
																			Lakes																
	Species list	Authority	3 Guardsmen	Alder	Atthilu	Axehandle	Donjek	Emerald	Fox Point	Grayling	Hidden	Hubcap	Hungry	Jenny	K805	K819	Keyhole	Lacourse	Long	LP	Patrick's	PC	Pickhandle	Pine	PL2	Rat	Scout	Small	St. Elias	Sulphur	Teapot	Trout	Washout	West Twin	Wolverine
1	*Candona acutula*	Delorme, 1967						20.0									12.1				4.5														
2	*Candona candida*	(Müller), 1776			32.1			4.0	2.0			44.8	36.5			14.1	6.1		19.6		18.2	1.6				12.0	2.5	16.2	2.7	24.5	0.9	4.0	2.5	1.5	
3	*Candona compressa*	(Koch), 1838											5.8	11.3																					
4	*Candona decora*	Furtos, 1933								2.8		8.3	31.4						35.3			10.2	7.5			8.0		8.8							
5	*Candona* cf. *distincta*	Furtos, 1933																									7.6								
6	*Candona ikpikpukensis*	(Swain), 1963							15.7	7.6																									
7	*Candona paraohioensis*	Staplin, 1963														4.7																			
8	*Candona protzi*	Hartwig, 1898		1.5		35.3				8.3			10.3			6.3					1.5	18.8	24.5			18.0	5.0		32.9						
9	*Candona rawsoni*	Tressler, 1957																												5.7	88.8				
10	*Candona* cf. *subtriangulata*	Benson & MacDonald, 1963																						13.0											
11	*Candona* sp. 1								9.8															35.2					13.7						
12	*Candona* sp. 2														2.0																				
13	*Cyclocypris ampla*	Furtos, 1933		69.1	57.1	56.9		20.0		8.3	3.3	36.5	12.2	5.7	2.0	43.8	62.1	4.0	5.9	25.9	62.1	20.3	18.9		1.6	18.0	0.8	39.7			1.9	40.0	42.5		
14	*Cyclocypris sharpei*	Furtos, 1933									45.9																0.8		24.7					1.5	
15	*Cypria ophtalmica*	(Jurine), 1820	28.6			2.0	17.0			3.4		1.0			3.9				27.5			15.6				10.0	8.4	1.5	13.7					6.2	23.1
16	*Cypria turneri*	Hoff, 1942				3.9	37.7		62.7	9.0		6.3								31.0	1.5	8.6	30.2	18.5	74.2	18.0	55.5	23.5			3.7	2.0			
17	*Cypria palustera*	Furtos, 1935								1.4												14.8													
18	*Cypridopsis vidua*	(Müller), 1776		13.2	1.8								0.6			9.4					4.5												10.0		
19	*Cytherissa lacustris*	(Sars), 1863																	9.8					16.7							1.9				
20	*Ilyocypris bradyi*	Sars, 1890						6.0						1.9			19.7													69.8					
21	*Ilyocypris gibba*	(Ramdohr), 1808							7.8										2.0												1.9				
22	*Limnocythere (Limnocytherina) itasca*	Cole, 1949						50.0						81.1							7.6														
23	*Limnocythere (Limnocytherina) varia*	Staplin, 1963											1.9			21.9											9.2								
24	*Cypria* sp	Zenker, 1854	54.0	1.5	7.1		45.3			58.6			1.3		5.9					24.1		10.2	13.2	13.0	21.0	14.0	10.1	8.8	12.3		0.9	6.0		56.9	63.5
25	*Cyclocypris* sp	Brady & Norman, 1889	17.5	14.7	1.8				2.0		50.8				86.3			92.0		19.0			5.7	3.7	3.2	2.0		1.5				48.0	45.0	33.8	13.5
26	*Cypridopsis* sp	Brady, 1868										3.1						4.0																	
27	*Cyprinotus* sp	Brady, 1886				2.0																													
28	*Limnocythere* sp	Brady, 1868								0.7																									

Appendix 6: Ostracode data - Concentrations

	Species list	Authority	3 Guardsmen	Alder	Atthilu	Axehandle	Donjek	Emerald	Fox Point	Grayling	Hidden	Hubcap	Hungry	Jenny	K805	K819	Keyhole	Lacourse	Long
	Lakes		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Sediment subsampled (cm^3)		8	14	11	10	10	26	30	5	20	10	5	18	21	20	10	13	15
	Number of specimens		63	68	56	51	53	50	51	145	61	96	156	53	51	64	66	50	51
	Concentrations (valves/cm^3)		7.9	4.9	5.1	5.1	5.3	1.9	1.7	29.0	3.1	9.6	31.2	2.9	2.4	3.2	6.6	3.8	3.4
1	*Candona acutula*	Delorme, 1967						0.38									0.80		
2	*Candona candida*	(Müller), 1776			1.64			0.08	0.03			4.30	11.40			0.45	0.40		0.67
3	*Candona compressa*	(Koch), 1838											1.80	0.33					
4	*Candona decora*	Furtos, 1933								0.80		0.80	9.80						1.20
5	*Candona* cf. *distincta*	Furtos, 1933																	
6	*Candona ikpikpukensis*	(Swain), 1963							0.27	2.20									
7	*Candona paraohioensis*	Staplin, 1963														0.15			
8	*Candona protzi*	Hartwig, 1898		0.07		1.80				2.40			3.20			0.20			
9	*Candona rawsoni*	Tressler, 1957																	
10	*Candona* cf. *subtriangulata*	Benson & MacDonald, 1963																	
11	*Candona* sp. 1								0.17										
12	*Candona* sp. 2														0.05				
13	*Cyclocypris ampla*	Furtos, 1933		3.36	2.91	2.90		0.38		2.40	0.10	3.50	3.80	0.17	0.05	1.40	4.10	0.15	0.20
14	*Cyclocypris sharpei*	Furtos, 1933									1.40								
15	*Cypria ophtalmica*	(Jurine), 1820	2.25			0.10	0.90			1.00		0.10			0.10				0.93
16	*Cypria turneri*	Hoff, 1942				0.20	2.00		1.07	2.60		0.60							
17	*Cypria palustera*	Furtos, 1935								0.40									
18	*Cypridopsis vidua*	(Müller), 1776		0.64	0.09								0.20			0.30			
19	*Cytherissa lacustris*	(Sars), 1863																	0.33
20	*Ilyocypris bradyi*	Sars, 1890						0.12						0.06			1.30		
21	*Ilyocypris gibba*	(Ramdohr), 1808							0.13										0.07
22	*Limnocythere (Limnocytherina) itasca*	Cole, 1949						0.96						2.39					
23	*Limnocythere (Limnocytherina) varia*	Staplin, 1963											0.60			0.70			
24	*Cypria sp*	Zenker, 1854	4.25	0.07	0.36		2.40			17.00			0.40		0.14				
25	*Cyclocypris sp*	Brady & Norman, 1889	1.38	0.71	0.09				0.03		1.55				2.10			3.54	
26	*Cypridopsis sp*	Brady, 1868										0.30						0.15	
27	*Cyprinotus sp*	Brady, 1886				0.10													
28	*Limnocythere sp*	Brady, 1868								0.20									

	Species list	Authority	LP	Patrick's	PC	Pickhandle	Pine	PL2	Rat	Scout	Small	St. Elias	Sulphur	Teapot	Trout	Washout	West Twin	Wolverine
	Lakes		18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
	Sediment subsampled (cm^3)		11	6	6	5	16	6	10	4	20	12	35	12	5	15	40	16
	Number of specimens		58	66	128	53	54	62	50	119	68	73	53	107	50	80	65	52
	Concentrations (valves/cm^3)		5.3	11.0	21.3	10.6	3.4	10.3	5.0	29.8	3.4	6.1	1.5	8.9	10.0	5.3	1.6	3.3
1	*Candona acutula*	Delorme, 1967		0.50														
2	*Candona candida*	(Müller), 1776		2.00	0.33				0.60	0.75	0.55	0.17	0.37	0.08	0.40	0.13	0.03	
3	*Candona compressa*	(Koch), 1838																
4	*Candona decora*	Furtos, 1933			2.17	0.80			0.40		0.30							
5	*Candona* cf. *distincta*	Furtos, 1933								2.25								
6	*Candona ikpikpukensis*	(Swain), 1963																
7	*Candona paraohioensis*	Staplin, 1963																
8	*Candona protzi*	Hartwig, 1898		0.17	4.00	2.60			0.90	1.50		2.00						
9	*Candona rawsoni*	Tressler, 1957											0.09	7.92				
10	*Candona* cf. *subtriangulata*	Benson & MacDonald, 1963					0.44											
11	*Candona* sp. 1						1.19					0.83						
12	*Candona* sp. 2																	
13	*Cyclocypris ampla*	Furtos, 1933	1.36	6.83	4.33	2.00		0.17	0.90	0.25	1.35			0.17	4.00	2.27		
14	*Cyclocypris sharpei*	Furtos, 1933								0.25		1.50					0.03	
15	*Cypria ophtalmica*	(Jurine), 1820			3.33				0.50	2.50	0.05	0.83					0.10	0.75
16	*Cypria turneri*	Hoff, 1942	1.64	0.17	1.83	3.20	0.63	7.67	0.90	16.50	0.80			0.33	0.20			
17	*Cypria palustera*	Furtos, 1935			3.17													
18	*Cypridopsis vidua*	(Müller), 1776		0.50												0.53		
19	*Cytherissa lacustris*	(Sars), 1863					0.56							0.17				
20	*Ilyocypris bradyi*	Sars, 1890											1.06					
21	*Ilyocypris gibba*	(Ramdohr), 1808												0.17				
22	*Limnocythere (Limnocytherina) itasca*	Cole, 1949		0.83														
23	*Limnocythere (Limnocytherina) varia*	Staplin, 1963								2.75								
24	*Cypria sp*	Zenker, 1854	1.27		2.17	1.40	0.44	2.17	0.70	3.00	0.30	0.75		0.08	0.60		0.93	2.06
25	*Cyclocypris sp*	Brady & Norman, 1889	1.00			0.60	0.13	0.33	0.10		0.05				4.80	2.40	0.55	0.44
26	*Cypridopsis sp*	Brady, 1868																
27	*Cyprinotus sp*	Brady, 1886																
28	*Limnocythere sp*	Brady, 1868																