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Early summer near-shore fish assemblage and environmental correlates in an Arctic estuary

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ABSTRACT

Knowledge of reference conditions and species–environment associations is required to ascertain ongoing aquatic biodiversity changes in Arctic regions. The objective of this study was to establish a baseline of fish community structure (species composition, incidence and relative abundance) in relation to salinity, pH and temperature gradients in an Arctic estuary, the Husky Lakes, Canada. Sampling involved an early-summer, standardized, experimental netting survey around the entire perimeter of all estuary basins and peninsulas. Detrended canonical correspondence analysis (DCCA) was used to evaluate species–environment associations. The ecosystem sustains an abundant and diverse fish community, characterized by co-dominance of coregonids and a marine schooling fish, *Clupea pallasii*, and high abundance of freshwater/freshwater-amphidromous species in the innermost basins. Highest richness and total abundance were related to mixing conditions, warmest temperatures, connectivity to nearby ecosystems, and diversity in species life histories. Salinity determined spatial patterns of fish species abundance and distribution. The incidence of freshwater fish was limited by the availability of low salinity habitat and potential community interactions. These fish, particularly *Salvelinus namaycush* and *Thymallus arcticus*, are considered as the most vulnerable to changes in freshwater habitat availability. The fish assemblage reflects environmental information from surrounding fluvial, freshwater, coastal marine and catchment ecosystems, and is thus a prime candidate for monitoring environmental change in the region. The results provide a benchmark against which future studies of fish communities can be compared to evaluate potential effects of climate change and anthropogenic development on fish populations from Husky Lakes and similar Arctic aquatic ecosystems.

Introduction

Canada's Arctic aquatic environments are expected to undergo important biodiversity transformation over the next few years, yet remain poorly sampled and under-described (Archambault et al., 2010; ACIA, Arctic Climate Impact Assessment, 2013). Changing climate and a growing incidence of anthropogenic activities are impacting aquatic habitat structure and productivity and may trigger changes in the occurrence, abundance and distribution of aquatic organisms (Roessig et al., 2004; Reist et al., 2006; Wrona et al., 2006; Pörtner and Peck, 2010). Information on reference conditions and the mechanisms that link species abundance and distribution with environmental drivers is required to better anticipate and evaluate changes in the biological integrity of northern aquatic environments.

Fish are mobile consumers that play a significant role in the functioning of Arctic aquatic ecosystems (Reist et al., 2006). The Arctic guild comprises fish species with limited distribution and/or narrow physiological ranges that are particularly sensitive to changing environmental conditions (Roessig et al., 2004; Reist et al., 2006; Pörtner and Peck, 2010). On the other hand, several Arctic fishes exhibit complex life histories enabling them to occupy a variety of habitats and take advantage of patchy and highly seasonal resources (Craig, 1984; Power, 1997; Tallman et al., 2002; Reshetnikov, 2004; Kissinger et al., 2015). Estuarine fish communities integrate environmental information from marine, freshwater and terrestrial (catchment) environments (Khlebovich, 1997; Whitfield and Harrison, 2008), and are thus excellent candidates for monitoring environmental change (Whitfield and Elliot, 2002). Compared to lacustrine or marine ecosystems, estuaries are likely to exhibit earlier responses to changes such as loss of native

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species, proliferation of exotic species and episodic or discrete extreme weather events (Roessig et al., 2004; Gillson, 2011; Nyitrai et al., 2012).

Environmental variables are key drivers of fish community structure and functioning in estuaries (Whitfield and Elliot, 2002). Salinity is often the main environmental parameter determining spatial organization in estuarine fish assemblages (Whitfield, 1999; Jaureguizar et al., 2004; Eick and Thiel, 2014). Water temperature, pH, turbidity and oxygen concentrations, are other key environmental variables that delimit the range of fish species through physiological demands and thus affect the structure of fish communities (Wetzel, 1983; Whitfield, 1999; Whitfield and Elliot, 2002; Barnes and Mann, 2009; Eick and Thiel, 2014). Water properties are one of two interrelated components of fish habitat, along with physical variables such as ecosystem size, bathymetry, and shoreline and catchment characteristics. Physical habitat structure has a direct influence on water property gradients (e.g., by determining horizontal and vertical mixing processes). Water properties are also readily influenced by changes in ambient conditions or disturbance. Climate changes that affect permafrost and erosion, freshwater runoff, and ice and snow accumulation (Prowse et al., 2006), are likely to have significant impacts on water properties and fish assemblages in Arctic aquatic systems. Changes in salinity and temperature gradients can affect habitat availability and feeding opportunities for fish in estuaries, as well as the timing and success of key life processes such as recruitment, growth and migrations (Roessig et al., 2004; Reist et al., 2006; Gillson, 2011; Morrongiello et al., 2014).

There is limited information on estuarine fish assemblages and their relationships to water property gradients in northern environments. The available studies are generally descriptive in nature, often based on incomplete sets of biological and/or environmental data, and lack detailed quantitative analyses of fish populations and communities (e.g., Alexander, 1975; Morin et al., 1980; Craig, 1984; Griffiths et al., 1998; Jarvela and Thorsteinson, 1999; Novikov et al., 2000).

This paper investigates the near-shore fish community of Husky Lakes, an Arctic estuary with historical and present-day economic and cultural importance to the Inuvialuit of Canada's Western Arctic (Cobb et al., 2008; ILA, Inuvialuit Land Administration, 2011). Aspects of the ecosystem that were previously described include primary production and the zooplankton community (Evans and Grainger, 1980; Grainger and Evans, 1982) as well as catchment hydrology, ice cover dynamics and physical oceanography (Gushue et al., 1996; Macdonald et al., 1999; Carmack and Macdonald, 2008). A number of fisheries-related studies focusing mainly on Liverpool Bay (adjacent to Husky Lakes) were conducted in the 1980s and early 1990s (e.g., Shields, 1988; Bond and Erickson, 1992, 1993).

A survey of the entire ecosystem, including data collection on physical habitat structure, water properties, zooplankton, and sampling of the near-shore fish community, was conducted in early summer (immediately after ice break-up) over four consecutive years (2001–2004). This provided the first comprehensive dataset on both the fish populations and habitat components of Husky Lakes. Information from all study components is summarized in Roux et al. (2014). In this paper, fish abundance and water properties (salinity, temperature and pH) data are used to characterize fish community structure in terms of species composition, richness, incidence and life histories and to identify patterns of fish species abundance and distribution in relation to salinity, temperature and pH gradients. Our objective is to establish a baseline of fish community structure in terms of species composition in relation to abiotic factors, to inform future assessments of ongoing climate and anthropogenic forcing on fish populations in Husky Lakes and similar Arctic aquatic environments.

Materials and methods

Study area

The Husky Lakes are located in the Arctic coastal tundra ecoregion between approximately 68°40′N and 69°70′N latitude, and 133°30′W and 130°55′W longitude (Fig. 1). The estuary consists of five interconnected basins, two sets of narrow channels (the 'outer fingers' and the 'inner fingers'), and a small inlet ('Kugaluk Channel') near the mouth (Fig. 1). A shallow sill near Thumb Island separates the Husky Lakes from Liverpool Bay (Carmack and Macdonald, 2008). From Thumb Island, the Husky Lakes extend approximately 130 km inland and cover an area of 1933 km^2. On average, the estuary is ice-covered eight months of the year, with ice thickness up to approximately 2 m (Macdonald et al., 1999). The system is supported by a small, truly Arctic drainage basin that is underlain by permafrost and becomes entirely frozen in the winter (Macdonald et al., 1999). The estuary is subject to semidiurnal tides of small amplitude ($<$0.5 m), and has a complex bathymetry characterized by alternating shallows and deep pools/channels (Roux et al., 2014). These physical features promote water mixing throughout the system, including saltwater intrusion more than 100 km inland (Carmack and Macdonald, 2008; Roux et al., 2014).

Data collection

Data on the near-shore fish community and water properties were collected during an experimental netting survey conducted shortly after ice breakup between late-June and mid- to late-July, over four consecutive years (2001–2004). Each year, the sampling period corresponded to the period of 24-h daylight. Due to the vast extent of the system and logistic constraints, annual sampling effort generally focused on a particular section of the estuary (see Roux et al., 2014 for details). Sampling was not replicated within or among years at any site.

A total of 585 experimental gill nets were set in Husky Lakes and Kugaluk Channel (Fig. 2). Multi-mesh gill nets that were 54.9 m in length and 1.8 m or 3.7 m in height were used. Each net consisted of three 18.3 m panels of 76-mm (3 in.), 38-mm (1.5 in.) and 64-mm (2.5 in.) knot-to-knot stretched monofilament mesh. Nets were anchored close to shore in approximately 0.5 m of water and set perpendicular to the shore at intervals of approximately 1 km along the perimeter of all basins and fingers/channel areas. The end panels of 76-mm or 64-mm were alternated at the shore end. Soaking time was approximately 60 min per set. Location, maximum depth and catch (counts of fish, by species) and effort (total fishing time, in minutes) information was recorded for all sets. Fish were identified to species and enumerated prior to release. Net depth was recorded at all sites using a Garmin GPSMAP 168 Sounder. Surface water temperature, salinity and pH measurements were taken at 196 random locations in Husky Lakes and at some of the netting sites ($n = 173$ for salinity/pH; $n = 369$ for temperature) in all years using a Horiba U-10 water quality profiler.

Data analyses

Environmental variables

Surface water properties (salinity, pH, and temperature), net setting depth and distance from the mouth were the environmental variables which comprised our basic dataset for Husky Lakes. Distance from mouth was determined for all net sets as distance from Thumb Island (69°27′N, 130°53′W, Fig. 1).

Salinity, temperature and pH data were interpolated to the entire Husky Lakes surface using inverse distance weighted averaging (cell size = 100 m, distance exponent (power) = 2) in ArcGIS. Interpolated data were used to assign temperature, pH and salinity measurements to individual net sets. Comparisons between observed and interpolated data produced average differences (mean ± sd) of 0.2 ± 1.7 °C for temperature; 0.01 ± 0.08 for pH; and 0.04 ± 0.41 ppt for salinity.

Multivariate hierarchical clustering (complete linkage) was used to group netting sites based on similarities in environmental variables. Cluster definition and validity were determined based on pseudo *T*-square and Duda–Hart indices (Duda and Hart, 1973).