SEASONAL MOVEMENTS OF NORTHERN PIKE IN MINTO FLATS, ALASKA

By

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A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of

Master of Science

in

Fisheries

University of Alaska Fairbanks

August 2016

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Abstract

Northern pike *Esox lucius* is a large, long-lived piscivorous species that are harvested in sport and subsistence fisheries in Alaska. My study described the seasonal movements of northern pike that inhabit the Minto Lakes portion (Goldstream Creek drainage) of the Minto Flats wetland complex, Alaska, from May 2008 through January 2010. Very high frequency (VHF) radio tags (n = 220) were surgically implanted in northern pike in Minto Flats in May 2007, 2008, and 2009, and fish were relocated with fixed telemetry stations and aerial- and boat-based telemetry surveys. Radio-tagged northern pike displayed a distinct spring pre-spawning migration into the Minto Lakes study area, where they remained for the duration of the open-water season. A protracted out-migration occurred between late September and early December, with downstream movements peaking in November and October of 2008 and 2009, respectively. Radio-tagged fish present in the Minto Lakes study area during the open-water season overwintered exclusively in a 26-km reach of the Chatanika River from its confluence with Goldstream Creek upstream to the Murphy Dome Road access point. Daily movement rates were greatest during May and August. In addition to providing a better understanding of northern pike life history in Minto Flats, these results will aid managers and researchers by identifying critical habitats and providing information to better design future population assessment experiments.

Table of Contents

List of Figures

List of Tables

Acknowledgements

I wish to express my gratitude for those who made this endeavor possible. My graduate advisor was Dr. Trent Sutton and my committee members were Matt Evensen, Dr. David Verbyla, and Dr. Joe Margraf. The Alaska Department of Fish and Game provided funding for this research. A special thanks to my friends and coworkers for their assistance with all aspects of this project from fieldwork, providing ideas and guidance, endless editing and keeping things fun: Phil Joy, Klaus Wuttig, Rick Queen, Brian Collyard, Nissa Pilcher, Kyle Schuman, Toby Viavant, Andrew Garry, James Reidman, David Lorring, Rachael Kvapil, Kathy Pearse, Christina Neuman, Katherine Mattingly, Tyler Amundsen, Susan Pace, and Marty Webb. Lastly, I will forever be grateful for the never-ending support that my family has given me not only during this project, but throughout my life.

General Introduction

Movement is a critical component of the daily activities and life history of many fish species. The ability to move allows fish to meet their resource needs in spatially and temporally variable environments, and can vary widely from diel movements among habitats to seasonal migrations between water bodies. Movement behaviors may also be directly and indirectly related to factors including prey availability, predator avoidance, spawning, and environmental conditions (Schlosser and Angermeir 1995; Matthews 1998; Lucas and Baras 2001; Koed et al. 2006).

Northcote (1978, 1984, 1998) defined migration as the movement that occurs when a fish changes location between two or more well-separated habitats, that occurs at regular intervals during the fishes lifetime, involves a large proportion of the fish population, and occurs with directed movement (i.e., not random movement or passive drift) at some stage of the life cycle. A broad range of long-lived iteroparous fishes residing in temperate regions have a spring migration from wintering to spawning areas and may remain within or close to those areas to feed (Langhurst and Schoenike 1990; West et al. 1992; Lucas and Bately 1996; Roach 1998b; Nykanen et al. 2004). During these periods, localized movements are observed that may be interpreted to be a home range or activity center. Localized movements of several hundred meters to kilometers can be important for survival and reproduction (Northcote 1978; Jordan and Wortley 1985; Northcote 1998). However, infrequent, longer-distance movements to new locations for foraging may also occur (Vostradovsky 1975, in Raat 1988; Bregazzi and Kennedy 1980; Lucas and Baras 2001 and references within; Kobler et al. 2008a). Some species that have been shown to display the aforementioned movement patterns include but are not limited to Arctic grayling *Thymallus arcticus*, European grayling *T. thymallus*, smallmouth bass

Micropterus dolomieu, barbel *Barbus barbus*, and northern pike *Esox lucius* (Langhurst and Schoenike 1990; West et al. 1992; Lucas and Bately 1996; Roach 1998b; Nykanen et al. 2004).

Northern pike have a circumpolar distribution, and are thought to be a relatively young species that arose in the late Pleistocene (Maes et al. 2003). It is believed that northern pike and their relatives radiated in freshwater before the separation of North America and Europe (Wilson et al. 1992; Crossman 1996; Crossman and Harington 1970). Northern pike are a predatory species at the top of the aquatic food web in most habitats (Craig 2008), are extremely plastic in their life history, and can occupy a wide range of fluvial, lacustrine, and brackish habitats (Maitland and Campbell 1992; Craig 1996). This species can be found in approximately 45% of the total freshwater surface area of North America. In these habitats, northern pike can tolerate a wide range of environmental conditions, but are primarily a mesothermal species that is adapted to shallow mesotrophic to eutrophic water bodies (Carlander et al. 1978). In Alaska, northern pike range throughout the state, but are only native north of the Alaska Range and in the Alsek and Taku River drainages of southeast Alaska (McPhail and Lindsey 1970; Lee et al. 1980; Morrow 1980; Lindsey and McPhail 1986; McPhail and Lindsey 1986). This species was illegally introduced to the Susitna River drainage in the 1970s and the Kenai Peninsula in the 1990s (Morrow 1980; B. Stratton in *Alaska Department of Fish and Game Currents*, Winter 2000-2001).

Northern pike are harvested in sport, subsistence, and commercial fisheries across their range in Alaska (Andrews 1989; Pierce and Cook 2000; Brase and Baker 2014; Brown et al. 2014). In the Tanana River Management Area (TRMA) in the eastern interior of Alaska, the estimated annual sport fishery catch of northern pike ranged from 10,330 to 36,710 fish from 2002 to 2012 (ADF&G 2015). Estimated sport fishery harvests of northern pike in the TRMA over that same period were between 1,209 and 4,895 fish (ADF&G 2015). Within the TRMA, the Minto Flats wetland complex sustains one of the most important northern pike fisheries (Brase and Baker 2014). From 2002 to 2012, estimated annual sport fishery catch and harvest in the Minto Flats wetland complex ranged between 3,911 to 21,159 fish caught and 386 to 2,052 fish harvested (ADF&G 2015). Over the most recent 11-year period for which data are currently available (2002-2012), the Minto Flats wetland complex accounted for 23 to 58% of the catch and 18 to 46% of the harvest of northern pike in the TRMA (ADF&G 2015). Over that same period, subsistence users reported harvests of northern pike from the Tolovana River drainage (including Minto Flats) that averaged 701 fish annually (ADF&G, Commercial Fisheries Division, unpublished data). Sport fishery catch and harvest of northern pike in the Minto Flats wetland complex declined after 2007 and remained below pre-2007 levels through 2012 (ADF&G 2015).

Northern pike initiate spawning behaviors in the spring, when water temperatures reach 8 to 12°C. Optimal spawning habitat includes shallow, sheltered areas with flooded grasses and sedges to entrap and suspend the eggs above the substrate (Casselman and Lewis 1996). Age-0 northern pike are closely associated with moderately dense submerged aquatic macrophytes with some interspersed floating and emergent vegetation (Anderson 1993; Casselman and Lewis 1996). The presence of vegetation in their habitat is important; for example, northern pike growth was significantly faster when fish were reared in tanks with vegetation (Johnson 1960). As northern pike grow, larger individuals in the population are more commonly found at the macrophyte-open-water interface, with smaller individuals displaced to more heavily vegetated areas due to increased vulnerability to predation (Chapman and Mackay 1984*a*, 1984*b*;

Casselman and Lewis 1996). As juveniles grow in size, their preferred habitat areas also increase in water depth (Casselman and Harvey 1973).

Movement and activity patterns of northern pike have historically been, and still are, an often-studied topic (Diana et al. 1977, Diana 1980; Cook and Bergersen 1988; Craig 1996; Klefoth et al. 2008). Northern pike have traditionally been considered a sedentary, sit-and-wait predator with a restricted home range (Malinin 1969, 1970; Makowecki 1973; Diana 1980; Raat 1988). With the use of ultrasonic and radio transmitters, this belief has been both challenged and supported. Malinin (1969, 1970) proposed that northern pike had a home range from 50 to 150 m in diameter based on telemetry and long-term mark-recapture data. Diana's (1980) study of northern pike on Lac Ste. Anne, Alberta, using ultrasonic telemetry strongly supported those results. Diana et al. (1977) concluded that ultrasonic-tagged northern pike moved randomly throughout a narrow zone along the lake edge and, while they did not have a well-defined home range, these tagged fish revisited some areas several times. These findings demonstrate why some mark-recapture studies have concluded that tagged northern pike exhibited minimal movements between marking and subsequent recovery locations. There is an increasing body of evidence that suggests that northern pike restrict their movements to specific activity centers for a period of time, followed by longer-ranging movements in which they may move to a new activity center (Diana et al. 1977; Cook and Bergersen 1988). Jepsen et al. (2001) suggested that northern pike in one water body employed three different movement behaviors: 1) residence in one restricted area; 2) utilization and movements between several "activity centers"; and 3) movements over larger areas with frequent habitat shifts.

Across their range in North America, northern pike have exhibited seasonal movement patterns that often closely fit the description of seasonal movements made by long-lived iteroparous fishes as described in Lucas and Baras (2001), Diana (1980), and Lucas et al. (1991). Cook and Bergersen (1988) found that activity increased in the spring in conjunction with spawning. In addition, numerous other studies have documented distinct spawning movements (Franklin and Smith 1963; Karas and Lehtonen 1993; Miller et al. 2001; Rosell and MacOscar 2002) and natal and spawning site fidelity (Carbine and Applegate 1948; Bregazzi and Kennedy 1980; Miller et al. 2001; Kobler et al. 2008a). Summer site fidelity in a small (25 ha) lake was tested and confirmed by Kobler et al. (2008b) when all translocated fish returned to their activity center within a 6-d period. Diana et al. (1977) and Cook and Bergersen (1988) found that northern pike restricted their movements in a lake to a narrow zone parallel to the shoreline and observed declining activity levels in late summer/early fall. Diana et al. (1977) concluded that tagged fish did not exhibit well-defined home ranges, but they did revisit locations where they had been previously located. Using a 95% and 50% kernel density probability, Kobler et al. (2008b) estimated summer activity center sizes of 1392.5 ± 389.0 m^2 and 190.8 ± 56.4 m^2, respectively, which agreed with the assertion of Grimm and Klinge (1996) that northern pike occupy a restricted activity center. Although earlier studies had estimated larger activity centers, they were conducted in much larger (~ 5,000 ha) lakes (Vostradovsky 1975, in Raat 1988; Diana et al. 1977). Casselman (1978) suggested that northern pike moved to winter refugia habitats when faced with less than optimal environmental conditions, such as low dissolved oxygen concentrations.

Certain environmental factors have been shown to affect habitat choice, movements, and activity of northern pike. Shorter-range movements have been shown to be responses by fish to specific preferences for water temperature, dissolved oxygen, and other physical-chemical properties (Matthews 1977; Matthews and Hill 1979). At dissolved oxygen concentrations between 2-3 mg·L^{-1}, activity and feeding of northern pike is reduced; below 2 mg·L^{-1}, feeding activity ceases (Adelman and Smith 1970; Casselman 1978). In open-water seasons, dissolved oxygen concentrations below 4 mg·L^{-1} cause some northern pike to actively seek habitats with higher concentrations (Headrick and Carline 1993). When faced with temperatures in the epilimnion in excess of 25°C and an anoxic bottom, northern pike experienced habitat compression and were found in the coolest waters available with oxygen concentrations over 3 mg·L^{-1} (Headrick and Carline 1993). Water temperatures as low as 0.1° C, such as what may be encountered during late fall or winter (i.e., during freeze-up), while resulting in reduced movement and activity, did not cause any observable stress in northern pike (Casselman 1978).

Cook and Bergersen (1988) observed that radio-tagged northern pike were found significantly farther from shore on windy days than on calm days. The authors noted that high winds caused large waves, which increased nearshore turbidity. Higher turbidity can negatively affect the ability of northern pike to effectively feed (Craig and Babaluk 1989). These authors noted that fish body weight was positively related to secchi depth, with a 6% increase in weight for every 1 m increase over the 3-m depth range. When faced with increased turbidity, Andersen et al. (2008) suggested that northern pike, especially larger individuals, may exhibit a greater diversity of behaviors.

Changing water levels can also affect activity of northern pike. Hodder et al. (2007) found that during periods of extreme flooding, estimated home ranges of northern pike were maximized. However, under partial flooding conditions, there was not a significant increase in estimated home range size. Masters et al. (2002) hypothesized that during flood conditions, pike utilized the increased availability of habitats for feeding rather than as escape areas from high flows. Under declining water conditions, northern pike increased both their activity and 24-h use areas (Rogers and Bergersen 1995).

There have been conflicting observations with respect to light intensity and its effects on northern pike movements and habitat selection. Cook and Bergersen (1988) found that on sunny days, northern pike were found in deeper water, but not farther from the shoreline. However, Chapman and Mackay (1984b) observed that northern pike selected shallow water on sunny days. Multiple authors have concluded that northern pike exhibit crepuscular activity peaks (Cook and Bergersen 1988; Beaumont et al. 2003; Hodder et al. 2007). Light intensity was identified as the most important factor controlling movements of age-0 (larval) fish from wetland rearing areas to habitats in the main lake (Hunt and Carbine 1951; Franklin and Smith 1963).

Early telemetry and mark-recapture studies of northern pike in the Minto Flats wetland complex focused on their seasonal movements over the entire area and identified spawning, summer feeding, and overwintering habitats (Alt 1970, 1971; Cheney 1971, 1972; Hallberg 1983, 1984; Holmes and Burkholder 1988; Burkholder 1989, 1991; Burkholder and Bernard 1994). These studies concluded that northern pike were dispersed throughout the wetland complex for spawning and summer feeding, but only utilized a few areas within the wetland complex during the overwintering period. Although Cheney (1971) and Hallberg (1984) found low (<1 mg·L^{-1}) dissolved oxygen levels in many sampling locations during winter, locations of overwintering northern pike only corresponded with areas that had higher levels of dissolved oxygen (2.5-8 mg·L^{-1}).

Burkholder (1989) separated the Minto Flats wetland complex into three major geographic areas and concluded that northern pike that inhabited those areas generally belonged to one of two sub-populations based on which area they utilized during wintering (i.e., Chatanika River/Minto Lakes and lower Tolovana River). Roach (1998a) conducted a telemetry study on northern pike during the open-water season in the Minto Lakes Study Area (MLSA) and concluded that fish showed high but not complete fidelity to that area on an annual basis. Based on the results of Roach (1998a) and the earlier studies completed in Minto Flats, improvements were made to the experimental design of northern pike abundance estimation experiments conducted by the Alaska Department of Fish and Game (ADF&G) in the Minto Flats wetland complex by shortening the period between marking and recapture events from several months or longer to several weeks or less. While informative, these early studies did not adequately describe in detail the seasonal movements of northern pike that utilized the MLSA area due to their use of too few radio-tagged or marked individuals, the short duration of radio-tag lifespans, and/or the long time periods between relocation events.

Through the use of radio-telemetry techniques, this study provides a more detailed description of the seasonal movements of northern pike that utilize the MLSA during the open-water season and overwinter in the Chatanika River. Active radio tracking was utilized for the identification of real-time fish locations during both summer and winter seasons while the use of passive telemetry techniques allowed for continued monitoring of fish movements past strategically placed stationary tracking stations during time periods between active tracking surveys or when field travel was unsafe or impractical. Using the collected data, I described the timing and magnitude of northern pike movements into, out of, and within the study area. The described movements resulted in a more detailed characterization of northern pike life history and will provide an increased body of knowledge to fishery managers to better define stocks of this species in the Minto Flats wetland complex, design more precise abundance estimation experiments, and regulate harvests for sustainability and quality. In addition, the detailed life-history information can also be applied to other populations of northern pike within Alaska, as well as throughout their circumpolar distribution.

Chapter 1

Introduction

Movement is a critical life-history strategy for all fish species and is needed to meet resource needs in spatially and temporally variable environments. Spatial movements can range from several meters to thousands of kilometers and temporally from daily to annual. These movements can be important for survival and reproduction and many of those movements are considered to be migrations (Northcote 1978; Jordan and Wortley 1985; Northcote 1998). Northcote (1978, 1984, 1998) defined migration as a movement that occurs when a fish changes location between two or more well-separated habitats, that occurs at regular intervals during the lifetime of a fish, involves a large proportion of the fish population, and occurs with directed movement (i.e., not random movements or passive drift) at some stage of the life cycle. Movements and migratory behaviors can be directly and indirectly related to a variety of factors including prey availability, predator avoidance, spawning, and environmental conditions (Schlosser and Angermeir 1995; Matthews 1998; Lucas and Baras 2001; Koed et al. 2006). A broad range of long-lived iteroparous fishes, including northern pike *Esox lucius*, which live in temperate regions have a spring migration from wintering to spawning areas and may remain within or close to those areas to feed (Schlosser and Angermeir 1995; Matthews 1998; Lucas and Baras 2001; Koed et al. 2006).

Northern pike are a large, predatory fish with a circumpolar distribution (Scott and Crossman 1973; Craig 2008; Skog et al. 2014). This species can be found in a wide range of fluvial, lacustrine, and brackish habitats, but is primarily considered to be mesothermal and best adapted to shallow, mesotrophic, and/or eutrophic habitats (Carlander et al. 1978; Maitland and Campbell 1992; Craig 1996; Westin and Limburg 2002).

Traditionally, northern pike have been considered to be a sedentary, sit-and-wait predator with a restricted home range; the use of ultrasonic and radio transmitters has both supported and challenged this belief (Malinin 1969, 1970; Makowecki 1973; Diana et al. 1977; Diana 1980; Raat 1988). Northern pike have been shown to generally restrict their movements to a narrow zone around the edge of a waterbody and can establish localized activity centers for periods of time followed by longer ranging movements to either a new or previously used activity center (Diana et al. 1977; Cook and Bergersen 1988; Hodder et al. 2007). Jepsen et al. (2001) suggested that northern pike in one water body could demonstrate different movement behaviors ranging from restricted movements in one area to movements over larger areas with frequent habitat shifts.

Seasonally, northern pike have shown increases in activity and movements in the spring associated with spawning and in many cases have distinct spawning movements (Franklin and Smith 1963; Cook and Bergersen 1988; Karas and Lehtonen 1993; Miller et al. 2001; Rosell and MacOscar 2002). Spawning, natal, and summer site fidelity has also been documented (Carbine and Applegate 1948; Bregazzi and Kennedy 1980; Miller et al. 2001; Kobler et al. 2008b). Movements to winter refugia habitats may occur when fish are faced with less than optimal environmental conditions, such as low dissolved oxygen concentrations (Casselman 1978).

In Alaska, northern pike range throughout the state, but are only native north of the Alaska Range and in the Alsek and Taku River drainages (McPhail and Lindsey 1970; Lee et al. 1980; Morrow 1980; Lindsey and McPhail 1986; McPhail and Lindsey 1986). Northern pike are harvested in sport, subsistence, and commercial fisheries across their Alaskan range and are utilized in both sport and subsistence fisheries within the Minto Flats wetland complex, which is located in the eastern interior of Alaska (Andrews 1989; Pierce and Cook 2000; Brase and Baker 2014; Brown et al. 2014). The northern pike fisheries that occur in the Minto Flats wetland complex are managed under joint sport and subsistence fishery management plans (Brase and Baker 2014).

Early telemetry and mark-recapture studies of northern pike in the Minto Flats wetland complex have focused on their seasonal movements over the entire area and identified spawning, summer feeding, and overwintering habitats (Alt 1970, 1971; Cheney 1971, 1972; Hallberg 1983, 1984; Holmes and Burkholder 1988; Burkholder 1989, 1991; Burkholder and Bernard 1994). These studies concluded that northern pike were dispersed throughout the wetland complex for spawning and summer feeding, but only utilized a few areas within the wetland complex during the overwintering period. Although Cheney (1971) and Hallberg (1984) found very low (<1 mg·L^{-1}) dissolved oxygen levels in many sampling locations during winter, locations of overwintering northern pike only corresponded with areas that had higher levels of dissolved oxygen (2.5-8 mg·L^{-1}). Burkholder (1989) separated the Minto Flats wetland complex into three major geographic areas and concluded that northern pike that inhabited those areas generally belonged to one of two sub-populations based on which area they utilized during wintering (i.e., Chatanika River/Minto Lakes and lower Tolovana River). Roach (1998a) conducted a telemetry study on northern pike during the open-water season in a portion of the Minto Lakes wetland complex termed the Minto Lakes Study Area (MLSA) and concluded that fish showed high but not complete fidelity to that area on an annual basis. Based on the results of Roach (1998a) and the earlier studies completed in Minto Flats, improvements were made to the experimental design of northern pike abundance estimation experiments conducted by the Alaska Department of Fish and Game (ADF&G) in the Minto Flats wetland complex by shortening the period between marking and recapture events from several months or longer to several weeks or less. While informative, these early studies did not adequately describe in detail the seasonal movements of northern pike that utilized the MLSA area due to their use of too few radio-tagged or marked individuals, the short duration of radio-tag lifespans, and/or the long time periods between relocation events.

My study utilized surgically implanted VHF radio tags and both active (airplane-, snowmobile-, and boat-based) and passive (stationary tracking stations) telemetry techniques to describe the seasonal movements of northern pike that inhabit the MLSA. I described the timing and magnitude of their movements into, out of, and within the study area, and overwintering habits. The characterization of life history, movement patterns, and habitats of northern pike enable fishery managers to better define stocks of northern pike in the Minto Flats wetland complex, design more precise abundance estimation experiments, regulate harvests for sustainability, increase the amount of detailed information to disseminate to fishery users, and tailor angler preferences for this valuable fishery and similar systems in Alaska.

Study Site

The Minto Flats wetland complex is located approximately 50 km west of Fairbanks, Alaska (Figure 1). This complex is a 200,000-ha series of marshes and lakes interconnected by numerous sloughs and five rivers (Goldstream Creek and the Chatanika, Tatalina, Tolovana, and Tanana rivers). With the exception of the Tanana River, these rivers are slow flowing and meandering. The Tanana River is a large glacial river that delineates the southern boundary of

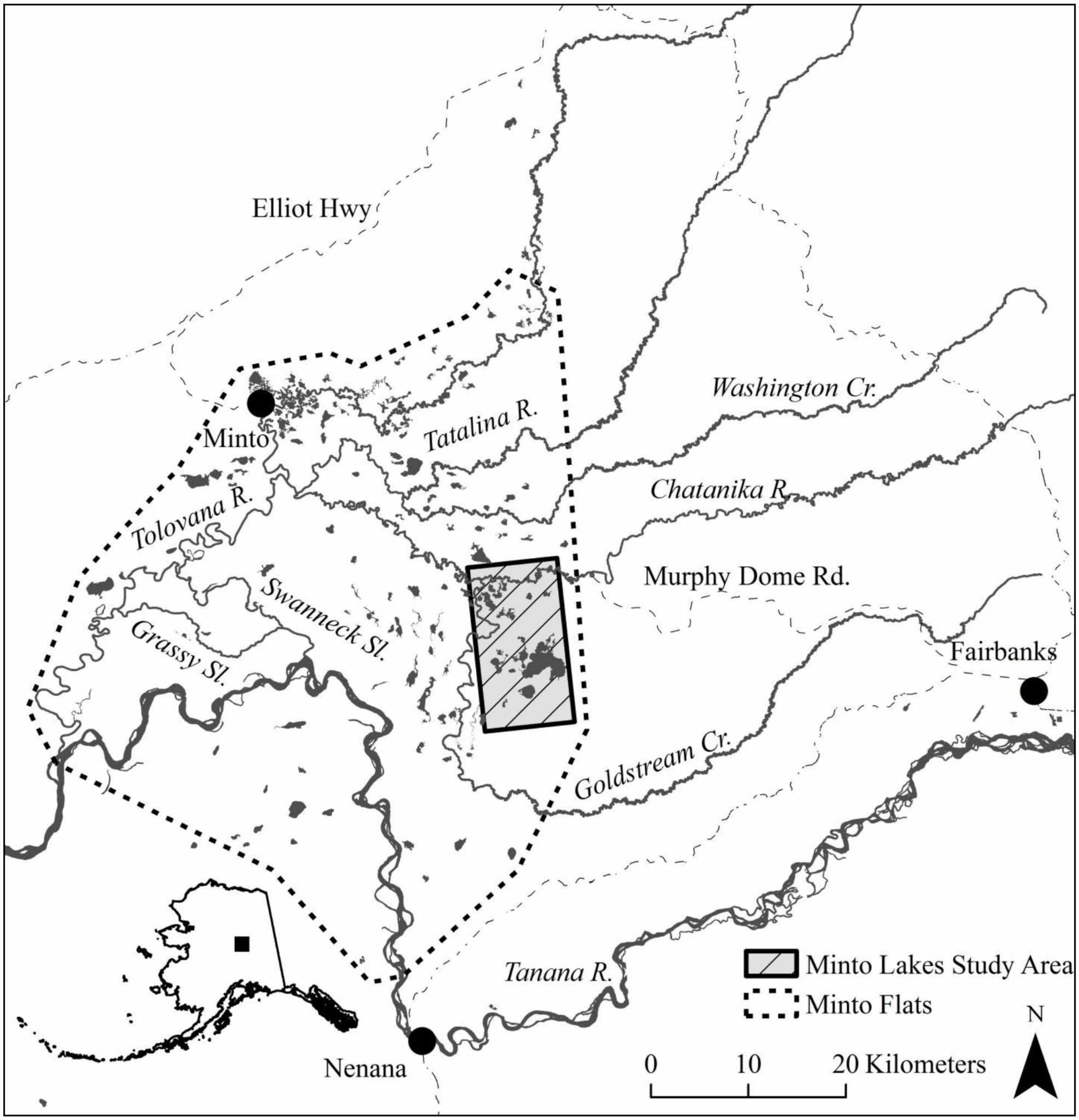

Figure 1. Map of the Minto Flats wetland complex near Fairbanks, Alaska. The dashed line denotes the boundary of Minto Flats, and the shaded cross-hatched rectangle denotes the Minto Lakes Study Area.

Minto Flats, and is the primary water source for Swanneck and Grassy sloughs that drain into the lower Tolovana River. The lakes are generally shallow (< 5 m) and contain large areas of dense aquatic macrophytes.

The Minto Lakes study area (MLSA) encompasses approximately 9,000 ha at the northeastern edge of Minto Flats (Figure 1). The study area is composed of five major lakes (Big Minto, Upper Minto, Side, New, and Marge Lakes) and there are three major connecting waterways (Lake Channel, Rotten, and Cancer Sloughs; Figure 2). There are also numerous intermittent sloughs, small lakes, and areas of flooded vegetation that are used by northern pike and other fishes depending on water levels. The MLSA is drained by Goldstream Creek from its confluence with Lake Channel Slough at the “Caches”, and also includes Goldstream Creek approximately 0.8 km upstream and 2 km downstream from Goldstream Creek’s confluence with Lake Channel Slough. Water levels in the MLSA have been observed to rapidly rise 0.5 to 1 m in less than 48 hours due to high flows from the Chatanika River and Goldstream Creek (Roach 1998b; P. Joy, ADF&G, personal communication; M. Albert, University of Alaska-Fairbanks, personal observation).

The ADF&G has described two geographic areas within the Minto Flats complex to define populations of inference for mark-recapture experiments of northern pike. Areas-A and B were used in the most recent mark-recapture experiment (2008) and Area-B was used in earlier (prior to 2008) experiments (Figure 3). Area-A is defined as all lakes (Big Minto, Upper Minto, Side, Marge, and New lakes), all sloughs (Beaver House, Cancer, and Rotten sloughs), the interconnecting Lake Channel Slough that drains into Goldstream Creek, and those portions of Goldstream Creek within an approximately 2-km radius of the confluence with Goldstream Creek and Lake Channel Slough. Essentially, Area-A included all habitable waters (during non-

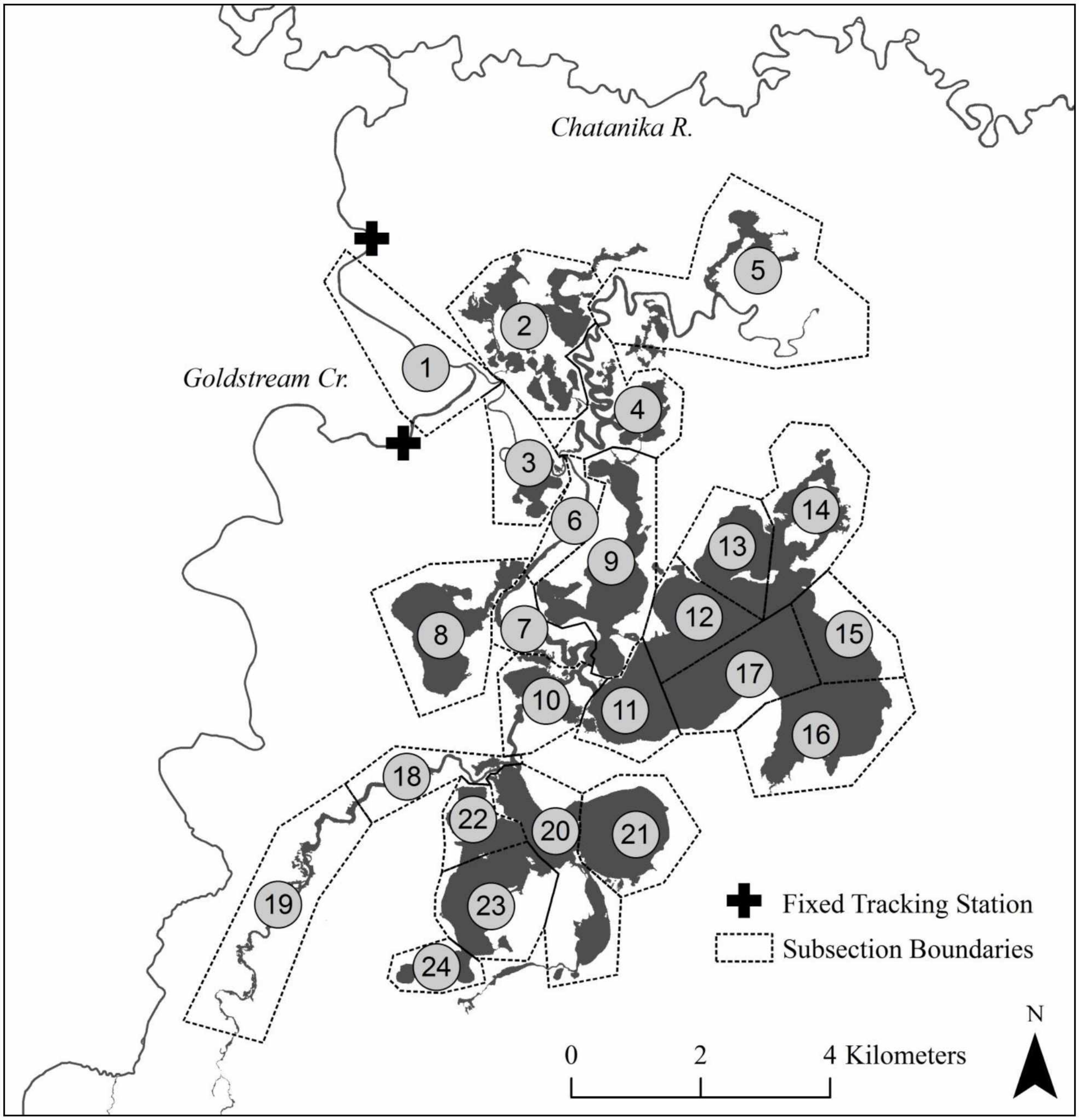

Figure 2. Map of the Minto Lakes Study Area located in the eastern section of Minto Flats near Fairbanks, Alaska. The dashed lines denote study subsection boundaries within the study area and the dark crosses indicate locations of fixed tracking stations. The numbers in the shaded circles identify each study subsection: (1) Goldstream Creek and lower Lake Channel Slough; (2) Marge Lake; (3, 6, 7, 10) Lake Channel Slough and connected off channel habitats; (4-5) Cancer Slough; (8) New Lake; (9) Side Lake; (11-17) Big Minto Lake; (18-19) Rotten Slough; and (20-24) Upper Minto Lake. The Chatanika River flows downstream from right to left.

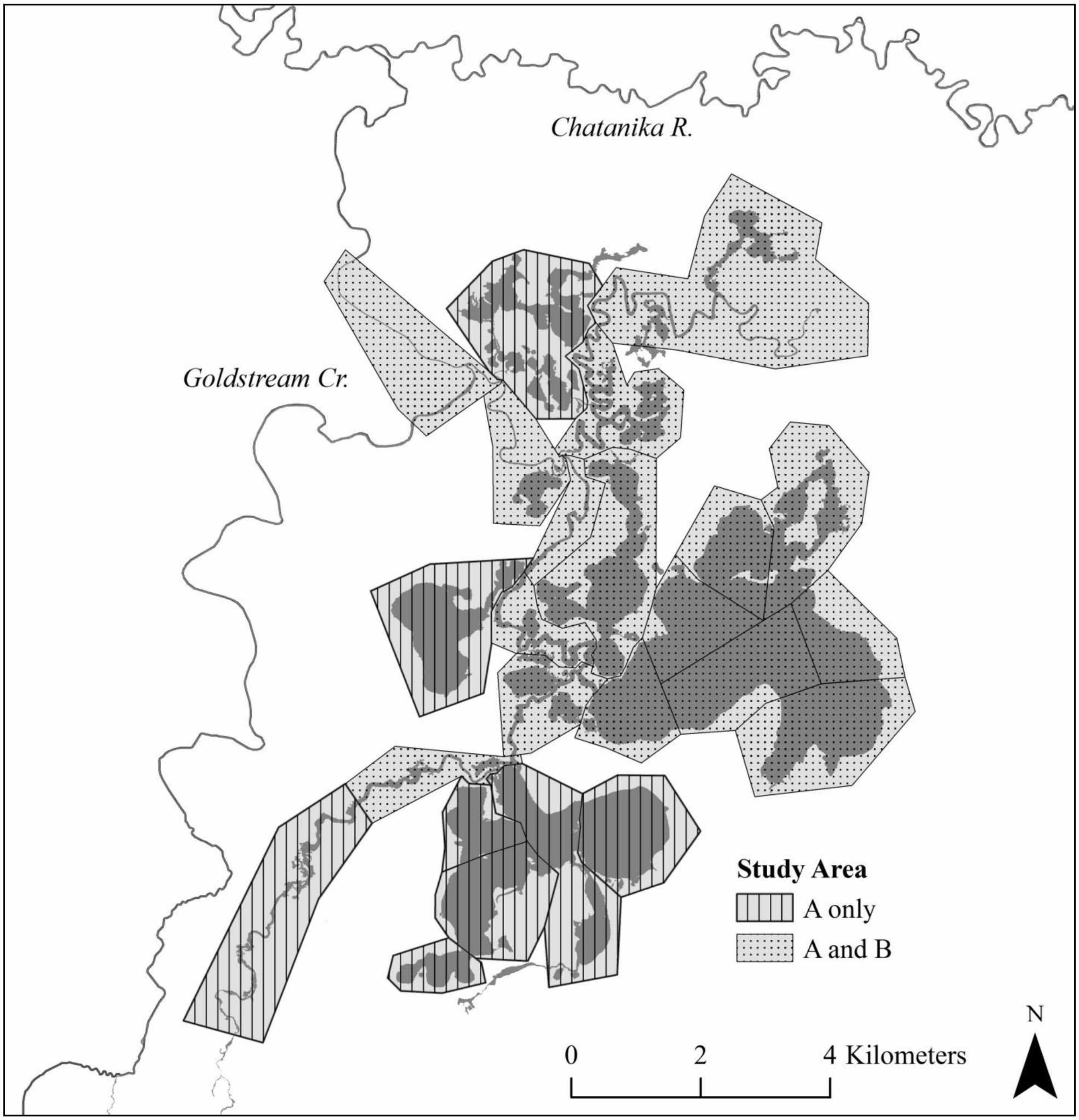

Figure 3. Map of study Area-A and Area-B. Study Area-A (hashed areas) includes all habitable waters of the Minto Lakes Study Area, while Area-B (stippled areas) coincided with sampling sections from pre-2008 mark-recapture experiments and is completely included within Area-A.

flood conditions) accessible from Goldstream Creek via Lake Channel. Area-B coincided with sampling sections from past mark-recapture experiments and excluded New, Upper Minto, and Marge lakes, the upper portion of Rotten Slough, and Goldstream Creek. In previous experiments, Area-B was subdivided into 16 sections to facilitate distribution of effort and assumption testing and this partitioning was utilized in 2008. Area-A used the partitioning scheme of Area-B plus eight additional sections (24 total sections; Figure 3). Summer habitat for northern pike and other fish species in Minto Flats covers an estimated 6,000 ha (R. A. Holmes, and G. A. Pearse, 1987 report to the Alaska Board of Fisheries on northern pike stock status and regulatory concerns in the Arctic-Yukon-Kuskokwim region). In addition to northern pike, Minto Flats is populated during the ice-free months with least cisco *Coregonus sardinella*, humpback whitefish *C. pidschian*, broad whitefish *C. nasus*, inconnu *Stenodus leucichthys*, Arctic grayling *Thymallus arcticus*, burbot *Lota lota*, longnose sucker *Catostomus catostomus*, Alaska blackfish *Dallia pectoralis*, lake chub *Couesius plumbeus,* and Arctic lamprey *Lethenteron camtschaticum*. Chinook salmon *Oncorhynchus tshawytscha* and chum salmon *O. keta* migrate through this area during their respective migrations to spawning areas in the upper Chatanika River. Although the winter distributions of these fishes are largely unknown, northern pike and humpback whitefish have been located in concentrated overwintering aggregations in several distinct locations in Minto Flats, including the Chatanika River upstream from its confluence from Goldstream Creek (Burkholder and Bernard 1994; Dupuis and Sutton 2014; P. Joy, ADF&G, personal communication; M. Albert, University of Alaska-Fairbanks, unpublished data).

Methods

Description of radio tags and tagging methodology

Northern pike were radio tagged by ADF&G during three different capture and tagging events: May 2007, March 2008, and March 2009. For the May 2007 event, 99 coded VHF radio tags with a 511-d operational life (Model F1850; Advanced Telemetry Systems, Inc., Isanti, Minnesota) were implanted surgically into northern pike captured in the Minto Lakes study area as part of a pilot telemetry study for this research project. Fish were captured after ice-out using hoop traps (0.91 m diameter hoops with 25.4-mm bar mesh and two 7.62-m wings) deployed in channels between water bodies or along lake shorelines and were checked every eight hours. Fish selection for tagging was based upon temporal, geographic, and size categories. To account for potential changes in the distribution of fish during late May 2007, radio tags were deployed in two temporal periods, with 50 tags deployed between 15-19 May and 49 tags deployed between 21-25 May. The geographic distribution of radio tags proportionally mirrored the distribution of 56 fish that were radio tagged in the Chatanika River in March 2007, by ADF&G, that migrated into the MLSA during April and May 2007. Radio tags were apportioned in a 2:4:2:1:1 ratio across five length categories (400-499, 500-599, 600-699, 700-799, and ≥ 800 mm fork length [FL]). The allocation of radio tags reflected the size distribution during the most recent ADF&G mark-recapture experiment in 2003 (Scanlon 2006).

During March 2008, 81 additional northern pike were sampled and radio-tagged from known congregations of overwintering fish in the Chatanika River based on telemetry surveys completed prior to tagging. From 18 to 20 March 2008, 61 coded 511-d and 20 coded 331-d radio tags (Models F1850 and F1840, respectively; Advanced Telemetry Systems, Inc.) were implanted into fish captured by jigging lures (baited and unbaited) through holes drilled in the ice. The Model F1840 radio tags were smaller in size and were reserved for fish < 500-mm FL.

For the March 2009 tagging event, collections of northern pike were again directed at known concentrations of overwintering fish in the Chatanika River based on telemetry surveys. Tagging occurred from 10-13 and 21-24 March 2009, which included the deployment of 40 coded 511-d radio tags (Model 1850; Advance Telemetry Systems, Inc.). To account for the low numbers of northern pike > 700-mm FL tagged in March 2008, large fish (> 700-mm FL) were targeted for tagging during this sampling event. However, due to low catch rates of large fish and time constraints, only 14 fish of this size or larger were radio tagged. The remaining tags (26) were implanted into fish < 700-mm FL. Capture locations were selected based upon the presence of previously radio-tagged fish, and a new location was chosen every 1 to 3 d when capture rates at a given location began to decline.

Surgical procedure

The surgical procedures for all tagging events were identical. All captured northern pike that were to be radio tagged were placed in a large tub filled with fresh water and sampled for sex (only possible for the May 2007 tagging event) and length (to the nearest 5-mm FL). Males were sexed by the presence of milt, which could be extruded before the onset and after the conclusion of spawning. Females were sexed by the presence of extruded eggs or a protruded urogenital duct.

Fish selected to receive radio tags were anesthetized in a clove oil solution at a concentration of 60 $mg \cdot L^{-1}$ until they lost equilibrium and lacked a response to handling (Anderson et al. 1997; Peake 1998; Klefoth et al. 2008). To improve its solubility in water, clove oil was dissolved in ethanol at a ratio of 1:10 (clove oil:ethanol). Each fish received an individually numbered t-bar anchor tag (Floy Tag, Inc., Seattle, Washington) that was inserted on the left side of the fish just posterior to the dorsal fin. Radio tags were surgically implanted into the peritoneal cavity through a 2-3 cm incision along the linea alba anterior to the pelvic girdle (Hart and Summerfelt 1975). The outlet incision for the trailing antenna was posterior to the pelvic girdle. The procedure used for the trailing antenna outlet incision was similar to that described by Ross (1982). A grooved director was placed into the abdominal cavity and oriented towards the rear of the fish where it directed a 16-gauge catheter inserted from posterior of the pelvic girdle towards the incision in the anterior. Once in place, the antenna was fed through the catheter and the groove director and catheter were removed from the fish. The incision was closed with three to five 3-0 monofilament sutures. After closing the incision, a layer of Vetbond^{TM} (3M^{TM}, St. Paul, Minnesota) was applied to further secure the sutures. During the surgical procedure, freshwater was continuously poured over the gills of the fish to prevent suffocation. Following surgery, radio-tagged fish were retained in a freshwater-filled tote until they could maintain equilibrium and then released.

Tracking and data collection

Radio-tagged fish were monitored using a combination of ground-based receiving stations and roving surveys using boat, snow machine, and fixed-wing aircraft. Two ground-based receiving stations identical to those described by Savereide (2005) were placed on Goldstream Creek, one approximately 800 m upstream and the other approximately 2 km downstream from the mouth of Lake Channel Slough. These fixed-receiving stations monitored northern pike movement into and out of the study area from April until mid-December 2008 and 2009.

Boat radio-tracking surveys of the entire MLSA during the 2008 open-water field season were completed from 17 to 22 May, 29 May to 5 June, 12 to 19 June, 26 to 2 July, 10 to 17 July, 23 to 30 July, 15 to 20 August, and 26 September. In 2008, each survey lasted between 7 and 14 h. Generally, survey duration decreased as the open-water season progressed due to declining water levels and increased emergent macrophyte growth. Typical field trips had durations of 10 d, with telemetry surveys conducted daily. The start time of surveys was alternated between 0500 and 1600 hours each day to cover the study area during all times of the day. The surveys rotated through four different starting locations to ensure that all areas were surveyed during all times of the day over the course of the tracking period.

During the 2009 open-water field season the daily duration of each boat survey was limited to no more than 7.5 hours due to funding limitations. Survey durations of 7.5 hours allowed for at least one-half of the study area to be surveyed each day of tracking. Boat-based telemetry surveys were completed 15 to 21 May, 4 to 10 June, 18 to 24 June, 24 to 30 July, and 18 to 22 August.

Boat radio-tracking surveys were conducted by a two-person crew using a receiver-datalogger equipped with an internal Global Positioning receiver (Model R4500C; Advanced Telemetry Systems, Inc.) using a dipole antennae mounted to a flat bottomed boat with a surface-drive outboard motor designed for shallow wetland operations (Model X-36; Pro Drive Outboard, LLC, Loreauville, Louisiana). One person piloted the boat at a moderate speed (24 to 32 $km \cdot h^{-1}$), while the other individual operated the telemetry receiver that recorded fish locations and identifications. Final fish location was determined as the point where the highest signal strength recording was encountered. Each survey covered all navigable waters that were safely accessible with a boat in the study area. Tracking in lakes involved piloting the boat around the perimeter of the lake while staying within 50 m of the shoreline, followed by an additional pass 200 m from shore. If the lake size was sufficiently large (> 500 m in width), additional passes were made 200 m offshore from the previous pass until the entire area of the lake had been completely surveyed.

Once ice conditions allowed for safe travel after freeze-up, snow machine surveys were conducted in the study area. Surveys utilized a single snow machine with a dipole antennae mounted to the rear cargo rack. These surveys followed a similar methodology as the boat surveys with the exception that the rider had to both pilot the snow machine and operate the receiver-data logger. Snow machine surveys were only conducted on the Chatanika River below the Murphy Dome boat launch and Goldstream Creek from its confluence with the Chatanika River upstream to the upper boundary of the Minto Lakes study area. Surveys were completed on 6 and 25 November 2008 and 20 January, 25 February, 10 March, 13 and 24 March, and 3,10, and 16 April 2009.

Aerial surveys were conducted when boat travel was not logistically feasible or when it was necessary to survey a larger area. Aerial surveys were completed on 20 October 2008, 11 December 2008, and 7 May 2009, and 19 January 2010. During aerial surveys, the Minto Lakes study area and nearby water bodies (including the upper Chatanika River and lower portions of Goldstream Creek) were surveyed as well as surrounding areas of Minto Flats including the lower Chatanika River, upper Goldstream Creek, Swanneck Slough, Tolovana River, Tatalina River, and their connecting lakes and sloughs

Based on this study and other northern pike telemetry evaluations, it was determined that locations of radio-tagged fish could always be accurately determined or “bracketed” to within a

100-m radius when utilizing a boat and to within a 800-m radius when aerial tracking (P. Joy, ADF&G, personal communication; M. Albert, UAF, personal observations). Although greater accuracy (e.g., 10 m when tracking from a boat) can be obtained, it was not time efficient to do so because each tracked fish would have to be bracketed multiple times at ever smaller radii.

Thirty water temperature loggers were deployed at strategic locations throughout the study area for the duration of both the 2008 and 2009 open-water seasons (Figure 4). The loggers consisted of 18 Hobo Water Temp Pro v2 loggers and 12 StowAway Tidbit Temp Loggers (Onset Computer Corporation, Bourne, Massachusetts). Loggers deployed at sampling locations in Goldstream Creek or slough channels were cabled to a secure anchor point on the bank above mean high water level and held in the thalweg with a 0.91-kg lead cannon-ball fishing weight. A second logger was attached to the cable so it was located in the shallow (< 0.33 m deep) littoral area next to the shoreline. It was not possible to sample surface water temperatures at these locations because they might have caused a navigational hazard for recreational boaters. In lentic habitats, water temperature loggers were attached 0.1 m below a 0.33-m long foam bullet-buoy and anchored to the bottom with a cable and 0.91-kg lead cannon-ball fishing weight. In locations with sufficient depth, a second water temperature logger was attached to the weight to sample bottom water temperatures; however, this was limited due to the shallow nature of the lakes and a limited number of water temperature loggers. Data from water temperature loggers were downloaded twice at regular intervals throughout the field season. Water temperature loggers were re-deployed in May 2009 at the same locations as in 2008 and removed on 21 August 2009.

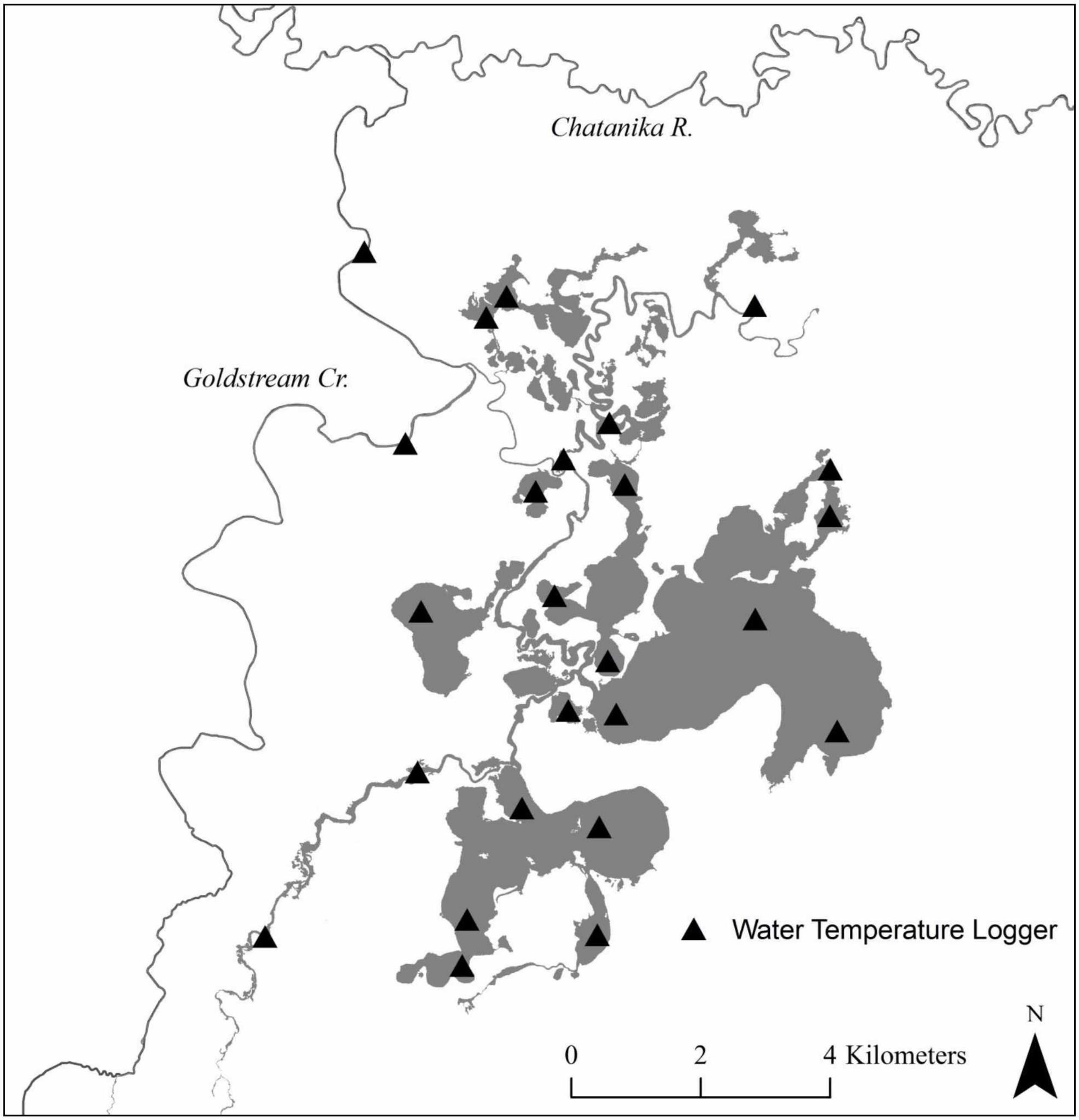

Figure 4. Map of the Minto Lakes Study Area depicting deployment locations of water temperature data loggers (dark triangles).

Data analyses

Statistical analyses were completed using Program R (R Development Core Team 2009). Spatial analyses were completed with both R and ArcMap 9.3.1 (Environmental Systems Research Institute 2009, Redlands, California). Unless otherwise stated, all statistical tests were conducted at a significance level of $\alpha = 0.05$.

Fish movements were described for four separate temporal periods in both 2008 and 2009: (1) 15 April to 15 May (spring; migration into MLSA and pre-spawning movements); (2) 16 May to 31 August (summer; period during which mark-recapture population assessment are traditionally completed and also when most of the sport fishing effort occurs); (3) 1 September to 30 November (fall/early winter; out-migration to the Chatanika River); and (4) 1 December to 15 April (winter; period when most subsistence fishing effort occurs). The summer temporal period was further divided into four shorter sub-periods by month to allow for a more detail analysis of movements. Movements of radio-tagged individuals by each tracking station were summarized over time using histograms showing daily and cumulative fish passage.

To analyze the movements of radio-tagged northern pike, the latitude and longitude of each detection location was plotted on a map of the Minto Flats wetland complex using ArcMap 9.3.1. Fish were classified as mortalities if no movement was observed between successive seasons. Geographic distribution was displayed by calculating a relative density of radio-tagged fish deemed alive that were detected in each pre-defined sub-sections of the MLSA and plotting those results using ArcMap 9.3.1. Relative densities of radio-tagged northern pike within the MLSA during each summer sub-period were calculated using the results of the single radio-tracking survey that detected the greatest number of tagged fish during the first survey period of each summer sub-period. Relative densities calculated for temporal periods outside of the summer period used the results of an individual telemetry survey during each temporal period.

For northern pike detected more than two times during the summer or winter periods, movement (m) was calculated by measuring the shortest distance traveled via connected water bodies between successive detections using the Cost Path Analysis tool and/or the Measure Distance tool in ArcMap 9.3.1. Time-at-large between fish detections was calculated by subtracting the Julian day and hour of the most recent detection from the prior detection for each fish. Movement rates ($m \cdot hr^{-1}$) were calculated using movement distance and time-at-large. Northern pike movement, time-at-large, and movement rates were not calculated for fish detected outside of the MLSA or for fish detected during the spring and fall periods because these detections were too infrequent. A two-tailed *t*-test was used to compare the mean FL of fish tracked during the 2008 and 2009 summer seasons. A quantile-quantile plot was used to assess normality of the distribution of the movement rates of the radio-tagged northern pike detected during the summer season in 2008 and 2009. All movement rates were log-transformed to correct for non-normal distributions of movement rates.

Analysis of northern pike movement data collected during the summer period 2008 and 2009 was limited to those movements with times at large ≤ 43 h, which was the longest time-at-large an individual fish could have been detected by successive daily telemetry surveys. For the 2008 and 2009 summer periods, linear mixed-effects models were constructed to investigate the relationships between movement rates and other study variables, using the lme4 package in R (Bates et al. 2015). Log-transformed movement rates were treated as the response variable, with FL, mean water temperature, and summer sub-period treated as fixed effects, and individual fish treated as a random effect. This allowed for testing of the effect of each study variable on movement rates, after accounting for the effects of all others, thereby isolating the effects of each variable. Inclusion of individual fish as a random effect served to mitigate the independence issue posed by repeated measures. Separate models were constructed for 2008 and 2009 due to differences in environmental conditions and study methods between years. In each year, 5 candidate models were evaluated to explain the observed movement rates of northern pike in the MLSA during the open-water season (Table 1). Models within each year were compared utilizing Akaike's information criterion (AIC; Burnham and Anderson 2002). For each year, the most parsimonious model was selected.

A Tukey's Honestly Significant Difference post-hoc test was used to detect pairwise differences in summer sub-period effects on fish movement rates within models for 2008 and 2009. Using ArcMap 9.3.1, the relative proportions of fish present in each sub-section of the MLSA were displayed by month from May 2008 through August 2009. Relationships between winter movements, time-at-large, and date were examined using simple linear regression.

Results

In May 2007, 99 northern pike from the MLSA were surgically implanted with radio transmitters as part of a pilot telemetry study conducted by ADF&G. In March 2008 and 2009, 81 and 40 northern pike, respectively, from the Chatanika River adjacent to the MLSA were surgically implanted with radio transmitters.

In May 2008, 98 radio-tagged northern pike had "active" signals and were considered to be alive (24 and 74 of the fish were radio tagged in May 2007 and March 2008, respectively). In May 2009, 83 radio-tagged fish were available for radio tracking (3, 42, and 38 fish were radio

Table 1. Candidate linear mixed-effects models used to estimate movement rates of northern pike with the following predictors: fork length (FL), mean water temperature (Temp), and summer sub-period (Period). All models included a normal residual error term and a normally distributed individual fish random intercept term ($ß_0$), increasing the number of parameters by two for each model for estimation of the residual and random effect variances. *K* is the number of parameters in each model.

Year	Model	Predictors	*K*	AIC	ΔAIC
2008	1	$ß_0$ + FL + Temp + Period	8	3,925.9	0.0
	2	$ß_0$ + FL + Period	7	3,926.1	0.2
	3	$ß_0$ + FL + Temp	5	3,981.6	55.7
	4	$ß_0$ + FL	4	3,998.6	72.7
	5	$ß_0$	3	4,028.8	102.9
2009	1	$ß_0$ + FL + Period	7	1,116.5	0.0
	2	$ß_0$ + FL + Temp + Period	8	1,118.9	2.4
	3	$ß_0$ + FL + Temp	5	1,124.9	8.4
	4	$ß_0$ + FL	4	1,160.8	44.3
	5	$ß_0$	3	1,164.6	48.1

tagged in 2007, 2008, and 2009, respectively). The mean FL of radio-tagged northern pike was 576 mm (range, 455-1,000 mm) in 2008 and 586 mm (range, 455-1,000 mm) in 2009. No significant differences were detected between mean FL of fish tagged in 2008 and 2009 ($t = -0.696$, $P = 0.49$).

In 2008, 1,852 relocations of 80 radio-tagged northern pike occurred, with each individual relocated an average of 23 times (SD = 14). Boat surveys had a detection rate of 82% (80 of 98 fish). Of the 18 fish not detected during 2008 boat surveys, 13 (72%) individuals were later determined to be residing in the lower Tolovana River near the village of Minto, four (22%) fish were never located or were unable to have a location assigned to them, and one (6%) fish was located in an area adjacent to the MLSA. Seventy-three radio-tagged fish were detected ≥ two times within the MLSA and were utilized for the analysis of movements during the 2008 open-water season.

In 2009, 990 relocations of 70 radio-tagged northern pike occurred and individual fish were relocated an average of 14 times (SD = 5). During 2009 boat telemetry surveys, 84% (70 of 83) of radio-tagged northern pike were detected in the study area. Of the 13 fish not detected during 2009 boat surveys, 12 (92%) fish were later determined to be residing in the lower Tolovana River near the village of Minto and one (8%) fish could not be assigned a location but was known to be alive with an active radio transmitter. Sixty-five radio-tagged northern pike were detected ≥ two times within the MLSA and were utilized for the analysis of movements during the 2009 open-water season.

Spring movements

The tracking stations located on Goldstream Creek upstream and downstream of the entrance to the MLSA became operational in March 2008 (Figure 2). The downstream station detected 51 radio-tagged northern pike passing upstream during an 8-d period between 23 and 30 April. Forty-two fish (82%) were recorded passing upstream during a 4-d period between 26 and 29 April (Figure 5). No downstream passage was detected by this tracking station from March through June 2008 and no radio-tagged fish were detected at the station located on Goldstream Creek upstream of the entrance to the MLSA between March and June 2008.

In 2009, the downstream tracking station detected 68 fish passing upstream in a 14-d period between 27 April and 10 May. Upstream passage by radio-tagged fish was detected on eight of 14 d, with 52 fish (76%) passing upstream on 29 and 30 April (Figure 5). All fish detected passing upstream beyond this station were later relocated via boat telemetry surveys within the MLSA during the 2009 open-water season. In April and May 2009, the tracking station located on Goldstream Creek upstream of the entrance to the MLSA detected 13 northern pike, 12 fish of which passed upstream of the station (some more than one time) for a total of 24 upstream passage detections. All upstream passage detections were later paired with a downstream passage detection by the same individual past this station within one to 88 h ($N = 8$ fish making 20 upstream forays; mean foray time upstream of the tracking station = 19.5 h) or were relocated within the MLSA at the onset of boat telemetry surveys ($N = 4$ fish). Seven fish made one upstream foray and six fish made ≥ two upstream forays above the upstream tracking station. All 13 fish were detected passing upstream past the downstream tracking station prior to detection by the upstream tracking station. Out of the 73 radio tagged northern pike detected ≥

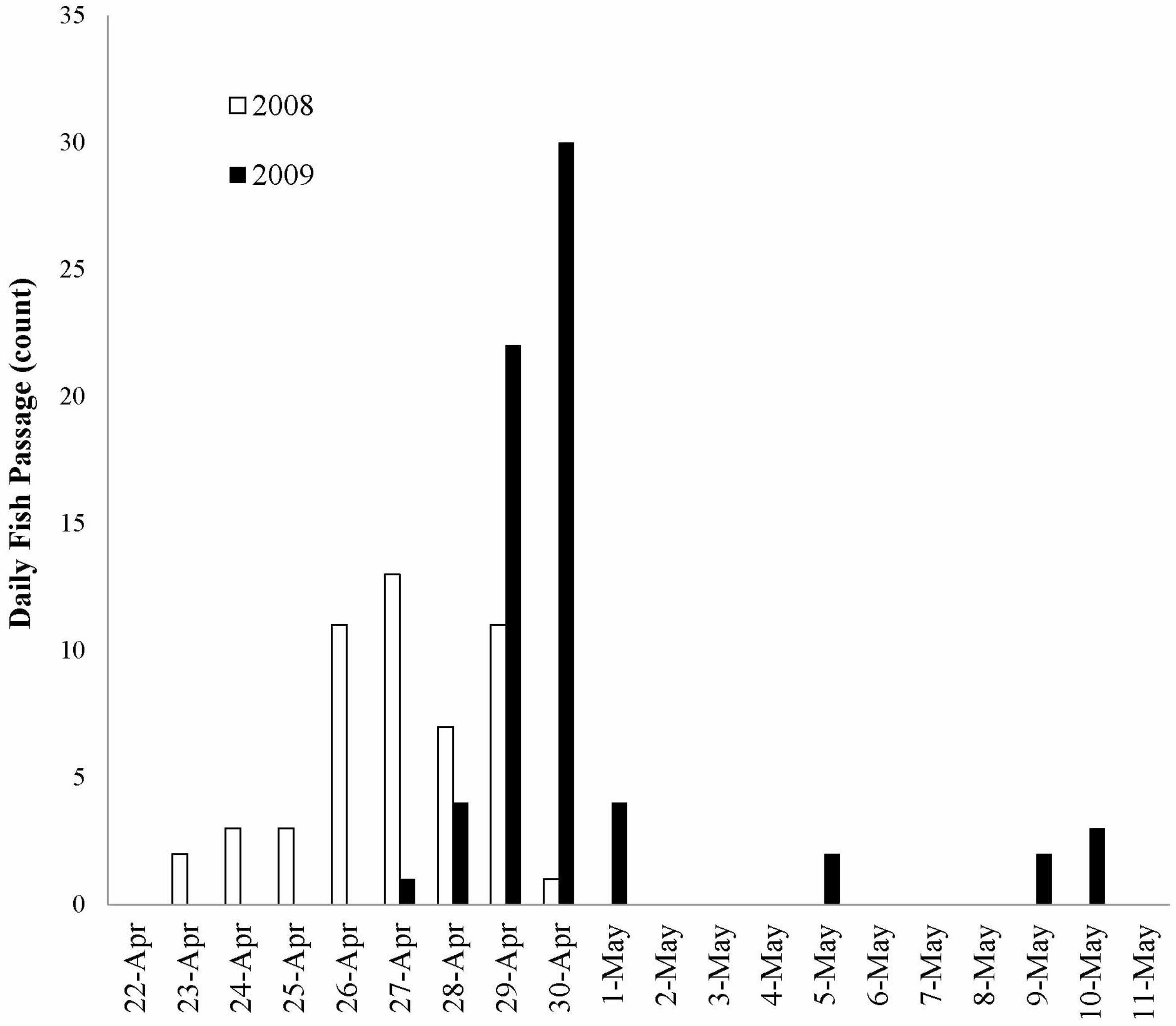

Figure 5. Daily upstream passage counts of radio-tagged northern pike between 22 April and 11 May 2008 and 2009 at the fixed receiving station located on Goldstream Creek below the entrance slough into the Minto Lakes Study Area.

two times in the MLSA during the open-water season of 2008, 43 (59%) were alive with actively transmitting radio tags by the spring of 2009. Forty (93%) northern pike returned to the MLSA in the spring of 2009, 1 (2%) fish was detected elsewhere in Minto Flats, and 2 fish were never detected after spring ice-out.

Summer movements

During the 2008 and 2009 open-water seasons, all radio-tagged northern pike that migrated into the MLSA post ice-out remained within the MLSA until out-migration began in the fall. No fish were detected passing upstream or downstream by the stationary tracking stations located on Goldstream Creek. Radio-tagged fish were widely distributed across the MLSA with fish rarely being evenly distributed and their distributions changing over time (Figures 6 and 7). The highest relative densities of radio-tagged northern pike during the summer months occurred during August of both summers (Figures 6d and 7d).

While radio-tagged fish did not display long-distance movements into or out of the MLSA during summer months (May-August), finer-scale movements were observed within the MLSA. There were 1,732 and 743 movements collected from relocations of individual radio-tagged fish during the 2008 and 2009 open-water seasons, respectively. After excluding movements for which radio-tagged fish were at-large for > 43 h, 1,192 and 329 movements were used for movement analyses from 2008 and 2009, respectively. During 2008, the mean movement rate for fish that were at-large for ≤ 43 h, was 16.1 $m \cdot h^{-1}$, while in 2009 the mean movement rate was 24.84 $m \cdot h^{-1}$ (Table 2).

Investigation of the relationship between movement rates and various study variables showed that in both years, the data supported (based upon lowest AIC and fewest parameters) a

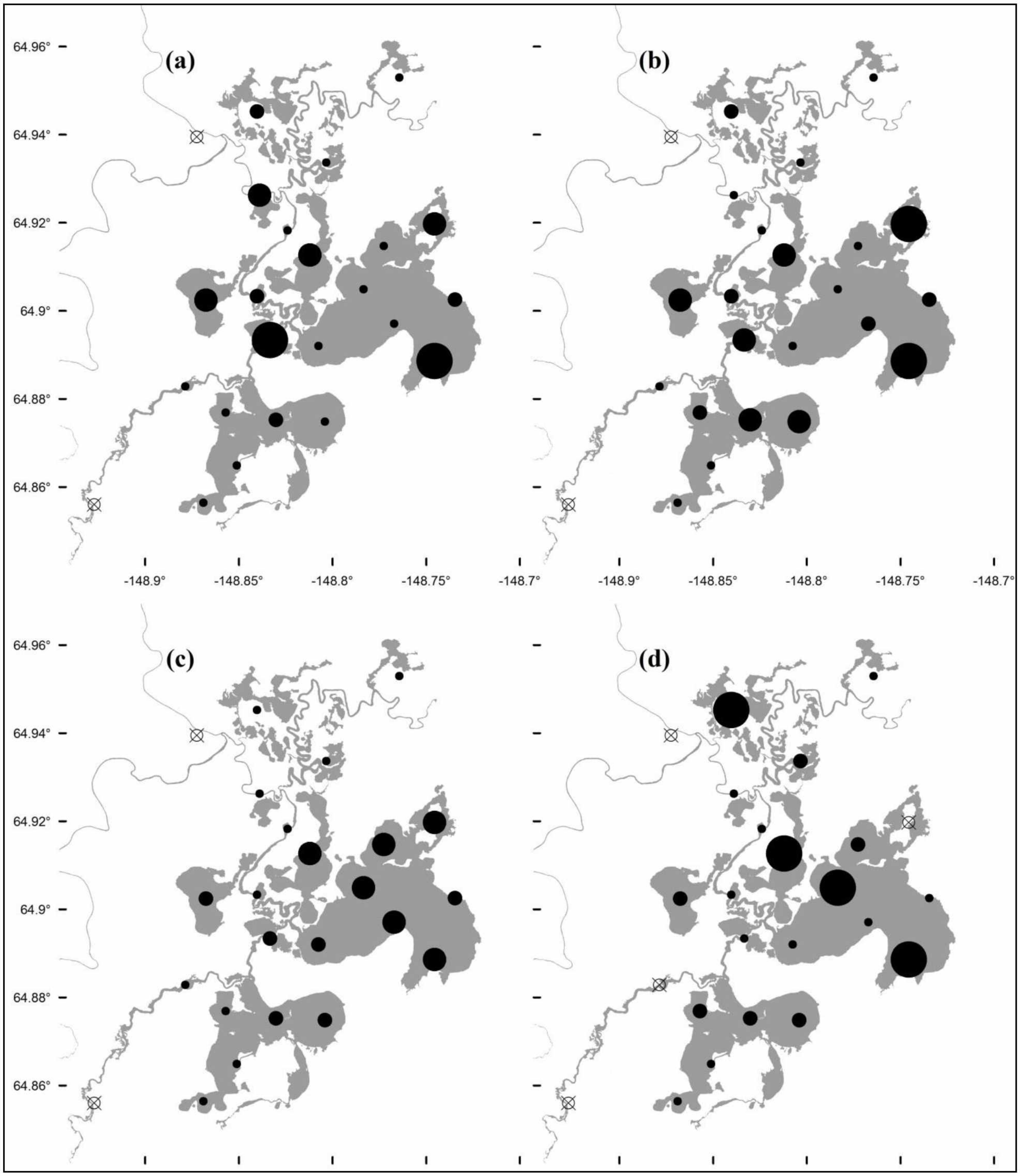

Figure 6. Relative density of radio-tagged northern pike in the Minto Lakes Study Area by month during the 2008 summer season: (a) May; (b) June; (c) July; and (d) August. Progressively larger black circles in each subsection indicate greater northern pike relative density, while “x” symbols indicate that no fish were detected in that study subsection.

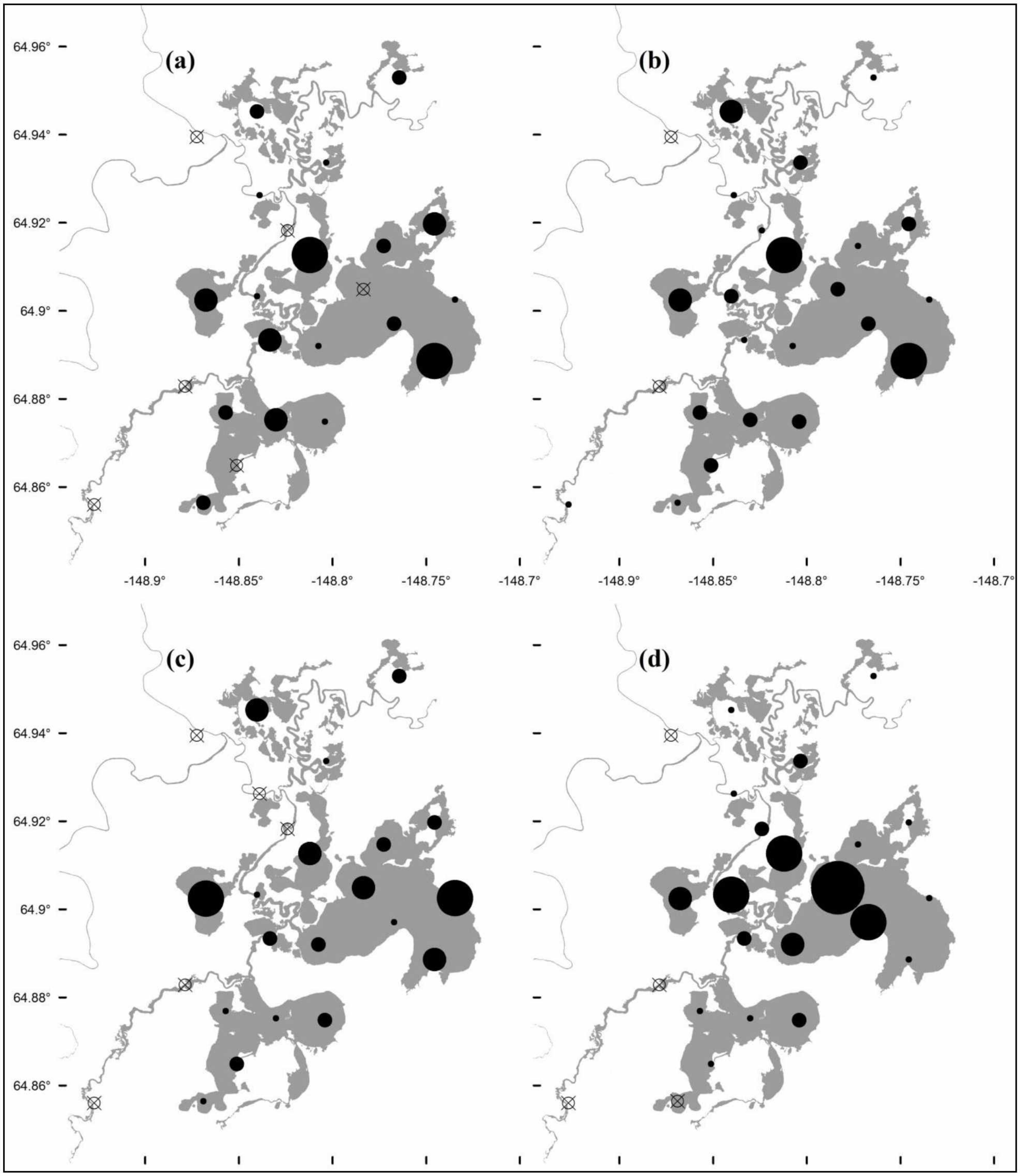

Figure 7. Relative density of radio-tagged northern pike in the Minto Lakes Study Area by month during the 2009 summer season: (a) May; (b) June; (c) July; and (d) August. Progressively larger black circles in each subsection indicate greater northern pike relative density, while “x” symbols indicate that no fish were detected in that study subsection.

Table 2. Summary statistics of radio-tagged northern pike in the Minto Lakes Study Area utilized for movement analyses during May - August 2008 and 2009.

		Time-at-Large (h)		Distance between subsequent detections (m)			Movement Rate ($m \cdot h^{-1}$)		
Year	*N*	Mean	SD	Mean	Median	Range	Mean	Median	Range
2008	1,192	22.04	8.14	334	118	1-8,468	16.1	6.36	0.07-360.31
2009	329	24.74	5.89	592	214	5-7,492	24.84	8.48	0.16-312.17

model structure that included fork length and summer sub-period, but not mean water temperature (Table 1). In 2008, while the next best model differed by < 2 AIC units, it also included an extra parameter and as such, was not the most parsimonious choice. In 2009, the next best model differed by > 2 AIC units. While mean water temperature did not add to the predictive power of the models selected, it did vary significantly among summer sub-periods in both years (Figure 8, 2008: $F = 1{,}126$, $P < 0.001$; 2009: $F = 1{,}433$, $P < 0.001$).

Log-normalized movement rates had a significant positive relationship with northern pike FL at the time of tagging after accounting for the effects of summer sub-period and individual fish in 2008 ($t = 4.28$, $P < 0.001$) and 2009 ($t = 2.93$, $P = 0.004$). Log-normalized movement rates of radio-tagged fish within the MLSA during 2008 were greatest in May and August (Figure 9). Movement rates in May were significantly greater than those observed in June ($P < 0.001$), but not July ($P = 0.64$) or August ($P = 0.08$). Movement rates were lowest in June and July, but were significantly different from each other ($P < 0.001$). Data collected in 2009 showed similar patterns as in 2008, with the movement rates of radio-tagged fish within the MLSA being greatest during May and August (Figure 9). Movement rates in May were significantly greater than those observed in June ($P < 0.001$) but not July ($P = 0.15$), or August ($P = 0.47$). Movement rates were lowest in June and July, and were significantly different ($P = 0.01$).

Fall/early winter movements

From 19 August to 15 October 2008, no emigration or immigration of radio-tagged northern pike to or from the MLSA was detected by the tracking stations on Goldstream Creek. Between 16 October and 30 November 2008, 28 radio-tagged fish were detected by the

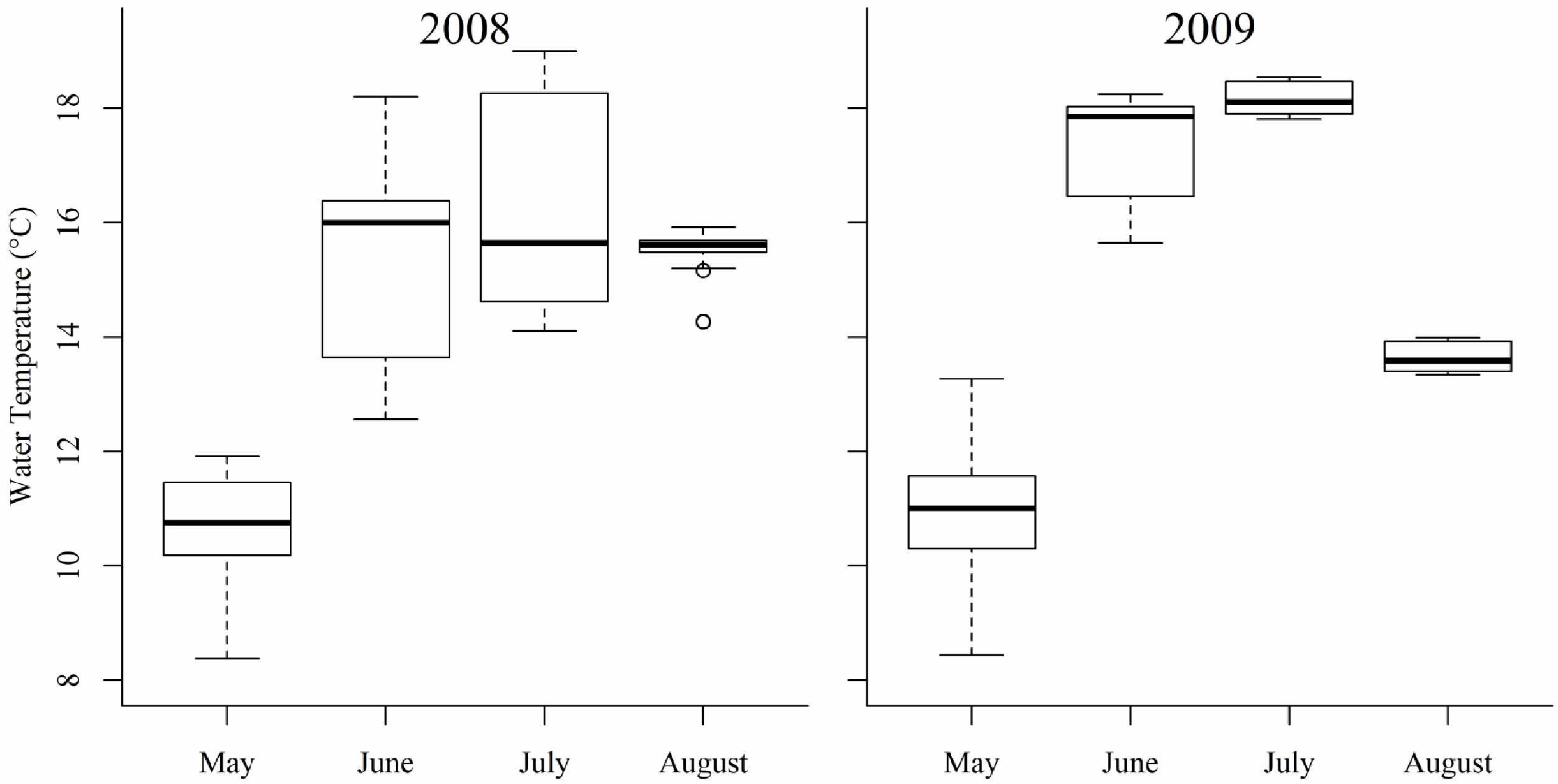

Figure 8. Boxplots summarizing maximum, minimum, median upper quartile, and lower quartile mean water temperatures recorded within the Minto Lakes Study Area during northern pike movements recorded during 2008 and 2009.

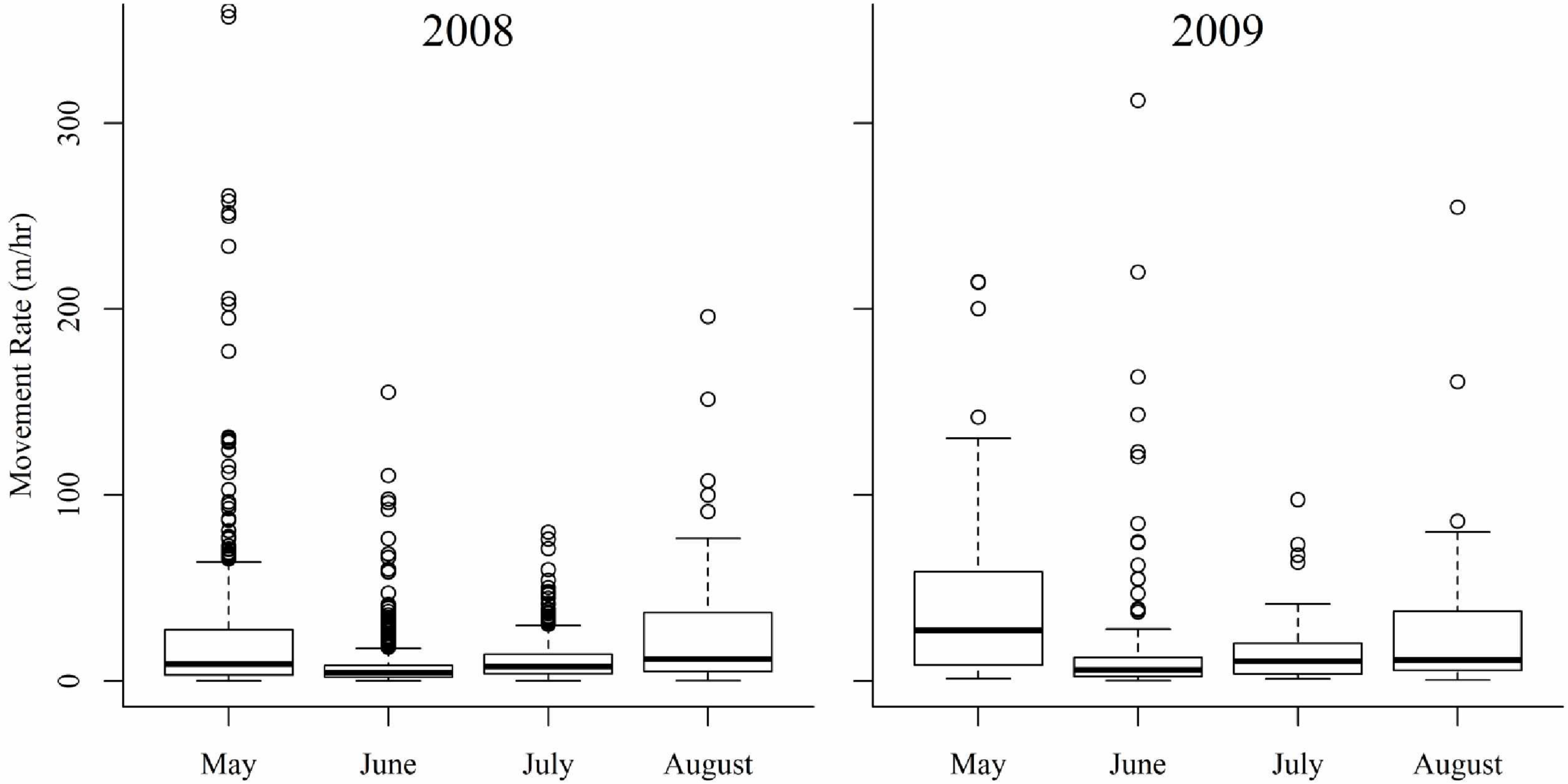

Figure 9. Boxplots summarizing maximum, minimum, median upper quartile, and lower quartile movement rates (m·h-1) of radio-tagged northern pike by month for 2008 and 2009.

stationary tracking station located on Goldstream Creek downstream of the entrance to the MLSA. Twenty-six (93%) fish were recorded passing downstream between 31 October and 27 November 2008. One (3.5%) fish passed downstream, passed back upstream, and was later located on 12 December 2008 in the Chatanika River downstream of the tracking station. One (3.5%) fish was recorded passing upstream, but had spent the summer located within the MLSA and was later located on 12 December 2008 in the Chatanika River downstream of the tracking station. No fish were detected by the stationary tracking station located on Goldstream Creek upstream of the entrance to the MLSA.

A boat telemetry survey on 26 September 2008 (Figure 10a) covered the Chatanika River between the Murphy Dome Road Landing and it's confluence with Goldstream Creek, Goldstream Creek to the entrance of the MLSA, and the MLSA. Forty-six radio-tagged fish were detected, with 43 fish detected within the MLSA and the remaining three fish detected in the Chatanika River upstream of Goldstream Creek. All fish detected within the MLSA had been previously detected within the MLSA from May through August. However, the three fish detected in the Chatanika River had not been detected within the MLSA during the preceding summer season.

Most radio-tagged northern pike remained within the MLSA until well after ice-up in 2008. An aerial telemetry survey completed on 20 October 2008 detected 53 radio-tagged northern pike and all but two (3.78%) fish were located within the MLSA (Figure 10b). The latter two fish were located in the Chatanika River upstream of its confluence with Goldstream Creek; note that these fish were also detected in this reach of river during the 26 September 2008 boat telemetry survey. Snow machine surveys completed on 6 November and 25 November 2008 detected seven and 12 radio-tagged northern pike, respectively, between the confluence of

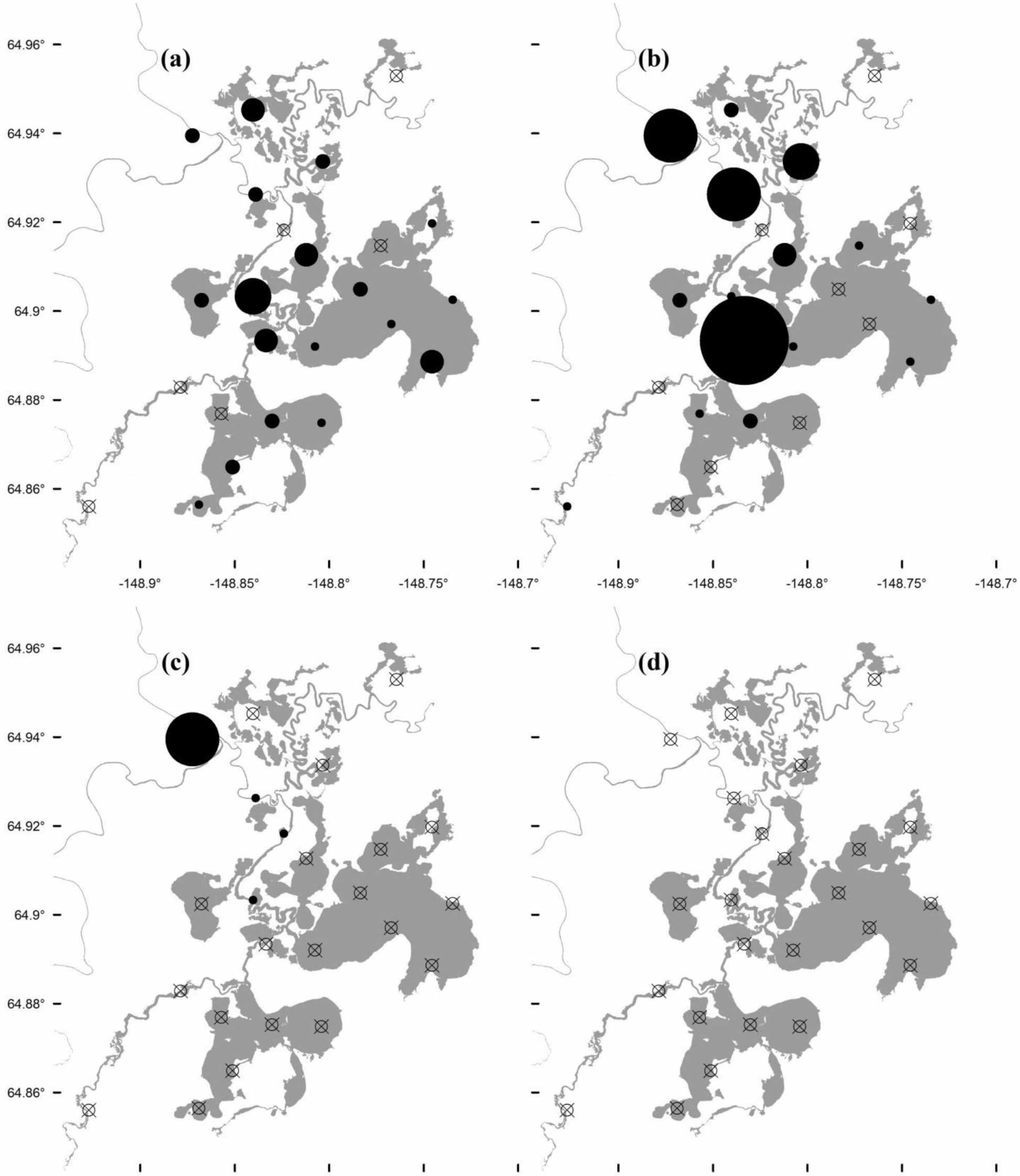

Figure 10. Relative density of radio-tagged northern pike in the Minto Lakes Study Area by month during the 2008-2009 fall, winter, and spring seasons: (a) September; (b) October; (c) November-December; and (d) January-April. Progressively larger black circles in each subsection indicate greater northern pike relative density, while "x" symbols indicate that no fish were detected in that study subsection.

Goldstream creek and the Chatanika River and the entrance to the MLSA (Lake Channel Slough confluence with Goldstream Creek). The aerial telemetry survey completed on 11 December 2008 detected 55 radio-tagged northern pike, all of which were located in the Chatanika River (Figure 10c). Forty-eight (87.27%) fish had been detected ≥ one time within the MLSA during the preceding open-water season and the remaining seven fish were never detected within MLSA during that same period.

In 2009, downstream migration of radio-tagged northern pike out of the MLSA occurred between 20 September and 9 November. Twenty-one radio-tagged fish were detected passing downstream by the tracking station located on Goldstream Creek downstream of the entrance to the MLSA. Peak downstream passage occurred between 9 and 31 October, during which time 86% ($N = 18$) of fish were detected passing downstream out of the MLSA. All fish detected passing downstream of the tracking station were later located in the Chatanika River during an aerial survey flown on 20 January 2010.

Mid- to late winter movements

During the 2008-2009 winter, 59 radio-tagged northern pike were detected ≥ one time in a 26-km reach of the Chatanika River between Goldstream Creek (rkm 49) and the Murphy Dome Road access point (rkm 75). Fifty three (90%) of these fish had been detected within the MLSA during the preceding open-water season. These fish comprised 98% (53 of 54) of the individuals that were detected within the MLSA during the preceding summer. No live fish with actively transmitting radio tags were detected outside of this reach of the Chatanika River from 11 December 2008 through 16 April 2009. Six (10%) fish detected in the 26-km reach of the Chatanika River were not detected via telemetry surveys within the MLSA during the 2008 open-water season. These fish were likely present either in the lower Tolovana River near the village of Minto or may have occupied other unknown locations within the greater Minto Flats/Chatanika River wetland complex. These assignments were based upon relocations of those fish ($N = 2$) during an aerial telemetry survey completed on 7 May 2009 or never detecting those fish ($N = 4$) outside of the aforementioned 26-km reach of the Chatanika River during the winter of 2008-2009.

Individual radio-tagged northern pike were relocated between one and 10 times after their initial detection within the Chatanika River overwintering area (mean number of detections per fish = 5, median = 4) and moved a cumulative distance of 131-26,767 m between all relocations for each individual. For fish relocated during more than one telemetry survey, the cumulative distance moved between subsequent relocations ranged from 1 - 26,690 m (mean = 811 m, median = 141 m). Fish spent, on average, 24 d at large between relocations (median = 16 d, range = 3 to 112 d). Radio-tagged northern pike that were detected within the overwintering area and then relocated ≥ one time between 20 October 2008 and 25 February 2009 telemetry surveys had a mean distance between subsequent relocations of 1,607 m per fish, which was significantly greater than the average distance moved between subsequent relocations of 136 m per fish for those fish relocated ≥ one time between the 25 February and 16 April 2009 telemetry surveys ($t = 8.73$, $P < 0.001$). Fish generally moved in an upstream direction over the winter, with 64% (34 of 53) of fish last relocated upstream of their first relocation in the Chatanika River during winter 2008-2009.

During winter 2009-2010, a similar winter distribution of radio-tagged northern pike was observed as in the prior winter season. One aerial telemetry survey was completed on 20 January 2010, which detected 23 fish with actively transmitting radio tags. Twenty-one (91%)

fish were located in the Chatanika River between its confluence with Goldstream Creek and the Murphy Dome Road access point. These 21 fish had all been present within the MLSA during the 2009 open-water season. The remaining two (9%) fish were located near the village of Minto and the lower Tolovana River and had not been located during the previous open-water season within the MLSA.

Discussion

The generalized movements of northern pike in the MLSA and Minto Flats observed in this study were consistent with previous research (Hallberg 1984; Holmes and Burkholder 1988; Burkholder 1989; Burkholder and Bernard 1994; Roach 1998a). Northern pike moved from an overwintering area in the Chatanika River into the MLSA from late April through May for spawning and summer feeding. Fish dispersed throughout the MLSA and remained for the duration of the summer, with peak movement rates within the MLSA in May and August. Most radio-tagged northern pike remained in the MLSA until after freeze-up. Outmigration began between late September and mid-October and was completed by late November and early December. Once present in the overwintering area in the Chatanika River, movements were greatly reduced until spring. Additional radio-tagged northern pike were detected overwintering in the Chatanika River that were not present in the MLSA during the open-water season.

In contrast to previous studies, my project utilized far more tagged individuals ($N = 220$), was focused specifically on the northern pike inhabiting the MLSA portion of Minto Flats during the open-water season, radio tags were distributed with less bias (i.e., fish were radio-tagged in the overwintering area and thus were randomly distributed during the open water period), and examined movements at much smaller temporal and geographic scales. This provided greater detail relative to describing migration timing, open-water season distribution within the MLSA, and overwintering distributions for northern pike that utilize the MLSA. The earliest study to utilize telemetry had few ($N = 4$) radio-tagged individuals and examined their movements over the entirety of Minto Flats (Hallberg 1984). Subsequent telemetry studies had larger sample sizes, but were either lacking in duration (lifespan of radio tags < 12 months), had few telemetry surveys completed per season (≤ 8-9 per year), or focused on the larger, coarse geographic regions making up the Minto Flats wetland complex (Holmes and Burkholder 1988; Burkholder 1989; Burkholder and Bernard 1994; Roach 1998a).

As has been observed with populations of northern pike that inhabit shallow stream-wetland complexes in Alaska (Hallberg 1984; Behrends and West 1987; Taube and Lubinski 1996; Roach 1998a; Joy and Burr 2004), the radio-tagged individuals in this study made a distinct migration in late fall and early winter from summer feeding habitats in the MLSA to the Chatanika River to overwinter. Once fish had moved to the Chatanika River, movements generally were greatly reduced until ice break-up. The timing of radio-tagged northern pike out-migration from the MLSA in this study is similar to the findings of previous research conducted in Minto Flats. Hallberg (1984) observed that movements of radio-tagged fish in Minto Flats from summer feeding areas to overwintering locations occurred primarily between early October and early November. Burkholder and Bernard (1994) reported that radio-tagged northern pike had high median net displacement velocities between relocations from October to December as they migrated from dispersed summer feeding areas to a few concentrated overwintering areas within Minto Flats. In contrast, Roach (1998a) observed that greater than 50% of radio-tagged northern pike that were located in the MLSA during summer months did not migrate to an overwintering area in the Chatanika River until after December 1995 and 1996. This migration out of shallow lakes and sloughs is likely due in part to the inability of those habitat types to provide suitable overwintering areas for northern pike. In a small Yukon River tributary, late summer and fall outmigration of adult northern pike were related to declining water levels (Joy and Burr 2004). Migration of age-0 northern pike from confined marshes and backwaters in the fall has been associated with lower water temperatures and reductions in dissolved oxygen levels in the upper Mississippi River and in marshes in west-central Manitoba (Holland and Huston 1984; Derksen 1989).

In both winters of this study, no radio-tagged northern pike were detected overwintering within the MLSA, which differed from the results of prior studies. Burkholder and Bernard (1994) and Roach (1998a) observed that radio-tagged fish utilized the Chatanika River as overwintering habitat. However, in those studies, a significant number of individuals remained in or near the MLSA (i.e., lower Goldstream Creek) for the duration of the winter. During the 1995-1996 and 1996-1997 winters, Roach (1998a) reported that the proportion of radio-tagged fish that remained within the MLSA was 0.36 and 0.33, respectively. Out of 87 northern pike in Minto Flats radio-tagged in fall 1987, Burkholder and Bernard (1994) determined that 16 (18%) fish overwintered in the Goldstream Creek drainage, with all but one of those individuals doing so within the current bounds of the MLSA. As was observed in prior studies in Alaska, once present at overwintering locations, radio-tagged northern pike displayed restricted movements over the winter (Hallberg 1984; Behrends and West 1987; Taube and Lubinski 1996; Roach 1998a; Joy and Burr 2004). Telemetry studies conducted outside of Alaska have shown mixed results regarding winter movements. For example, in both a natural lake and a nearby reservoir in Denmark, Jepsen et al. (2001) reported that radio-tagged northern pike had greater winter movements than those in summer. Koed et al. (2006) also reported similar results from a nearby

Danish lowland river. However, none of the water bodies in the studies conducted by Jepsen et al. (2001) or Koed et al. (2006) were subject to winter ice cover. Cook and Bergersen (1988) and Kobler et al. (2008a) both observed reduced winter movements of northern pike, but their study lakes (a mesotrophic reservoir in Colorado and a lowland German lake, respectively) were subject to winter ice cover. In contrast, Diana et al. (1977) did not observe a change in northern pike movements between winter and summer months, but only had a small sample size ($N = 9$) of acoustic-tagged northern pike. However, inferences drawn from these studies are limited because methods and habitat types varied and the northern pike in the aforementioned studies were not subject to an extended period of winter ice cover.

Radio-tagged northern pike in wetland and river complexes in the Tanana and Yukon River drainages of Alaska have been observed to make similar choices of overwintering locations. Fish typically concentrate into specific areas, and researchers have hypothesized that dissolved oxygen levels influence overwintering locations (Behrends and West 1987; Taube and Lubinski 1996; Chythlook and Burr 2002; Joy and Burr 2004; Scanlon 2006). Adult northern pike are able to detect low dissolved oxygen concentrations and some individuals will move to avoid those areas once levels get below 3-4 $mg \cdot L^{-1}$ (Casselman 1978; Headrick and Carline 1993). Much of the MLSA is shallow in depth (< 3 m) and is impacted by declines in water levels that typically occur in conjunction with freeze-up. In the MLSA, water levels have been observed to decline 1-2 m in winter (Roguski 1967). Oxygen concentrations in water bodies also typically decline once ice cover has formed, sometimes quite rapidly (as much as 80%) within several days of freeze-up (Whitfield and McNaughton 1986). Factors that regulate dissolved oxygen concentrations under the ice in lentic waters include reduced re-aeration, lower photosynthesis due to low water temperatures and reduced light levels, consumption of oxygen by the decomposition of organic materials, duration of ice cover, and an increase in the proportion of poorly oxygenated groundwater that contributes to the water body (Schreier et al. 1980; Robarts et al. 2005). Very low levels of dissolved oxygen (< 1 mg·L^{-1}) have been measured in various locations in the MLSA and Minto Flats (Roguski 1967; Cheney 1972; Hallberg 1984). Within the MLSA, shallow under-ice water depths (0.33-1 m) have been recorded, and some areas, including the outlet into Goldstream Creek, may also completely freeze to the bottom (Roguski 1967; Cheney 1972; Hallberg 1984). However, several locations within Minto Flats have consistently shown higher winter dissolved oxygen levels (8-2.5 mg·L^{-1}), including the reach of the Chatanika River utilized for overwintering by radio-tagged northern pike in the current study (Cheney 1972; Hallberg 1984). Previous telemetry studies of northern pike in Minto Flats have recorded fish overwintering in these areas which had higher levels of dissolved oxygen (Burkholder and Bernard 1994; Roach 1998a).

The differences between overwintering location choice by northern pike between the current study and previous studies may be due to long-term change in the availability of suitable overwintering habitat in the MSLA. This change in winter habitat may be related to the documented decline in the size and number of closed-basin water bodies in low lying areas across interior Alaska. From the 1950s until the early 2000s, closed-basin water bodies in Minto Flats declined in area by 25% and in number by 36% (Riordan 2005; Riordan et al. 2006). Riordan et al. (2006) concluded that the reduced surface area and number of closed-basin water is reflective of large-scale changes occurring in low lying wetland areas due to a lowering of the water table. Reduced water table elevations could result in lower surface water elevations, especially during winter when groundwater, which is low in dissolved oxygen, is the primary water source. In a study of two rivers in the Yukon Territories, Canada, severe dissolved oxygen depletions in winter were attributed to groundwater inputs, with low levels of dissolved oxygen increasing their contribution to stream flow in winter when surface inputs were greatly reduced (Schreier et al. 1980). Measurements taken from groundwater flowing into the Chena River near Fairbanks, Alaska, showed dissolved oxygen levels near 0.0 $mg \cdot L^{-1}$ at most sites (Hinzman et al. 2000). In addition, Goldstream Creek once was the inlet channel into the MLSA. Between 1929 and 1952, deposition of sediment created by placer gold mining operations in the upper reaches of Goldstream Creek changed Upper Minto and Big Minto Lakes from deep, clear waterbodies to their current shallow, eutrophic state. Due to aggradation, the channel of Goldstream Creek migrated west of the MLSA to its current location (Shepherd and Matthews 1985). The shallow water depths in the MLSA could allow a small reduction in winter water depth to have a significant impact on overwintering habitats for northern pike and increase the risk of a winterkill event. Suggested characteristics of waterbodies that are at risk of winterkill are those that have little or no inflow, shallow (< 3 m) depths, extensive snow and ice cover, and abundant aquatic macrophyte production (Nickum 1970; Guenther and Hubert 1991).

Migration of potential prey species out of the MLSA may also impact overwintering habitat choices by adult northern pike. Bregazzi and Kennedy (1980) reported that most migrations of northern pike were associated with shallow water regions and suggested that those distributions were based on prey availability. Diet samples collected from northern pike in Minto Flats by Alt (1969) and Cheney (1972) indicated that least cisco, humpback whitefish, and small northern pike were the primary vertebrate food items consumed by adult northern pike, with diet samples collected after freeze-up in early winter being comprised of approximately 75% northern pike. A review of dissolved oxygen requirements of northern fish species by Barton and Taylor (1996) determined that whitefish *Coregonus spp.* require dissolved oxygen levels > 2 mg·L^{-1}. Dissolved oxygen levels in much of the MLSA are likely below this threshold for much of the winter season. A telemetry study of humpback whitefish indicated that they migrated from the MLSA in late summer and fall and did not return until the next spring (Dupuis and Sutton 2014). While small northern pike are more tolerant than larger individuals of low dissolved oxygen levels that would occur once ice cover has formed, there would also be a corresponding reduction in the density of submerged macrophytes and a loss of littoral habitat due to ice formation. These habitats are used by smaller northern pike as cover and protection from predation (Inskip 1982; Holland and Huston 1984). Without adequate cover, smaller northern pike would face increased risk of cannibalism, especially when the abundance of alternative prey species is reduced (Grimm 1981; Bry et al. 1992; Nilsson and Brönmark 2000). I hypothesize that many, if not all, of the available prey fishes migrate from the MLSA for winter once habitat changes likely compressed the availability of suitable areas for survival. Consequently, adult northern pike also exhibit similar movement patterns. Potential prey species and adult northern pike that inhabit the MLSA in summer depart that area in early winter because the fitness benefits of migration (i.e., greater food availability, higher quality overwintering habitat) relative to the energetic cost of migration are greater than the fitness of a non-migratory life-history strategy.

During the 2008 and 2009 springs, not all newly radio-tagged northern pike in the Chatanika River returned to the MLSA for spawning and summer feeding. These fish were detected in locations in the lower Tolovana River and in the wetland/lake complex near Minto Village. These observations provide additional support to the conclusions of Holmes and Burkholder (1988) that the majority of northern pike in Minto Flats belong to one of two geographic subpopulations whose delineations are based on the general area of Minto Flats utilized to overwinter (lower Tolovana River area or Chatanika River). Roach (1998a) concluded that there was high, but not complete, site fidelity of northern pike to spawn in the MLSA in successive study years, with the proportion of radio-tagged northern pike returning to the MLSA for spawning between years at 0.68 (SE = 0.07) from 1995-1996 and 0.79 (SE = 0.08) from 1996-1997. The current study also documented that radio-tagged northern pike that utilized the MLSA in the open-water season displayed high spawning site fidelity between years, with 93% of the radio-tagged fish having spawned in the MLSA in 2008 and returned to spawn in 2009. A mark-recapture experiment in Kabetogama Lake, Minnesota, showed that only 1.3 to 4.8% of the northern pike marked at two different spawning sites were recaptured at a different spawning site the following three springs after being marked and the annual geographic ranges of both northern pike groups overlapped outside of the spawning season (Miller et al. 2001). Spawning site fidelity has also been documented for other esocids, such as muskellunge *Esox masquinongy* (Crossman 1990; Jennings et al. 2011).

Previous telemetry studies on northern pike have described the timing of migration between the overwintering area of the Chatanika River and the MLSA between March and May (Burkholder and Bernard 1994; Roach 1998a), with peak passage into the MLSA occurring between late April and early May (Roach 1998a). Similar timing of movements between overwintering and spawning areas has been observed for populations of northern pike in other interior Alaskan wetlands associated with flowing waters (Taube and Lubinski 1996; Chythlook and Burr 2002; Joy and Burr 2004). In the current study, northern pike were visually observed passing upstream in Goldstream Creek into the MLSA during late April and early May 2008 through the ice-free margins along the shoreline. Fish were also observed in the ice-free margins at the edges of some of the waterbodies within the MLSA (P. Joy, ADF&G, personal communication). These observations coincided with the peak upstream passage as recorded by the stationary tracking station located on Goldstream Creek below the entrance into the MLSA. Priegel and Krohn (1975) observed that movement of northern pike to spawning areas in a Wisconsin lake coincided with ice break-up. Koed et al. (2006) noted a significant increase in the activity of radio-tagged northern pike in a lowland Danish river between mid-March and mid-May, which coincided with spawning, even though those fish were not subject to overwinter ice cover and did not make major shifts in distribution between seasons. Some radio-tagged female northern pike in the Koed et al. (2006) study were also observed to make distinct longer range movements for spawning, even though suitable spawning habitat was available nearby to those fish.

The lack of movement of radio-tagged individuals in or out of the MLSA during the summer season observed in the current study was in contrast to the results of earlier studies which recorded up to 22% of the radio-tagged fish exiting the study area during the summer (Burkholder and Bernard 1994; Roach 1998a). This lack of movement out of the MLSA may be partially attributed to the generally higher than normal water levels observed in Minto Flats during both summers of the current study. Higher than normal water levels could potentially alleviate density-dependent factors on movement and distribution, which would cause northern pike to disperse from the area. Nilsson (2006) suggested that avoidance of intraspecific competition is an important contributing factor to the spatial distribution of northern pike. In a review of 71 studies that included 66 fish species, Woolnough et al. (2009) concluded that fish tend to exploit a greater proportion of an available waterbody as waterbody size increases. As such, during periods of higher water levels (as were observed during periods of this study) and at significantly reduced population levels (which also occurred during this study; the ≥ 400-mm FL northern pike abundance estimates for the MLSA in 2008 were 16,045 fish and 25,227 fish in 2003), density-dependent factors may have played a less significant role in determining the distribution and movements of northern pike inhabiting the MLSA (Scanlon 2006; Joy 2009). In addition, significant numbers of northern pike radio-tagged in this study were recorded utilizing areas within the MLSA that were outside of the traditional mark-recapture abundance experiment area (study area-B) but were within the expanded area utilized in 2008 (study area-A). These observations were consistent with the results of the 2008 abundance estimate for northern pike within the MLSA, which estimated 16,045 northern pike ≥ 400-mm FL in the expanded mark-recapture area as compared to 9,854 fish in the smaller historical study area. Based on those observed distributions, prior abundance estimates that only utilized study area-A, were likely biased low, especially if completed during periods of high water.

Daily movement rates of radio-tagged northern pike within the MLSA were greatest in May 2008 and 2009, which was likely related to spawning. During a capture-recapture experiment that took place in late May and early June 2008, ADF&G staff observed that spawning was completed by the end of the first week of June (P. Joy, ADF&G, personal communication). The greater movement rates observed in May of both study years, when spawning was taking place, are in agreement with observations by Cook and Bergersen's (1988) observations that the highest annual activity rates of radio-tagged northern pike were associated with the spring spawning period. Following spawning in both years, movement rates of radio-tagged northern pike in the MLSA followed a similar pattern as those in a Scottish loch described by Lucas (1992), with reduced post-spawning movement rates during June and July. Overall mean daily movement rates observed during the open-water season in the current study were comparable to mean movement rates of radio-tagged northern pike (20.4 $m \cdot h^{-1}$) observed by Kobler et al. (2008a) in northeastern Germany.

Movement rates not only varied by month, but also by water temperature. However, I determined that the inclusion of water temperature did not increase the predictive power of the mixed-effects model results. Other researchers have generally found that northern pike movements had either a positive relationship with water temperature or no significant relationship. Northern pike movements in a Danish reservoir were not related to water temperature; however, there was a positive relationship in water temperature with movements of northern pike present in a nearby lake (Jepsen et al. 2001). In two shallow lakes in the Rocky Mountain Arsenal, Colorado, Rogers and Bergersen (1995) observed widely ranging water temperatures during a five-month period, even though northern pike movements were unchanged during that same time period. In contrast, Diana (1980) and Cook and Bergersen (1988) found that swimming velocities of northern pike were higher in summer than winter. Northern pike have also been shown to exhibit movements to cooler refugia when temperatures are above 20°C (Headrick and Carline 1993). These field studies are supported by the findings of Casselman (1978), who found that in laboratory studies northern pike swim shorter distances in colder water. In this study, the coolest water temperatures were recorded during the pre-spawning and spawning periods (May) and in early fall as fish begin to stage for movements to winter locations (August) and these periods coincided with maximum observed movement rates.

Length and movements of northern pike have generally been reported to be positively related (Jepsen et al. 2001; Masters et al. 2005; Vehanen et al. 2006; Kobler et al. 2008a). While the current study was in agreement with these observations, daily movement rates did vary widely between individuals. As was also observed in the current study, Masters et al. (2005)

found that similar-sized individuals can have wide variations in movement rates. Larger individuals have greater food demands, which can lead to increased foraging activities. Further, with their increased body size, there is a lower predation and cannibalism risk, both of which facilitate greater movement rates (Grimm and Klinge 1996; Kobler et al. 2008a).

The movements and distributions of northern pike described in this study pertain to the population of fish present in the MLSA of Minto Flats during the open-water season. Northern pike in other areas of the greater Minto Flats wetland complex may or may not have similar movement and distribution patterns due to different habitat availability. The wetlands associated with lower Tolovana River drainage portion of Minto Flats allow northern pike more direct access to larger lotic water bodies (e.g., Tolovana River, Grassy Slough, Swanneck Slough, and Tanana River), which provide an additional habitat type that is not as readily available to the fish that inhabit the MLSA. Waterbody size and shape has been shown to affect movements of many fish species and, as such, one can hypothesize that the differing availability of various habitat types can have an effect on the movements and distribution of northern pike in different areas of Minto Flats (Woolnough et al. 2009).

It is also possible that the population structure and relative abundance of northern pike inhabiting other areas of Minto Flats is different than that of the MLSA. In 2009, 40 northern pike were radio tagged in the Chatanika River overwintering area, with 17 of these fish ≥ 655-mm FL, which is considered to be “preferred sized” or larger for sport fishing (Gabelhouse 1984). For northern pike ≥ preferred size, 7 (41%) fish did not migrate to the MLSA for spawning and summer feeding, but were instead located in the lower Tolovana River drainage portion of Minto Flats. None of the 23 remaining northern pike radio tagged at the same time and location that were ≤ 655 mm were detected migrating to locations outside of the MLSA.

This observation is corroborated by a radio-telemetry research project completed in 1987 which recorded that 52% of northern pike tagged near Minto Village and 17% of fish tagged in the lower Tolovana River utilized the same reach of the Chatanika River as fish from the MLSA for winter (Holmes and Burkholder 1988). Length-frequency sampling completed by Holmes and Burkholder (1988) concluded that the area of Minto Flats that included the lower Tolovana River and Swanneck Slough tended to support northern pike with a larger size composition than other areas. More recent observations indicate that there are greater numbers of large (≥ 750-mm FL) northern pike in this area relative to the MLSA (A. Gryska, ADF&G, personal communication). Although population structure varies annually, the similarity in the length distribution of northern pike radio tagged among years in the current study supports that annual comparisons for these fish are valid. The mean FL of radio-tagged fish for which location data was collected during the 2008 and 2009 field seasons (576 mm and 586 mm, respectively), was similar to the sizes of northern pike radio-tagged by Roach (1998a) and those sampled during a capture-recapture experiment completed in the MLSA in 2008 (Joy 2009).

While these results have provided a better understanding of this subset of the larger northern pike population inhabiting the Minto Flats/Chatanika River wetland complex, the same information detailed by my research is still lacking for remaining portions of the area which also contribute to the sport and subsistence fisheries. I recommend that future research on northern pike in Minto Flats should include investigations of seasonal movements, with an emphasis on those northern pike that do not utilize the MLSA during the open-water season to document important spring spawning, summer feeding, and overwintering areas where the potential for overharvest could occur. This study provided further documentation of MLSA summer resident northern pike utilizing the Chatanika River for overwintering. Considerations should be made regarding the feasibility of estimating abundance for northern pike that utilize that area. Population structure data and abundance estimates of northern pike inhabiting areas of the Minto Flats/Chatanika River wetland complex other than the MLSA are also lacking and/or outdated. Examination of the population segment that typically inhabits the lower Tolovana River drainage portion of Minto Flats will allow for direct comparisons between those fish and individuals that utilize the MLSA. Due to the limited number and size of known overwintering areas, there is also an opportunity to better document and characterize those habitats. This information, coupled with a better understanding of seasonal movements, will provide a more complete account of life history and seasonal movements of northern pike over the entirety of the Minto Flats wetland complex as well as provide for better informed management choices.

Management Implications

Northern pike in Minto Flats and the MLSA are harvested in both an open-water season sport fishery and a year-round subsistence fishery. One of the primary management challenges for the northern pike inhabiting the MLSA is their vulnerability to harvest during the winter subsistence fishery. This study and previous research has strongly demonstrated that these fish exclusively overwinter in a 26-km reach of the Chatanika River from its confluence with Goldstream Creek upstream to the Murphy Dome Road access point (Hallberg 1984; Burkholder and Bernard 1994; Roach 1998a). Burkholder and Bernard (1994) and Roach (1998) also reported that approximately 9-35% of the radio-tagged fish in their studies overwintered upstream of the Murphy Dome Road access point. While the spatial distributions of overwintering northern pike in the current study remained relatively constant between years, Roach (1998a) noted longitudinal (upstream or downstream) shifts in the spatial distribution of overwintering fish in the Chatanika River between winters.

The overwintering area within the Chatanika Harvest Area (CHA; Chatanika River upstream of its confluence with Goldstream Creek to the Fairbanks Non-Subsistence Area Boundary near the Murphy Dome Road access point) is easily reached and targeted by subsistence fishers from both rural (e.g., Minto Village) and urban (e.g., Fairbanks) areas. Sport fishing for northern pike in Minto Flats is closed by regulation from 15 October through 31 May. However, the subsistence fishery does allow for harvest of northern pike in Minto Flats year round. During winter months, the fish are typically captured by angling through the ice. From 2007-2013, reported harvests of northern pike in the Tolovana River drainage subsistence fishery (including the Minto Flats area) ranged between 100 and 1,837 fish annually (Commercial Fisheries Division, ADF&G, unpublished data). In 2013 and 2014, 87 and 81%, respectively, of reported northern pike harvest in the Tolovana River drainage subsistence fishery occurred within the CHA (Commercial Fisheries Division, ADF&G, unpublished data). Summer sport fishery harvests within Minto Flats ranged between 258 and 1,712 fish over the same time period (ADF&G 2015). The combined mean annual estimated harvests of northern pike by sport and subsistence users from 2007-2013 was 1,294 fish (ADF&G 2015; Commercial Fisheries Division, ADF&G, unpublished data). The maximum allowable harvest of northern pike is 3,209 fish when the 20% maximum exploitation rate for all users stipulated by the sport and subsistence fishery management plans (Minto Flats Northern Pike Management Plan {Sport}. Alaska Administrative Code, section 5 AAC 74.044.; Minto Flats Northern Pike Management Plan {Subsistence}. Alaska Administrative Code, section 5 AAC 01.244) is applied to the most recent abundance estimate of 16,045 northern pike > 400-mm FL (completed in 2008; Table 3) for the Minto Flats index area (which includes the MLSA). Thus, recent harvest levels have not exceeded the allowable threshold, thereby alleviating any conservation concerns under the current management plans.

While harvests in both the sport and subsistence fisheries are generally below the maximum exploitation rate allowed by their respective management plans in 2007 and 2008, harvests still reached levels which triggered fishery restrictions. Due to a harvest of over 1,500 northern pike in the winter subsistence fishery in 2007, the ADF&G Division of Commercial Fisheries closed that fishery by emergency order (3-NP-UY-01-07) on 23 February 2007. As such, prior to the opening date of the sport fishery, the ADF&G Division of Sport Fish also issued an emergency order (No. 3-NP-01-07) that reduced the summer season sport fishing daily bag and possession limits in Minto Flats to two fish per day, with only one fish of which could be ≥ 762 mm (30 in) in length. In 2008, ≥ 1,200 northern pike were harvested in the winter subsistence fishery and, as such, the Division of Sport Fish again issued an emergency order (No. 3-NP-01-08) prior to the start of the sport fishing season that had similar restrictions as the emergency order issued in 2007. With such a high proportion of the winter northern pike subsistence fishery users prosecuting overwintering fish from the MLSA in a relatively limited reach of the Chatanika River, there exists the potential for overharvest or detrimental effects on the size and age structure and, by default, the sex structure of the population to occur. During the January 2016 Alaska Board of Fisheries meeting in Fairbanks, a user-submitted proposal was put into regulation which closed a portion of the Chatanika River to subsistence fishing from its confluence with Goldstream Creek to a point 4.83 km (3 mi) upstream to protect MLSA summer resident northern pike over-wintering in the Chatanika River. Overwintering location data collected by this research project was utilized to construct the proposal.

Table 3. Estimated northern pike abundance in the Minto Lakes Study Area (MLSA), 1987-1988, 1990-1991, 1996-1997, 2000, 2003, and 2008.

	≥ 400 mm (~16 in)		≥ 525 mm (~20 in)		≥ 600 mm (~24 in)	
Year	Abundance	SE	Abundance	SE	Abundance	SE
1987	–	–	11,257	3,075	–	–
1988	–	–	13,233	3,143	–	–
1990	–	–	27,418	6,800	–	–
1991	–	–	17,633	5,480	–	–
1996	23,850	7,799	20,695	6,765	7,616	883
1997	16,547	1,754	14,639	1,552	3,251	174
2000	–	–	–	–	5,331	1,152
2003	25,227	4,529	13,900	2,918	7,683	2,347
2008[a]	9,854	1,701	–	–	2,092	448
2008[b]	16,045	3,132			2,219	397

[a] Abundance estimate for Study Area-B waters (study area within MLSA that previous abundance estimates utilized).
[b] Abundance estimate for Study Area-A water (includes all of Study Area-B and additional areas).

Source: Burkholder (1989, 1990); Hansen and Burkholder (1992); Roach (1997, 1998b); Scanlon (2001, 2006); Joy (2009).

Detrimental effects to this concentrated population during winter could occur because of the tendency of anglers to harvest a proportionally greater number of large individuals from the population, either through size-selective fishing gear, high-grading practices (keeping only larger fish), and/or catch-and-release-induced mortality. Arlinghaus et al. (2008) determined that hook-and-line fishing gears can have a size-selective bias for larger northern pike if larger baits are utilized and that the use of natural baits (which is commonly used in the Tolovana River drainage winter northern pike subsistence fishery) will increase catch-and-release mortality. Creel surveys in Minnesota and Wisconsin indicated that anglers are more likely to retain captured northern pike when fishing through the ice (Pierce et al. 1995; Cook and Younk 1998; Margenau et al. 2003). Cook and Younk (1998) also found that anglers in Minnesota were less likely to release larger northern pike, with approximately 85% of the fish released being less than 508 mm. Large northern pike (> 748-mm FL) are typically females, and fecundity increases with body size (Inskip 1982; Craig 1996). Thus, targeting and removing larger individuals from a population could negatively affect recruitment. It is commonly known among recreational anglers that northern pike are very susceptible to angling through the ice. This was confirmed by Margenau (1987) in a small Wisconsin lake where they were able to capture radio-tagged northern pike through the ice with standard recreational fishing techniques when their locations were known. With a relatively small amount of angling effort (450 angler hours) in a shallow boreal lake in Ontario, anglers were able to remove 50% of the annual northern pike production (Mosindy et al. 1987). As such, the winter subsistence fishery could be causing greater rates of mortality for smaller (< 500 mm) size classes and, at the same time, also remove the largest and most productive individuals from the population of northern pike overwintering in the Chatanika River. It is important to note that while the winter subsistence fishery likely harvests a high proportion of MLSA summer-resident individuals, the effects of this harvest are lessened because northern pike from other areas of Minto Flats also overwinter in the same area.

The results of this study will also be utilized by ADF&G to aid in the design and implementation of future mark-recapture population assessment experiments conducted within the MLSA. Researchers will now have more information with which they can use to guide experimental design changes and ensure current experimental assumptions are being met. The improved understanding of the seasonal migrations of northern pike into and out of the MLSA provided by this project can be used to ensure that assumptions of population closure are being met and additionally can be used to guide timing of sampling events. Open-water season distributions and movement rates of northern pike in the MLSA described by this project can be used to identify optimal sampling periods when catches and mixing of marked and unmarked fish will be maximized and can also guide the apportionment of sampling effort across the study area.

Obtaining adequate precision in a radio-telemetry study while minimizing study costs is a function of both the number of radio tags deployed and frequency and sampling events (telemetry surveys). Relative to the number of radio-tagged fish utilized in this study, we believe that the overall sample size was adequate because of the descriptive nature of the study objectives. Due to the compressed timing of the spring migration into the MLSA, fewer radio-tagged fish would have likely provided similar migratory timing information. In contrast, description of the protracted fall outmigration would have benefited from additional radio-tagged fish. We believe that summer northern pike distributions within the MLSA were adequately represented by the current radio-tag sample sizes used in this study. Using fewer radio-tagged fish could have potentially resulted in missing or under-representing fish use of lower density areas (i.e., areas or waterbodies in this study, in which only 1-2 radio-tagged fish were present or areas that were only used infrequently). However, the number of daily surveys could have been reduced significantly to as few as three surveys in each summer temporal sub-period (i.e., May, June, July, August) with little loss in the precision of the spatial distribution data collected. Fewer radio-tagged fish would have also provided an acceptable representation of the overwintering distribution because all fish present in the MLSA during summer overwintered in one distinct area. For future studies in this area or other areas, sample sizes and experimental designs should be based upon meeting the most important research objectives.

The current study described seasonal movements of northern pike that inhabit the MLSA portion of Minto Flats in greater detail than has been conducted previously. Fishery managers will be able to use the collected data when considering the impacts of future management decisions for this important sport and subsistence fishery. The current joint sport and subsistence fishing management plans that direct ADF&G's management of the Minto Flats northern pike fishery only allow for area-wide (Minto Flats wetland complex) management actions (i.e., when harvest in the Tolovana River drainage subsistence fishery from the confluence of Goldstream Creek and the Chatanika River upstream to the Fairbanks Non-subsistence Boundary is > 750 fish, the sport fishery daily bag limit will be reduced from 5 to 2 fish per day in the lakes and flowing waters of Minto Flats). However, if increased temporal or geographic specificity of management actions is needed in the future, the movement and distribution data collected by my study can be used by ADF&G to craft and submit such proposals to the Alaska Board of Fisheries or provide guidance as they consider proposals pertaining to northern pike in Minto Flats submitted by the general public. The collected data can also be used to estimate when and to what degree the summer resident northern pike population of the MLSA is persecuted by the summer sport and winter subsistence fisheries. In addition, these data can be used by ADF&G to make general conclusions and assumptions about northern pike inhabiting other shallow wetlands in Alaska as they design research projects or consider potential management actions.

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