THE ECOLOGY OF WESTERN PAINTED TURTLES (*CHRYSEMYS PICTA BELLI*) IN A NORTHERN CANADIAN RESERVOIR

BY

NICOLE REBECCA CELIA BASARABA
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Thesis examining committee:

Karl Larsen (PhD), Professor and Thesis Supervisor,
Natural Resource Sciences, Thompson Rivers University

Purnima Govindarajulu (PhD), Adjunct Faculty Member,
Natural Resource Sciences, Thompson Rivers University

Tom Dickinson (PhD), Dean of Science, and Associate Professor,
Biological Sciences, Thompson Rivers University

Christine Bishop (PhD), External Examiner
Research Scientist, Environment Canada

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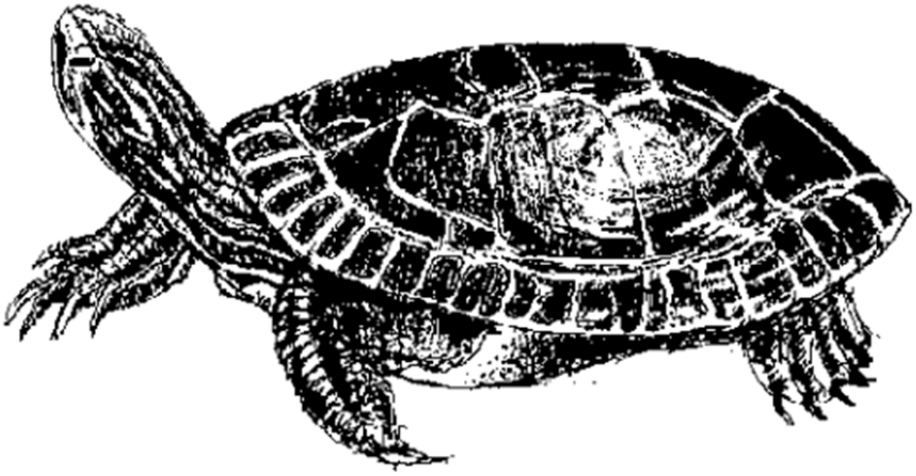

Thesis Supervisor: Professor Karl W. Larsen (PhD)

ABSTRACT

Impoundment of water by hydroelectric reservoirs and resulting fluctuations in water levels (drawdown zone) may have significant impacts on the surrounding ecosystems. For herpetofauna that live in cold climates, such human-induced alterations may amplify the difficulties in coping with the environment. My study explored the ecology of an extreme northern population (Revelstoke, British Columbia, Canada) of western painted turtles (WPT; *Chrysemys picta bellii*) inhabiting a reservoir that constantly fluctuates due to hydroelectric operations. The potential challenges this environment poses include inundation of nesting sites, increased winter mortality due to water level changes, and changes in the availability of aquatic habitat. I used radio telemetry and mark-recapture to identify where turtles were nesting and overwintering, and to assess demographics and turtle behaviour in relation to the changing water levels. My data suggest that adults and juveniles of both sexes used and overwintered in the drawdown zone. Nest inundation as a result of reservoir operations did not appear to be a significant threat to the animals as all detected nests lay above the high-water mark. Similarly, no incidents of turtle mortality were directly attributable to reservoir operations. Changes in water levels did affect habitat availability: areas in which turtles were located during early spring were subsequently lost as water levels rose, while flooding in other areas created seasonal, suitable habitat for turtles that otherwise was not accessible. Modelling turtle response to water levels, water temperature, and season suggested that changes in water levels did not significantly impact behaviour as measured. Appropriate management for this species and other semi-aquatic species that reside within drawdown zones is complex, given the reliance on both terrestrial and aquatic habitat, the life cycles of the species, movement, changing water levels, and sub-zero winter temperatures. This research provides a baseline for understanding the ecology of turtles in dynamic northern environments.

Keywords: Western painted turtle, *Chrysemys picta bellii*, northern, hydroelectric, fluctuating environment, species management

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CHAPTER ONE

INTRODUCTION TO RESERVOIR HABITATS, PERIPHERAL SPECIES, AND PAINTED TURTLE ECOLOGY

Reservoirs and Wildlife Populations

The impoundment and control of water has been used since the beginning of civilization for irrigation, flood control, urbanization, waste disposal and water supply (Baxter 1977; Malmqvist and Rundle 2002). As a management tool, it has expanded to include flow rate control, recreation, and energy harnessing (Baxter 1977). Although water systems are naturally dynamic, the ever increasing pursuit and demand to generate hydroelectric energy can have significant impacts on the surrounding environment (Malmqvist and Rundel 2002). Water levels in reservoirs fluctuate for various reasons including the release of water for downstream requirements such as drinking water, habitat, management, irrigation, flood control, recreation, and power generation. Furthermore, waters levels within each reservoir can fluctuate seasonally based on precipitation, temperatures that affect the rate of snow melt, and demands for power or irrigation.

Wildlife species occupying water bodies subject to flow regulation may be particularly susceptible to abrupt changes to habitat type and availability. Both aquatic and terrestrial species may be impacted in this manner; however, there is a relatively limited amount of research dealing with the ecology and responses of wildlife due to water impoundment (Rosenberg *et al.,* 1997; Reese and Welsh 1998; McAllister *et al.,* 2001; Greathouse *et al.,* 2006; Limpus *et al.,* 2006; Boyle 2012). For the flora and fauna that live in cold climates these human-induced alterations may affect their ability to tolerate and endure an already-harsh environment.

Hydroelectric developments create environments where water levels fluctuate, generating significant changes to animal habitat. Research has shown that reservoirs, weirs, and independent power projects can increase mercury concentrations in fish (Bodaly *et al.,* 2007), promote the establishment of invasive species (Light 2003), as well as alter water temperatures, oxygen levels, and flow patterns. This in turn can strand fish, dewater or flood spawning/nesting habitat, change water depth, and alter habitat for both aquatic and terrestrial organisms (McAllister *et al.,* 2001; COSEWIC 2006; Greathouse *et al.,* 2006; Clark *et al.,* 2009; Irvine *et al.,* 2008). Changes in flow patterns have indirect effects upstream and downstream by altering nutrient flow patterns, and sedimentation (McAllister *et al.,* 2001; Greathouse *et al.,* 2006; Clark *et al.,* 2009). Some operations create barriers between channels and water bodies thereby blocking the movement of animals, such as spawning fish, amphidromous shrimp, algal and invertebrate communities (Rosenberg *et al.,* 1997; Freeman *et al.,* 2003 Antonio *et al.,* 2007). These blockages can decrease populations or ultimately eliminate certain habitat types (Reese and Welsh 1998; Freeman *et al.,* 2003; Greathouse 2006).

Anthropogenic changes that affect wildlife habitat (via reservoirs, or any other process) may be particularly felt by peripheral populations of animals (Arthington *et al.,* 2006; Irvine *et al.,* 2009). Peripheral populations can be defined two ways; the first applies to populations that are geographically separated or disjunct, the second where populations are ecologically marginal. Such populations experience difference environmental influences such as sub-optimal or marginal habitats. Geographically peripheral populations can also be ecologically marginal populations. Peripheral populations have smaller population sizes, and are more susceptible to catastrophic events in comparison to other populations occupying the core of their range (Lesica and Allendorf 1995). However, peripheral populations are known to genetically diverge from core populations due to added selection pressures, enabling them to inhabit environments with harsher conditions (Safriel *et al.,* 1994; Lesica and Allendorf 1995). Thus, peripheral populations may become more adapted to living in transitional environments, and playing an important role in the survival of the species or even the expansion of its range (Lesica and Allendorf 1995; Frazier et al 2006). More importantly, these species may be better able to cope with anthropogenic changes to the landscape. However, the combined impacts of natural environmental constraints and habitat alteration on peripheral populations needs to be more fully explored (Lesica and Allendorf 1995).

One group of species that has attracted a reasonable amount of interest in terms of peripheral population ecology is herpetofauna (reptiles, amphibians and turtles). Herpetofauna are ectothermic organisms, and therefore are dependent on environmental conditions to regulate their body temperature and various other biological processes (Voituron *et al.*, .2002). The ecology and distribution of herpetofauna is dictated, to a large extent, by ambient conditions. Herpetofauna occupying extreme northern climates have evolved to cope with various environmental constraints such as relatively cool, short summers and long, cold winters. Through the use of behavioural and physiological adaptions, such as super cooling, freeze tolerance, and hibernation, these animals can then endure the limited time available to feed, grow and reproduce through trade-offs between growth and reproduction (St. Clair *et al.,* 1994; Storey and Storey 1996; Pfrender *et al.,* 2008; Voituron *et al.,* 2002; Shine 2005). Survival is dependent on their ability to tolerate the environment (Voituron *et al.,* 2002), including adaptability to changing landscapes and multiple stressors.

Northern turtle populations have been the focus of a number of ecological studies (Macartney and Gregory 1985; Ultsch *et al.* 1985; St. Clair *et al.* 1994; Litzgus *et al*. 1999; Carriére 2007; Greaves and Litzgus 2007; Yagi and Litzgus 2012). The Canadian landscape provides a good backdrop for this type of work, as 11 species of native freshwater turtles reach their northern limit in the country (SARA 2008). The limitation is due, at least in part, to the short summer growing season, mean ambient temperatures for egg incubation, and extreme winter temperatures (St. Clair and Gregory 1990; Costanzo *et al.,* 1995; Carroll and Ultsch 2007). Extensive research has focused on how these animals deal with the environmental constraints of cold weather, particularly in those species that range relatively far north, such as the painted turtle (*Chrysemys picta*; St. Clair and Gregory 1990; Costanzo *et al.,* 1995; Packard *et al.,* 2001; Willmore *et al.,* 2001; Packard and Packard 2004; Ultsch 2006; Rollinson *et al.,* 2008). Understanding how change in the habitats of these animals (and all other herpetofauna) influence ecology and life-history requisites are critical for developing effective management plans that encompass all parts of these animals' life cycles (Heppell and Crowder 1996; Heppell 1998).

Northern, freshwater turtle populations (and those at range peripheries) may be subject to the effects of water reservoirs, particularly the dynamic water levels created by many hydroelectric operations. Given that freshwater turtles rely on both aquatic and terrestrial environments to complete their life-history, the combined effect(s) of dealing with northern environmental constraints and those potentially brought on by reservoirs needs to be more fully explored. Turtles are long-lived species with low juvenile survival rates, and delayed sexual maturity in northern environments (Reese 1996; Reese and Welsh 1998; COSEWIC 2006). These factors can impede recovery from periods of high adult mortality and can cause cumulative impacts on northern turtles who deal with sub-zero temperatures, short growing seasons, and habitat loss and fragmentation. Enhancement and mitigation measures have been attempted to manage impacts from road mortalities, loss of nesting habitat, human disturbance, and nest predation (Macarteny and Gregory 1985; Maltby unpublished; Clarke and Gruein 2003, Lee 2011). Continued research on the ecology of northern turtles is needed to provide a better understanding of how these animals manage their environment and increasing human pressures, as well as what elements of their habitat may be critical to survival in northern climates.

Turtles and Reservoirs

Populations of northern freshwater turtles have a reliance on both terrestrial (nesting, basking) and aquatic (feeding, mating, hibernating) environments. Thus, there are a number of possible pathways by which these animals may be impacted by reservoir operations:

- seasonal or permanent change or loss in available habitat, and/ or the elimination of habitat types required by all or some segment of the population;

- loss of shoreline nesting habitat through generally higher year-round water levels, forcing females to travel further inland to find alternative sites to lay eggs, in turn, this may add to energy expenditure and risk of predation, both for adult females and newly-hatched nestlings returning to the water (COSEWIC 2006);

- seasonal or periodic inundation of nesting sites within the high and low water mark (also known as the drawdown zone): females may choose nesting sites that later on become inundated with rising waters, negating the reproductive effort;

- fluctuating water levels create, alter, or inundate habitat used for shelter, foraging, and basking;

- changes in water temperatures, particularly during winter hibernation; changes in winter water levels may expose submerged hibernating turtles to unexpected freezing temperatures as the animals lay dormant above or buried within the muddy substrates of ponds and lakes (Rollinson *et al.,* 2008);

- alteration of flow patterns and nutrient levels, creating changes in food production; and

- entrapment of individual turtles in outflow currents.

Despite the potential linkage between reservoir operations and impacts on freshwater turtle populations, relatively little study has been done to examine this relationship. Research on western pond turtles (*Clemmys marmorata*) in the Trinity

River in northwestern California revealed that the elimination of slow-moving waters through hydroelectric operations eliminated habitat for smaller turtles (juveniles and hatchlings), thereby skewing the age distribution towards adults (Reese 1996; Reese and Welsh 1998). Limpus *et al.*, (2006) found that during periods of high water release by the Fairbairn Dam (Central Queensland, Australia), turtles were becoming trapped by the current on the trash screens and drowning. The study recommended additional research to determine if turtle mortality was occurring only during high water and if reservoir operations caused barriers to movement. Aside from these two studies, the impacts of reservoirs on turtles have been virtually unstudied.

Study Species

Painted turtles (*Chrysemys picta*) are the one of the most northerly freshwater turtle species in the western hemisphere. The species consists of four subspecies (C.p. *marginata, picta, bellii, dorsalis*), with a distribution extending from New Mexico and Louisiana east to the Atlantic Ocean and west to the Pacific (Figure 1-1). In Canada, the species reaches its northern limits, with extreme northerly populations found near William's Lake and Revelstoke in the province of British Columbia.

Painted turtles are members of the Family Emydidae, a taxon that includes most of the world's omnivorous, freshwater turtle species. They are a medium-sized turtle with females tending to be larger than males. Their common name is derived from their cream to orange coloured plastrons, specifically the plastron of the subspecies *bellii* that can display bright orange and red colours, with a dark design through the centre that is present throughout all life stages (Figure 1-2a).

Painted turtles display a typical pond turtle life history with some notable exceptions (i.e. neonates can overwinter in the natal nest, and display freeze-tolerance; St. Clair and Gregory 1990; Costanzo *et al.,* 2004; Carroll and Ultsch 2007). Females and males in northern climates tend to be larger at sexual maturity then conspecifics in southern latitudes (St. Clair *et al.,* 1994). Within southern populations both male and females mature between the ages of four and five respectively, while in more northern climates male and female turtles reach maturity between 8-10 years and 12-15 years respectively (Ernst and Lovich 2009). However a study conducted by St. Clair *et al.*, (1994) comparing growth curves of southern and northern populations found that females were older at sexual maturity than their southern conspecifics, but males appeared to mature at a similar rate.

Courtship begins in early spring as the water warms and mating occurs in shallow waters; painted turtles have been known to also mate in the fall (Pearce and Avise 2001). When searching for nesting sites, female painted turtles can move up to 200 m or more from the shoreline (COSEWIC 2006; Ernst *et al*. 2009). They appear to choose their nesting sites based on an open canopy, slope, aspect, and drainage, with sites typically composed of patches of well-drained soil or sand along beaches, roadways, and fields facing south to south-west (Schwarzkopfa and Brooks 1987; COSEWIC 2006). Once a suitable site is located, the female digs a flask-shaped nest, 4 to 14 cm in depth, after voiding cloaca water on the chosen site. A female may lay anywhere from 1 to 23 eggs in a nest (average ~12); she then covers the nest and returns to the water, providing no post-hatchling care (Pearse and Avise 2001; COSEWIC 2006). The eggs incubate in the nest and hatch in late summer or fall of the same season. Newly-hatched painted turtles in the northern extent of their range, overwinter in their nest emerging the following spring (Packard *et al.,* 2002; Costanzo *et al.,* 2004; COSEWIC 2006). These northern neonates can remain in their natal nest because they are freeze-tolerant, being able to survive temperatures below -10 ˚C (Packard *et al.,* 2002). More southern conspecifics emerge from the nest the same year that they were laid, overwintering in the water.

In this study, I focused on the western painted turtle, the only native freshwater turtle found in the Canadian province of British Columbia. There are two disjunct populations in British Columbia and these are designated as the Pacific Coast Population and the Intermountain – Rocky Mountain Population units (COSEWIC

2006). The animals in the interior of the province are categorized as ‘special concern’ under both provincial and federal listings, in part because this population exhibits characteristics that make them particularly sensitive or vulnerable to human activities or natural events. The coastal population is considered “Red-Listed” by the province and “Endangered” by the federal government, as this population faces the imminent risk of extirpation or extinction (COSEWIC 2006; SARA 2008).

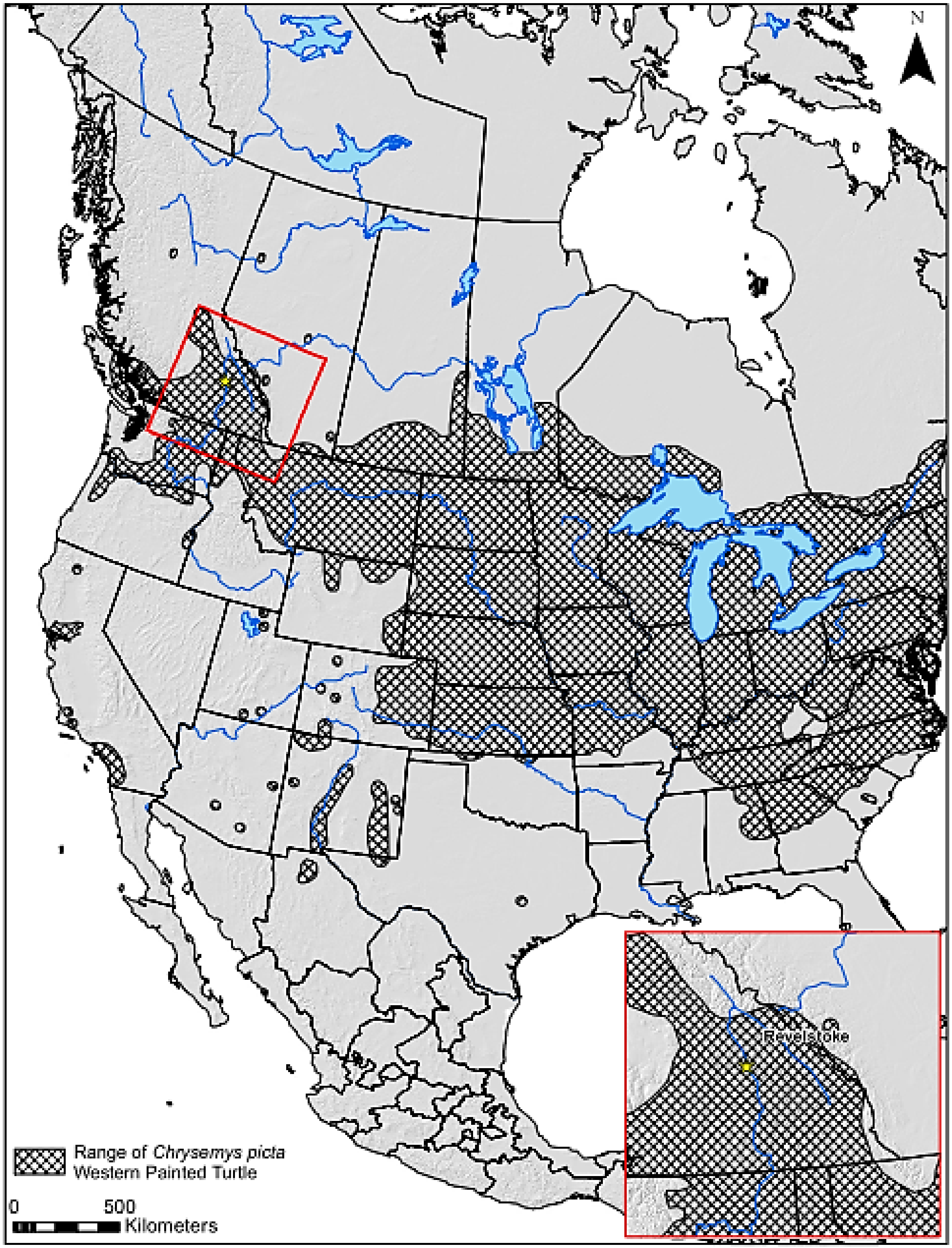

Figure 1-1 Western painted turtle (*Chrysemys picta bellii*) range map. Star indicates location of study site.

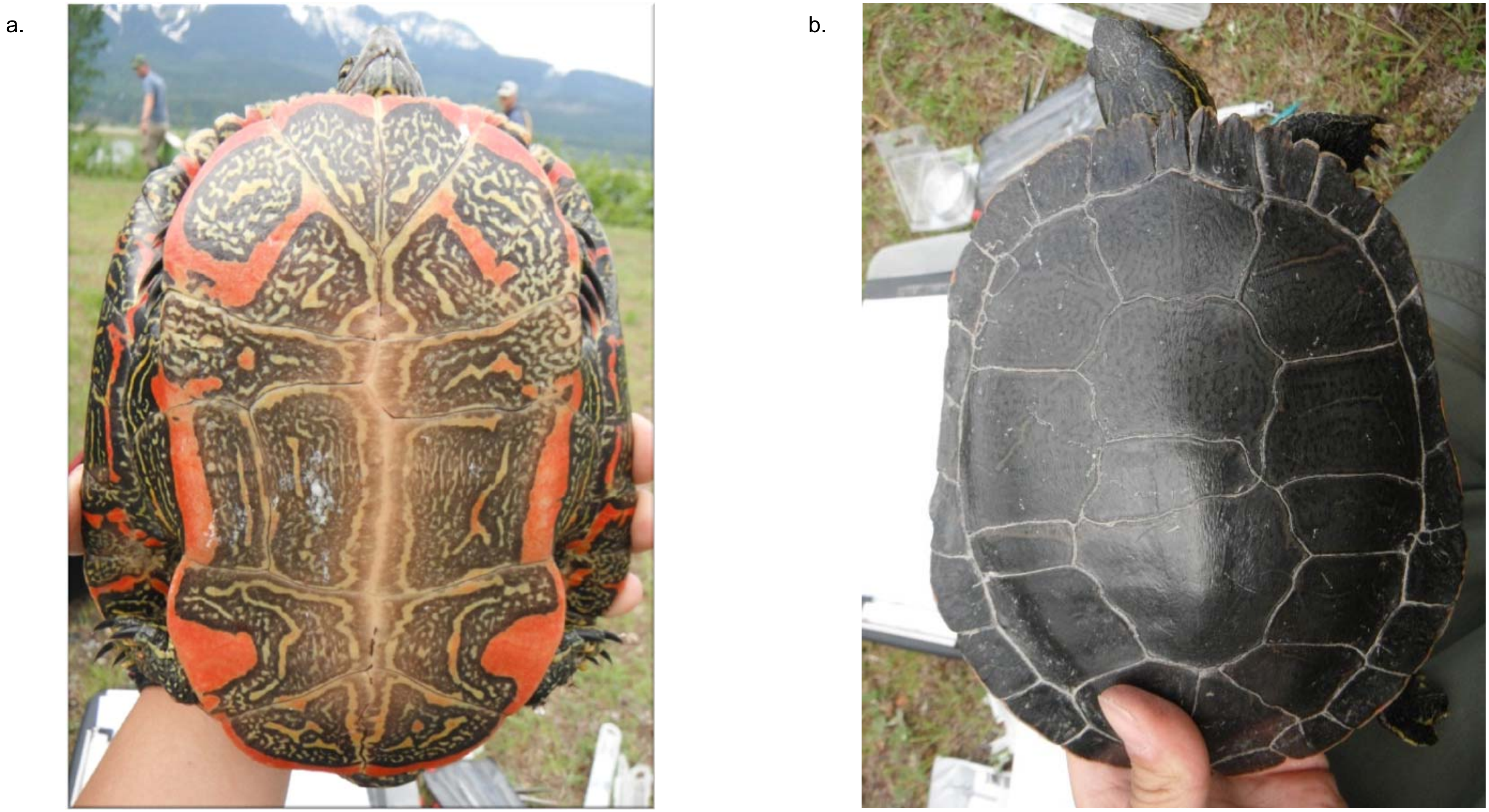

Figure 1-2 Western painted turtles (*Chrysemys picta bellii*). a. plastron profile and b. carapace profile (Photos by N. Basaraba)

Study Site

The Arrow Lakes Reservoir is a portion of the Columbia River that was modified in 1968 with the construction of the Hugh Keenleyside Dam near Castlegar, British Columbia, Canada. The reservoir itself is influenced from outflows of the Revelstoke Dam, constructed in 1984 approximately 20 km upstream of my study site. The Arrow Lakes reservoir lies within a region of the province that contains a unique ecosystem, namely one of the few inland temperate rainforests in the world (Goward and Spribilee 2005; Sanborn *et al.,* 2006). The region receives an average annual precipitation of 945.5 mm that mostly falls as snow, although precipitation can vary from year to year (Environment Canada 2012). Temperature and precipitation averages for the past 30 years and during the years of my study (2010 and 2011) are displayed in Figure 1-3. During the first year (2010) of my study, precipitation was below the 30 year average, except for the month of September when precipitation was higher than average. During 2011, precipitation appeared to be above average from January to August, but dropped below average for September and finished the year around the average levels. The average air temperatures for both years of my study were similar to the 30 year average.

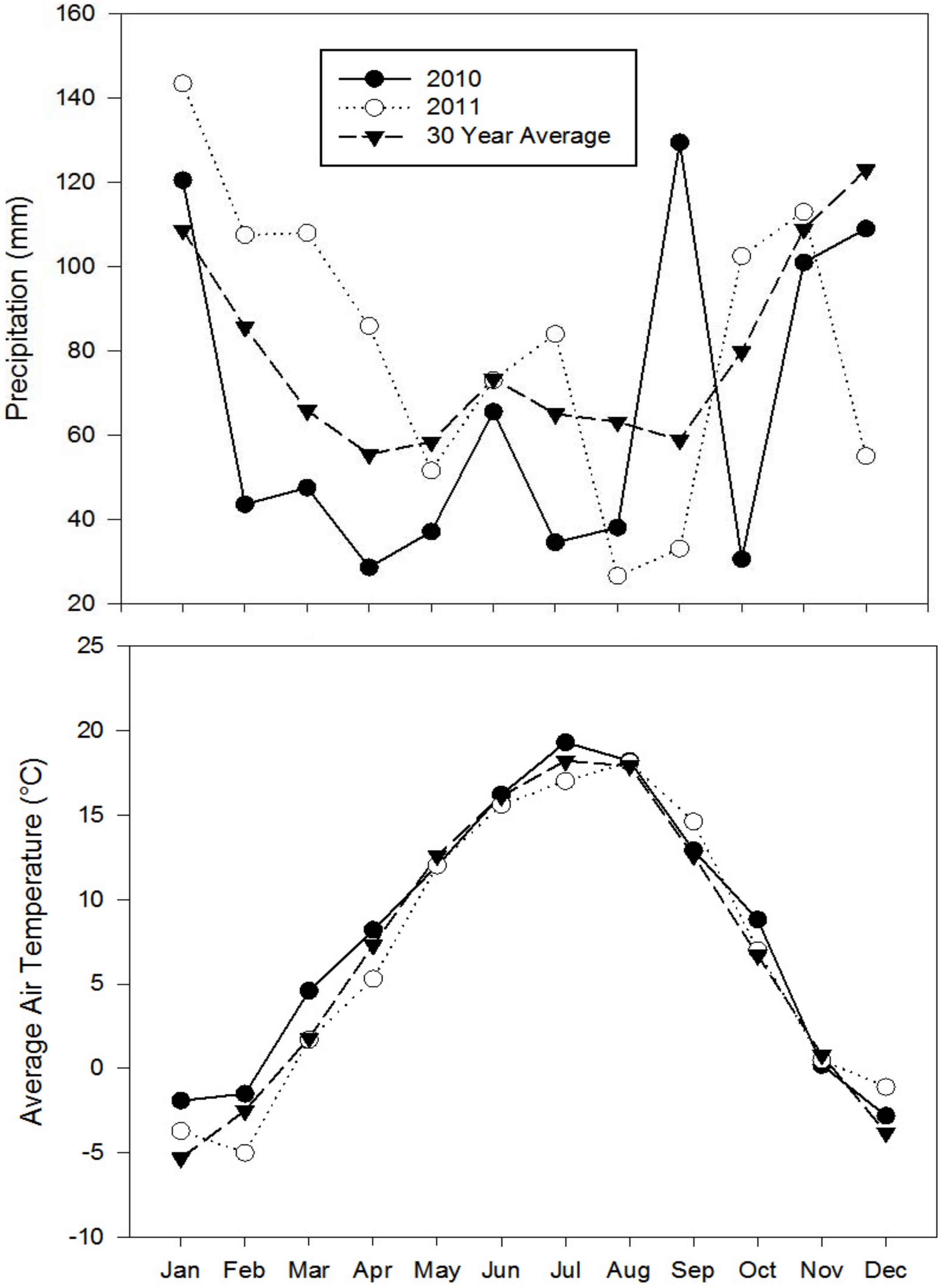

Figure 1-3 Monthly mean precipitations (mm) and air temperatures (°C) for Revelstoke, BC (Revelstoke Airport) for the study periods of 2010, 2011, and the 30 year average (1971 to 2000; Environment Canada 2012).

The Arrow Lake Reservoir can be divided into the Upper and Lower Arrow Lakes, which span approximately 230 km between the Monashee Mountains (to the west) and the Selkirk Mountains (to the east). The mountains rise to an elevation of 2600 m and are heavily forested within the Interior Cedar Hemlock (ICHmw3) biogeoclimatic zone (Braumandl and Curran 1992). Revelstoke Reach, where my study sites were located, is found at the north end of the Upper Arrow Lakes. It is approximately 40 km long and 20 km south of the Revelstoke dam. The current water licence allows for a 20 m (420 m – 440.1 m MASL) fluctuation in water levels within the so-called drawdown zone, and annual reservoir levels vary both in time and in magnitude (BC Hydro 2005). Water levels during 2010 and 2011 were higher than the 10 year mean, particularly during the spring and winter (Figure 1-4). These fluctuations can drastically change the landscape of the river and the floodplains, therefore altering the available habitat over a short period of time (Figure 1-6 to Figure 1-9).

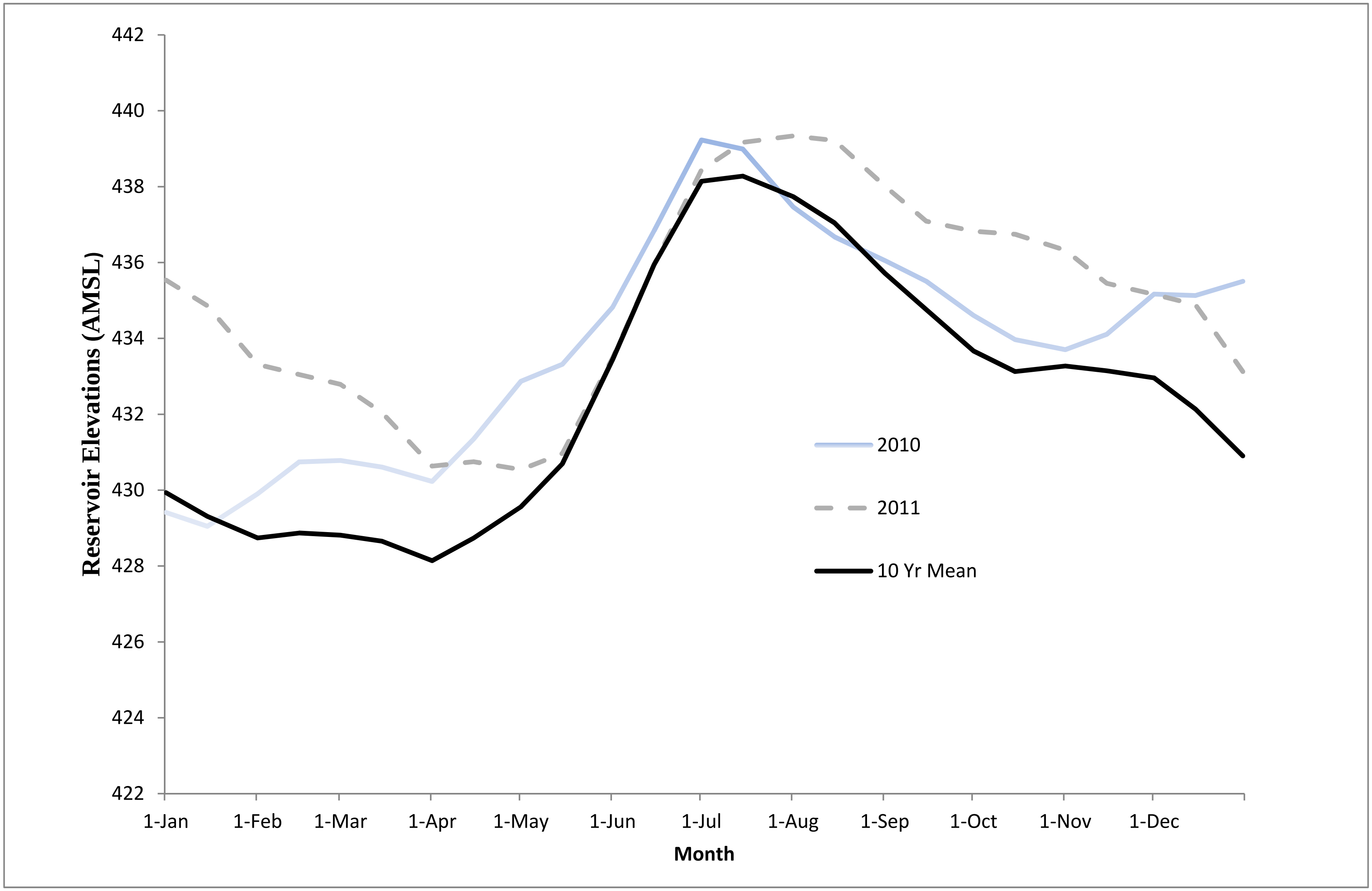

Figure 1-4 Water levels within the Arrow Lakes Reservoir over the course of 2010 and 2011 in relation to the 10 year average (1968 – 2012).

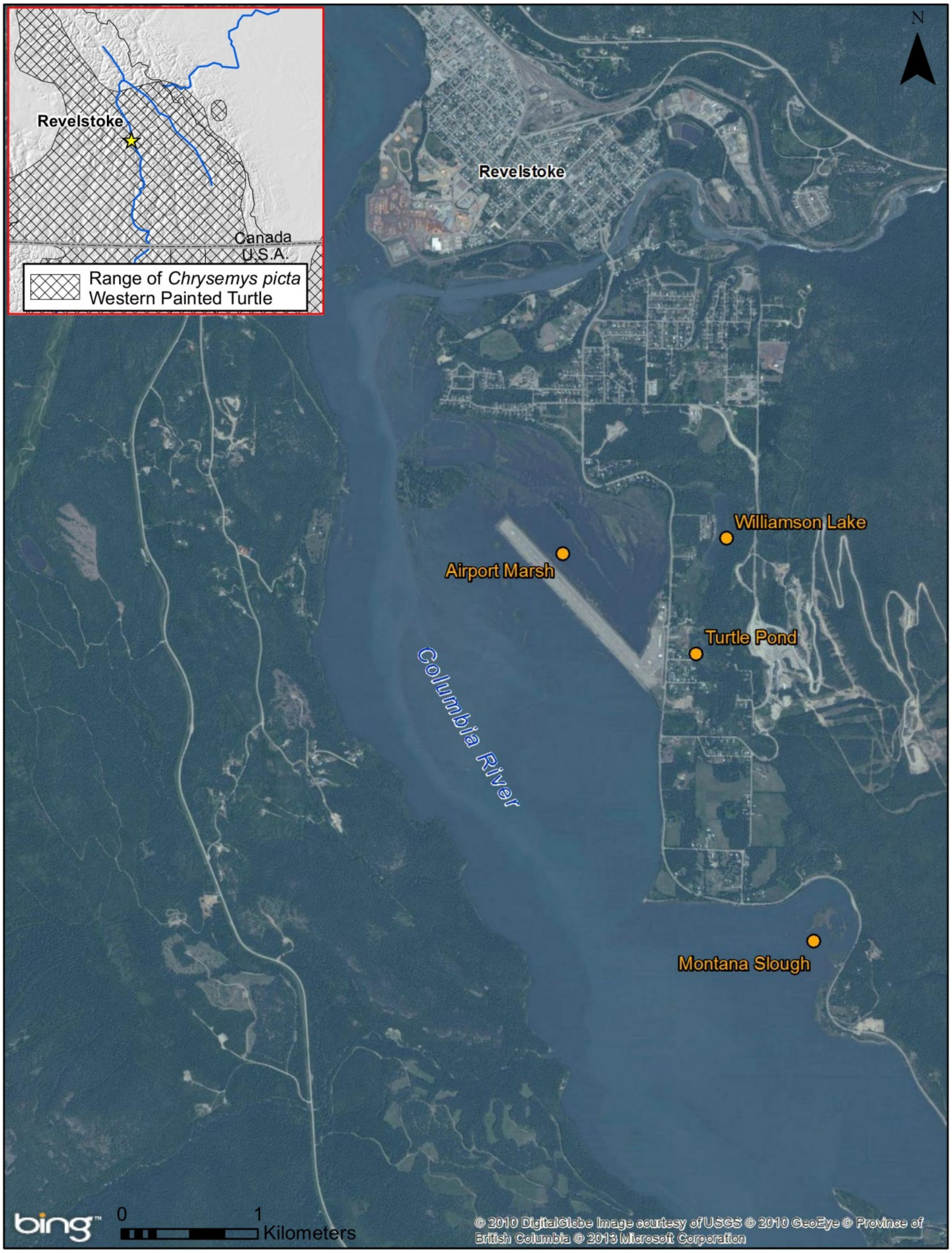

Figure 1-5 Western painted turtle study locations, Airport Marsh (AP) and Montana Slough (MS), Revelstoke Reach, Upper Arrow Lakes Reservoir, Revelstoke Reach B.C. Canada.

Figure 1-6 Photos a and b of Airport Marsh, Upper Arrow Lakes Reservoir at low water, fall of 2009(Photo courtesy of LGL Ltd. 2009).

Figure 1-7 Airport Marsh, Upper Arrow Lakes Reservoir at high water, summer 2010 (Photo by N. Basaraba).

Figure 1-8 Photos a and b of Montana Slough, Upper Arrow Lakes Reservoir during low water, fall 2009 (Photo courtesy of LGL Ltd. 2009).

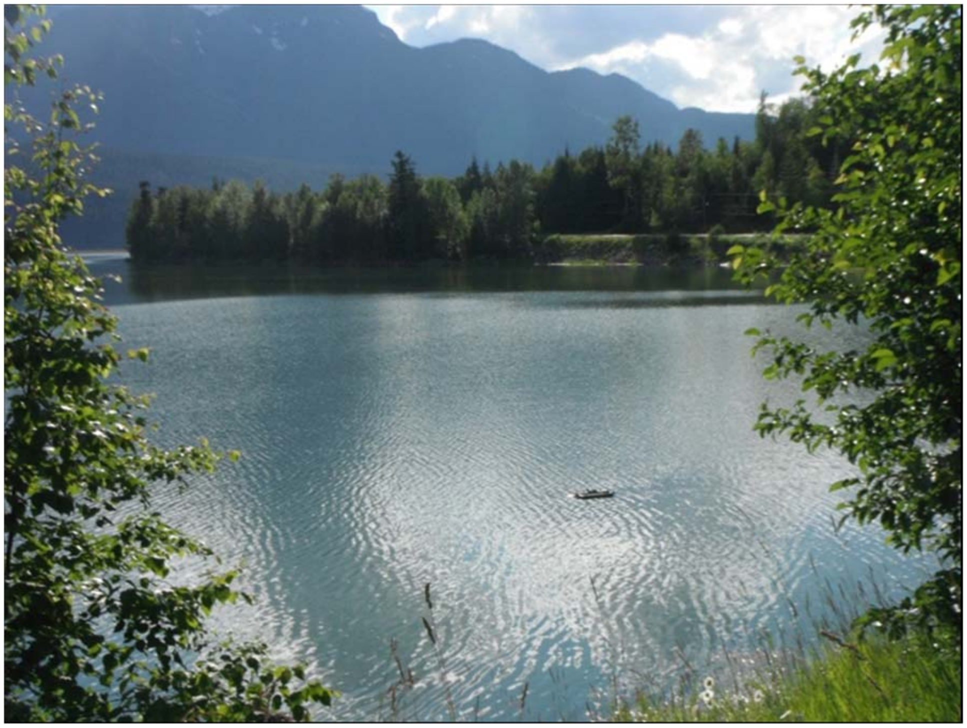

Figure 1-9 Montana Slough, Upper Arrow Lakes Reservoir at high water, summer 2010 (Photo by N. Basaraba).

Within Revelstoke Reach I focused on two primary research sites, Airport Marsh (AP) and the Montana Slough (MS). Aside from these two main sites in the reservoir, two additional water bodies upland of the reservoir, Williamson Lake (WL) and Turtle Pond (TP), were known to contain turtle populations (Figure 1-5). I focused my work on the AP and MS sites, having determined through initial surveys that turtle sightings within the reservoir were rarely made elsewhere (pers. observ.; Hawkes and Tuttle 2010). Site WL and TP were considered secondary sites and surveyed periodically throughout the study (active season; average once/week, winter; once/month) to investigate movement, and compare detectability of the turtles (Appendix E).

Airport Marsh (AP) is a large (approximately 81 ha based on water levels in June) area that has an extensive emergent vegetation along the shoreline. This area is at a higher elevation, 438 m AMSL, in comparison to MS and is sheltered from the main channel of the Columbia River by the airport runway (see Figure 1-6 and 1-7). When water levels rise, the marsh expands as the adjacent land is inundated. This creates a series of interconnected shallow ponds and ephemeral wetlands dominated by bulrush (*Schoenoplectus tabernaemontani*), common cattail (*Typha latifolia*), pondweed (*Potamogeton* spp.), milfoil (*Myriophyllum* spp) and reed canary grass (*Phalaris arundinacea*) where turtles were often found basking on or in submerged vegetation.

Montana Slough (MS; approximately 28.3 ha based on water levels in June) is a wetland complex adjacent to Airport Way Road at an elevation of 436 m AMSL and approximate 2.5 km south of AP. This area exists as a functional wetland that completely floods as reservoir levels rise, with the exception of a large floating island of vegetation (fen) approximately 1 to 2 ha in area (at high water). The wetland's dominant vegetation is moss (*Sphagnum* spp.), willows (*Salix* spp.), sedge (*Carex* spp.) and reed canary grass.

Thesis Objectives

I studied western painted turtles (*Chrysemys picta bellii*) near Revelstoke, British Columbia, Canada. These animals represent one of the most northerly, peripheral populations of freshwater turtles in North America. These animals exist under relatively harsh climatic conditions, but also inhabit an environment that regularly changes due to the fluctuating water levels caused by upstream and downstream hydroelectric facilities.

Given the lack of historical data on this population, the overarching goal of my thesis was to provide an ecological baseline for an extreme-northern population of western painted turtles inhabiting a hydroelectric reservoir. My interest was in understanding how this population compares to other more northerly populations of the same or similar species, but also how and if the population was coping with the extreme and repeated fluctuations in water levels brought about by the reservoir. I therefore investigated the following:

1) the demographics (age class, sex ratio, population numbers) of the turtles occupying a northern reservoir environment;

2) nesting placement: were turtles nesting in the drawdown zone, and if so what was their nesting success and recruitment?;

3) the potential effect(s) of fluctuating water levels on turtle behaviour;

4) the movement patterns of turtles within the reservoir, and between it and neighbouring water bodies that are smaller and more stable;

5) the methods and techniques best used to observe and capture turtles within the Arrow Lakes Reservoir and similar environments; and

6) if turtles were overwintering in the drawdown zone, and if so, what were their hibernating tactics and levels of success.

All the above aspects of the turtles' ecology were highly intertwined, so I have chosen to present my work as a single chapter (Chapter 2). In Chapter 3, I summarize the major management and conservation concerns surrounding the turtles in relation to reservoir operations. Based on my work, I generate recommendations for (1) future research and monitoring (2) habitat enhancement tools, and (3) and other mitigation measures for reservoir operations. I also discuss current and future management issues that turtles face outside the boundaries of the reservoir.

Because of the relevance of my work and planned long-term research on the Revelstoke turtle population, I provide a considerable amount of my 'raw' data in Appendices A-D. This material will provide future researchers with documented records of individual turtles and other important data. In Appendix E, I present a short report on work to determine if the 'sightability' of the turtles in the reservoir could be predicted through various environmental metrics. The goal of this work was, again, to provide other researchers with a possible tool for improving the detection and monitoring of turtle populations.

Implications for Conservation

This work has added importance given the status of the western painted turtle in this region. Within the interior of B.C. this species is listed by the provincial government as “Special Concern” due to their sensitivity to (1) habitat loss and fragmentation, (2) loss of suitable nesting locations, and (3) susceptibility to road mortality. At the federal level, the turtle is also ranked as “Special Concern” under Schedule 1, affording the species protection, and the development and implementation of recovery measures. Concern over this status of the animal is due to at least five processes:

- increased urbanization of natural areas;
- infilling of wetlands;
- increased resource extraction and management;
- increased recreation in natural habitats; and
- the introduction of invasive species (COSEWIC 2006).

The Columbia Water Use Plan was developed by a multi-stakeholder consultative process to inform best operating procedures for BC Hydro’s hydroelectric operations; the procedures are intended to balance environmental and cultural/heritage values, recreation, power generation, navigation, and flood control. As part of determining the environmental values and potential effects of the hydroelectric operations on various species, a long-term monitoring program (Wildlife Effectiveness Monitoring of Re-vegetation and Wildlife Physical Works) was developed. Through this process the western painted turtle was identified as a species of interest under the Columbia Water Use Plan, because it is the only native freshwater turtle found in B.C., local interest was high, and it has ‘at risk’ status. BC Hydro is committed to the ongoing monitoring and habitat enhancement of species that are potentially influenced by their operations, and as such, this study was initiated as a means to provide preliminary data and directions for future action.

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CHAPTER TWO

THE ECOLOGY OF WESTERN PAINTED TURTLES (C*HRYSEMYS PICTA BELLII*) IN A NORTHERN CANADIAN RESERVOIR TURTLE

Introduction

Herpetofauna in northern areas of the globe face a combination of environmental and human-induced stressors. Because of strong seasonal patterns, these animals generally have limited time to feed, grow, and reproduce, resulting in trade-offs between growth and reproduction (St. Clair *et al.,* 1994). With increased human development and population growth, the effects of these northern environmental stressors are now coupled with anthropogenic effects, including the loss and degradation of habitat, introduced species and pollution, as well as the potential effects of climate change (Gibbons *et al.,* 2000; Turtle Conservation Fund 2002). Clearly, the persistence of these northern populations is dependent not only on the adaptive resiliency of the animals, but also our ability to recognize and effectively mitigate natural, anthropogenic, and cumulative effects on the animals.

One area of human activity that is contributing to the pressure on northern herpetofauna is energy production. Many natural areas of the north contain current or potential energy sources, which create conservation challenges for many species, not just reptiles (Cuddihy *et al.,* 2005; Prowse *et al.,* 2009). ‘Green’ or renewable sources of energy such as, wind, solar, geothermal, and hydro power are generally considered favourable because of limited environmental impacts. Even with these types of energy production, there can be unforeseen consequences (Abbasi and Abbasi 2000). For example, research has shown that animals are impacted though habitat loss and alteration during construction of facilities (Walter *et al.,* 2006), that birds and bats are impacted through collisions with wind turbines (Hoover and Morrison 2005: Mabee *et al.,* 2006; Kunz *et al.,* 2007), and that changes in water levels will alter available habitat for birds, amphibians and reptiles found in or around reservoirs (CBA 2011; Boyle 2012).

In general, hydroelectric power is considered a relatively benign form of energy production compared to the burning of fossil fuels. However, reservoirs created by water impoundment for power generation may create unnatural habitat for many animals. The blockage or alteration of water flow, the creation of artificial water bodies, and the ongoing operation of the reservoirs all have been linked to impacts on wildlife. These impacts have been well studied in fish (Crivelli *et al.,* 1995; Antonio *et al.,* 2007; Bodaly *et al.,* 2007) although other species have also been shown to be affected (Crivelli *et al.,* 1995; Reese and Welsh 1998; Boyle 2012). Hydroelectric operations and impoundments have been found to increase mercury concentrations in fish (Bodaly *et al.,* 2007), alter flow patterns, impact the biodiversity of an area, block fish migration routes by creating obstacles (Rosenberg *et al.,* 1997; Antonio *et al.,* 2007), eliminate certain habitat types required by certain species or age classes, (Reese 1996; Reese and Welsh 1998) and alter food webs (Tuker *et al.,* 2012), all which may have significant impacts on aquatic or semi-aquatic animals, for example fish, turtles, and amphibians. Even terrestrial animals that forage in riparian habitat may be forced to alter their hunting patterns in response to the establishment of reservoirs, as well as the changing water levels associated with the ongoing operation of these structures (Boyle 2012).

Turtles may be particularly susceptible to the effects of reservoirs, especially in northern climates. Changing water levels due to reservoir operations may drastically alter suitable habitat for aquatic or semi-aquatic turtles, or it may create habitat, varying spatially and temporally. These alterations in habitat may affect home range size and turtle behaviour in an already-short active season. Increased water levels may impact recruitment by eliminating shallow shorelines that neonate and juveniles turtles require (Reese 1996; Reese and Welsh 1998) or inundate nesting areas. These impacts to recruitment or the nesting areas may vary depending on the season, or if multiple clutches are laid during a year, each clutch may be impacted differently (Congdon and Tinkle 1982). Water levels can fluctuate on any given year or day, depending on dam operations, seasonal precipitation, and the demand for energy resulting in varying degrees of influence, causing additional complexity to the impacts and management of the dam’s operations. Furthermore, these influences from reservoir operations may be compounded by living in a northern climate, limited available habitat, and suitable nesting and overwintering sites. Overwintering locations may freeze and/or be scraped by ice shifting in response to changes in water levels. Changes in winter would be exacerbated by the fact the animals may be experiencing decreased oxygen levels and increased levels of lactic acid created during hibernation (St. Clair and Gregory 1990). All told, these processes may have a significant impact on turtle populations in reservoirs.

The western painted turtle (*Chrysemys picta belli*) is a species that extends further north than any other turtle species in the western hemisphere (Ultsch *et al.,* 1985). Painted turtles living at their northern range and associated with reservoirs face the combined effects of climate and the reservoir environment. In addition to those listed above, these potential effects could include changes (spatial and temporal) to the temperature of the water body and the potential loss of basking sites as water levels fluctuate. Understanding the ecology of northern populations of painted turtles (and other northern species) within reservoir environments is thus important for ensuring the persistence of these animals, particularly if mitigation techniques are needed (Reese 1996; Reese and Welsh 1998).

I studied the ecology of the western painted turtle (*C. p. bellii*) in a hydroelectric reservoir near the extreme northern limit of the species’ range (approx. 51.01 °N Lat) within the interior mountains of British Columbia (B.C.), Canada. Although turtles have been observed in the reservoir for a number of decades, no formal study has been conducted to determine how or if this extreme northern population is likely to persist under the conditions created by the artificial water body. Therefore, the goal of this research was to (1) conduct a broad pilot study on the ecology of these animals in order to determine basic demographics and distribution of the population; (2) identify whether overwinter and nesting locations maybe subject to freezing or inundation, (3) determine the effects of fluctuating water levels on turtle behaviour and habitat space use and, (4) provide a preliminary assessment on whether or not the population is self-sustaining, or whether the viability of the population is dependent on immigration from neighbouring populations of turtles.

Methods

Study Area

This study was conducted during the years 2010 and 2011 in the Revelstoke Reach area (approx. 40 km long) of the Upper Arrow Lakes Reservoir, near the town of Revelstoke, B.C. (51.01°N, 118.21°W; 420 - 480 m.). The Monashee and Selkirk Mountain ranges and the amount of precipitation in this area combine to create one of the few inland temperate rain forests in the world (Goward and Spribilee 2005; Sanborn *et al.,* 2006), approximately 560 km from the Pacific Ocean. Western red-cedar (*Thuja plicata*), western hemlock, (*Tsuga heterophylla*) and Interior Douglas-fir (*Pseudotsuga menziesii*) are the predominant tree species in the lower parts of the valleys (Braumandl and Curran 1992). Annual precipitation is approximately 94.6 cm in Revelstoke, a large part of this precipitation is in the form of snowfall (the Mt. Fidelity weather station, approximately 47 km northeast from the Revelstoke town site, records the highest annual snowfall in Canada at 1471 cm; Environment Canada 2012; Osborn 2013). Daily average temperatures above 0°C occur from early March through to early October and an average daily temperature during this time period of 12°C (Environment Canada 2012).

The Upper Arrow Lakes Reservoir is part of an extensive series of hydroelectric developments occurring along the Columbia River in B.C. and the American states of Washington and Oregon. Created in the 1960s by the construction of the Hugh Keenleyside Dam, the water levels in the reservoir are now, in turn, controlled primarily through the release of water by the upstream Revelstoke Dam (constructed in 1984) and the downstream Hugh Keenleyside Dam. The operations of these reservoirs fall under the responsibility of British Columbia Hydro (BC Hydro), which is a crown corporation that reports to the Government of B.C. The current water licence allows for a 20 m fluctuation in water levels (from 420 – 440.1 MASL) within the “drawdown zone” (the area between the high and low water mark). Annual reservoir levels vary both in time and by the amount in which they fluctuate (BC Hydro 2005). During my study years, water levels were slightly above the 10 year average, specifically during the spring and winter (Chapter 1; Figure 1-4). Water levels generally increased during the spring (May), reaching full-pool (highest water levels) during the months of July and August, and would decrease starting in September or October. The lowest water levels are in March and April.

The majority of this research focused on two specific sites, Airport Marsh (AP) and Montana Slough (MS; Figure 2-1) within the Revelstoke Reach. These sites were identified by earlier surveys (pers. observ; Hawkes and Tuttle 2010) as supporting the two main aggregations of turtles in the reservoir. Additional visual surveys of all areas of Revelstoke at the outset of this project detected only the occasional individual turtle outside of the two main sites. Habitat outside of these two sites was more exposed and often part of the main channel of the Columbia River, resulting in faster moving water, cooler temperatures and little to no emergent vegetation for foraging or shelter.

The two main study sites occurred along the east side of the reservoir, which owing to the orientation of the valley receives the most direct sunlight. The first site, Airport Marsh, (AP, 438 MASL) is relatively sheltered from the reservoir by an airport runway strip that runs out into the reservoir; this site floods at a slower rate when the water level is raised and it has a larger area to flood in comparison to the other site. The second site, Montana Slough, (MS, 436 AMSL) is located approximately 2.5 km (straight-line distance) downstream of AP. During high water, the only land in the MS site that remains above water, aside from the shoreline, is a large matt of floating vegetation that, essentially creates an island (Fig. 2.1). Aside from the two main study sites in the reservoir, two adjacent upland sites were identified to support turtle populations, namely Williamson Lake (WL) and Turtle Pond (TP). The former is a recreational lake approximately 460 m from AP, and it is directly adjacent to a campground. Turtle Pond is approximately 360 m from AP and 550 m south of Williamson Lake. This pond is located along a residential street and is boarded by private property.

Population Assessment

I conducted a mark-recapture study on the turtles from April 2010 to October 2011. Hand captures, basking traps (2010 and 2011), and hoop traps (2011) were the three methods I used to capture turtles. Hoop traps were introduced in 2011 in an effort to determine if a highly-skewed female sex bias in my 2010 sample (see Results) could be attributed to trapping methods (Ream and Ream 1966; Gamble 2006). Basking traps were set on warm sunny days throughout April to August where turtles were likely to be basking. Hoop traps were set at the beginning of a five day shift, checked every 12 hours and closed the morning of the fifth day, throughout the entire active season (April to October). Turtles were also caught using nets from in the boat or on foot while wading through shallow water and emergent and submergent vegetation.

Each captured turtle was permanently marked by notching the marginal scutes of the shell with a triangle file, allowing for individual identification of turtles in the mark-recapture study (Cagle 1939; RISC 1998). Neonates and some juveniles were not marked, as their shells are soft and not fully ossified, and notching may cause deformities or become lost as they grow (Cagle 1939). In addition, morphometric data was collected on each turtle captured. Animals were weighed using a hand-held Pesola® spring scale (nearest 0.1 g). The straight line length and width of the plastron (bottom of shell) and carapace (top of shell) were measured (Grayson and Dorcas 2004). The width of the carapace was measured from the seventh scute on either side of the turtle (pers. comm. Govindarajulu). The average sizes of the turtles were reported as mean plastron length rather than mass, to account for changes in the latter through the retention or loss of eggs, and/or water (Gibbons 1967; Macartney and Gregory 1985).

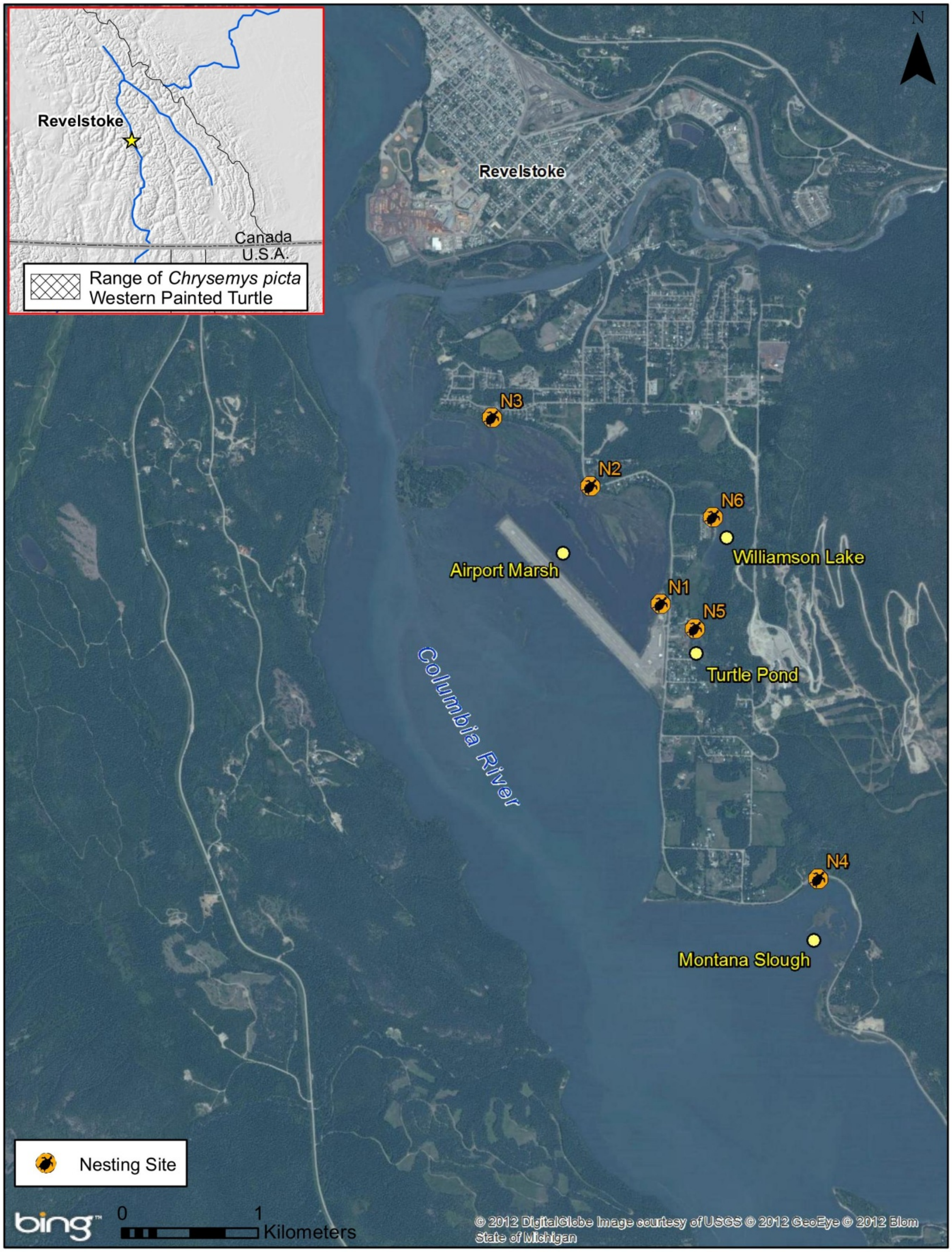

Figure 2-1 Map showing study sites (Airport Marsh (AP) and Montana Slough (MS), Williamson Lake (WL), and Turtle Pond (TP), and nesting locations (N1-N6) within the Upper Arrow Lakes Reservoir, Revelstoke Reach B.C.

The sex of each turtle was determined using secondary sexual characteristics and the relative positioning of the cloaca (Macartney and Gregory 1985; Matsuda *et al.,* 2006), and placed in an age class category (Adult, Juvenile, Neonate). Smaller turtles that could not be sexed were labelled as juveniles. The identification of neonates and juveniles as either male or female is a limitation of many turtle studies because to determine sex dissection is required (Vogt and Bull 1984).

Movements Behaviour and Habitat

Forty-one captured turtles were outfitted with VHF radio transmitters (17 turtles in 2010 and 24 turtles in 2011; Appendix A). I used stainless steel wire to secure transmitters (SI-2F or AI-2F Holohil Systems Ltd. Transmitter, Ontario Canada) to the posterior of the carapace. Small holes were drilled along the marginal scutes (usually scutes nine and eleven on the left side of the carapace to minimize interference with breeding) using a cordless power drill (Grayson and Dorcas 2004). Epoxy putty was used to streamline the edges of the attachment to prevent snagging on vegetation (Edge *et al.,* 2009; pers. comm. Litzgus). The entire transmitter package did not exceed 5% of body weight (CCAC 2003).

I located each turtle randomly a minimum of once per week from the time they were outfitted with a transmitter through to October, after a separate study by myself (Appendix E) found that time of day did not have a significant effect of whether a turtle was detected or not. A subsample of turtles (four turtles during the 2010/2011 season and 16 turtles during the 211/2012 season) from both sites was selected to retain radio transmitters over the winter months and these turtles were tracked periodically from November to March and then again more extensively beginning in April. I used a Lotek Biotrack wide-band radio receiver (138-174 MHz; Lotek Wireless Fish and Wildlife Monitoring) and a three-element Yagi antenna to track the animals.

Study sites were surveyed once per week in efforts to determine distribution, and detectability of the turtles between sites. Habitat information was collected at the point where any turtle was located through telemetry, visual searches, or incidental observations. This assessment consisted of a location using the Universal Transverse Mercator (UTM: marked with Garmin® GPSmap76CSX; ≤ 3m), time, date, water depth, water temperature (taken approximately 10 cm below the surface of the water), air temperature at turtle location, precipitation, wind, cloud cover, distance to water/shore, and activity of the turtle. The activities of all turtles sighted or captured were recorded as basking, walking, mating, nesting, stationary, swimming or unknown. In addition, the type of substrate being used by any turtle found basking was recorded (Table 2-1; Marchand and Litvaitis 2004).

Other Data Collection

I conducted turtle nesting surveys (daily from mid-May to mid-July) and neonate emergent surveys (every other day from April to May) by walking known nesting sites and areas that contained suitable nesting substrates. Emergent surveys consisted of searching for neonates that had left their natal nest, as evident by emergent holes in the nesting substrate (small holes in the soil with the approximate diameter of 5 cm).

Table 2-1 Description of substrate categories for locations where turtles were detected basking.

Substrate	Description
Emergent Vegetation	Vegetation that is above the surface of the water
Floating and Subsurface Vegetation	Vegetation floating on the surface of the water or just below the surface
Gravel	A collection of small unconsolidated rocks (2mm to 4mm)
Mud	Mixture of soil, organic debris and water
Water	Solely water with minimal vegetation
Wood	Large or small woody surface

Data Analysis

Population Size Estimation

To estimate population size, I combined turtle capture records within each year into two capture periods (2010 and 2011 respectively), and used the Lincoln-Petersen method following Pollock (1991) and Carriére, (2007); *i.e.*:

Estimate of N= ((n1+ 1) (n2 + 1) / (m + 1)) -1), where
n1 = total number of animals captured in first season;
n2 = total number of animals captured in second season; and
m = the number of animals re-captured in the second season that were originally marked in the first.

I omitted data from neonates found on shore or in the water from this analysis, due to the poor recapture rate for these animals (Reese 1996). Multiple methods of trapping and hand capture of turtles were used to help satisfy the assumption of equal catchabiltiy within the population of juveniles and adults.

Spatial habitat use patterns

The individual space used by each telemetered turtle(excluding nesting movements by females) was measured with the 100% minimum convex polygon (MCP) method (“mcp” function in library “adehabitat” in R - Calenge 2006). Although MCP can overestimate the space used by animals (Row and Blouin-Demer 2006), I chose to use this method because it is a simple way of describing the area of occupation by the turtles based on water levels. In addition, this method provides comparison with past research, and does not depend on an underlying statistical distribution such as normality (Litzgus and Mousseau 2004; Row and Blouin-Demer 2006). Furthermore, most herpetofauna tend to use certain locations multiple times and generally do not move far, with the exception of natal dispersal, nesting, and overwintering movements. This allows for MCP to accurately represent home range or space use for most herpetofauna (Row and Blouin-Demer 2006). Hereafter I use the term 'habitat space' to refer to the MCP that encompasses all locations detected for each telemetered turtle over the course of an active season (April to October).

I calculated MCP for 11 turtles in 2010 and 19 in 2011, for a total sample of 30, with four individuals being tracked in both years. Data between years were combined to provide a larger sample size and turtles with less than five locations were omitted from the MCP analysis. Data points were considered independent from one another if separated by a 24 hour period (Compton *et al.,* 2002).

Comparisons of spatial use by adult turtles were made between and within sites during the active season, and between male and females using the Mann Whitney U-test because (i) there were multiple comparisons, (ii) the data did not follow a normal distribution, and (iii) the sample size between groups was unequal. In addition, spatial use by turtles was compared between low water (April to June 11) and high water (June 12 to September 30, full-pool) time periods. Male and female comparisons between high and low water could not be done because of low sample sizes for males during low water.

A description of habitat type was presented based on the percentage of turtle detections and the top three dominant species of vegetation within on a 5.64 m radius plot (100m^2; a standard used in forestry inventory method to measure plant diversity; Province of British Columbia 1999). The substrate that each turtle was found basking on was recorded and a comparison between the frequencies of use of each substrate was made in relation to each site.

Influence of water level fluctuation and season on turtle behaviour

To examine the effects of water level fluctuations on turtle behaviour, I used linear mixed-effects and binary generalized mixed-effects modeling. Mixed-effects models include both fixed and random variables in their analysis, thus accommodating for repeated measures, statistical non-independence and unbalanced study designs (Hansen and Jones 2009). Restricted maximum likelihood estimates (REML) were used to determine the model structure for random effects, and maximum likelihood (ML) estimates were used for the fixed effects structure of the model (Hansen and Jones 2009; Zuur *et al.,* 2009). Heterogeneity between groups and temporal correlations were accounted for in the random effects of each model using the functions "lme" and gls"from the library "nlme" (Venables and Ripley 2002) and "glmer" from the library "lme4" (Bates *et al.,* 2012) in Program R; following the protocol set out by Zuur *et al.,* (2009).

I considered three basic measurements of turtle behaviour, namely the average daily distance moved (ADD), distance to shore (DTS), and basking. Potential explanatory variables that I entered into the models were water level (m), water temperature (Cº) and Season (Table 2-2). To account for repeated measures on the same turtle, turtle identity (ID) was used as a random effect in all models. The behaviour response variables ADD and DTS were log transformed to help meet assumptions of normality within the models (Roulin and Bersier 2007). Due to a scarcity of adult males and juveniles (see Results), sex and age were not incorporated within the models, and data were pooled over both years to increase sample size.

Statistical analyses and graphing were performed using R version 2.14.2 (R Development Core Team 2003). An alpha value of α = 0.05 was used to guide interpretation of the results.

Table 2-2 Response, fixed and random variables associated with turtle behaviours and mixed effects models.

Abbreviated Variables	Description
Response Variables	
ADD	Average daily distance moved (m). Standardized by dividing the distance moved by the number of days since the last location
DTS	Distance to the closest shore (m)
Basking	Turtle detected basking or not. Binary variable: 0=not basking, 1=basking
Fixed Variables	
H^2OTemp	Water temperature (°C) where the turtle was located, approximately 10 cm below the surface of the water
Season	Periods of time defined around nesting: Pre-Nesting season; April 01 to May 11, Nesting; May 11- July 10, Post-Nesting; July 11 – September 30.
Level	Average water levels based on elevations (m) recorded on the day of detection
Random Variables	
ID	Individual turtle identification

Prior to the construction of the mixed-effect models, I first checked for correlation between the potential explanatory variables using Spearman rank correlation matrices. I omitted the variable less likely to have biological relevance if two variables were strongly correlated (R> = 0.75 or R< = -0.75; Reese 1996). However, if the correlated pair of variables included a categorical variable, I checked if the correlation was occurring within only one of the categories (Level) of the variable in question. If so, both variables were retained for the modelling exercise.

Stepwise comparisons and Akaike's Information Criterion (ΔAICc) were used to determine the top ranking models (Zuur *et al.,* 2009). The model with the lowest AIC was considered the top ranked model and was used as the baseline model to calculate ΔAICc for model comparisons. Models with a difference of less than 2 in the AIC scores were considered competing models; in this case, the model with the fewest variables was considered the most parsimonious model and ranked higher (Burnham and Anderson 2002 & 2004).

The amount of variation explained by the linear mixed effect models was determined using Pseudo R^2 values, and a confusion matrix was used to determine the predictive power of the binary mixed effects model for turtle basking behaviour (Kohavi and Provost 1998; Zuur *et al.,* 2009). In the latter case, I looked for the model that generated equal predictability for both binary categories (i.e. not basking versus basking) (Pearce and Ferrier 2000; Boyce at al. 2002). Typically, threshold values for assessing the predictive power of binary logistic regression models (the confusion matrix) are arbitrarily set at is 0.5; however, because my data set was biased towards non-basking events, I considered basking to be a 'rare' event and I halved the default threshold value 0.05 twice to obtain a threshold value of 0.125.

Results

Population Assessment

A total of 198 individual turtles (81 adults female, 13 adult male turtles, 32 juveniles, 72 neonates) were captured in the reservoir during the 2010 and 2011 field seasons. This number includes a large proportion (35%) of neonates that were captured as they emerged from nests which were not included in the Capture-mark-recapture estimate of population size. Adult females were over-represented, both in 2010 and 2011, while neonates appeared to be over-represented in 2010 (Figure 2-2). My mark-recapture data provided a population estimate of 242 turtles (SE = ± 42.1, 95% CI = 160, 325) (excluding neonates) in the study area. This represented a density estimate of approximately 2.2 turtles/ha (the AP and MS sites combined) before high water (June) and a density of 2.0 turtles/ha during the highest water levels in late July.

During the first year of the study, the combination of basking traps and hand captures produced a sample of 3 ♂♂ and 51 ♀♀ adults, a ratio of 1:17. In the second year of the study, when hoop traps were used in conjunction with basking traps, a sample of 11 ♂♂ and 30 ♀♀ adult turtles were produced, for a ratio of 1: 3. Thus, the overall sex ratio of all adult turtles captured during the two-year study was 14:81, which was significantly different from a 1:1 ratio (χ^2 = 49.2, df = 1, p-value <0.001). During 2011, 17 turtles were captured using hoop traps, with a sex ratio of 7 ♂♂: 10 ♀♀, or 1:1.4 (not significantly different from a 1:1 ratio: χ^2 = 0.53, df = 1; P = 0.46). However, the hand-capture sample in this year was still strongly biased towards females (4 ♂♂: 20 ♀♀, or 1:5; χ^2= 10.7, df = 1; P <0.001).

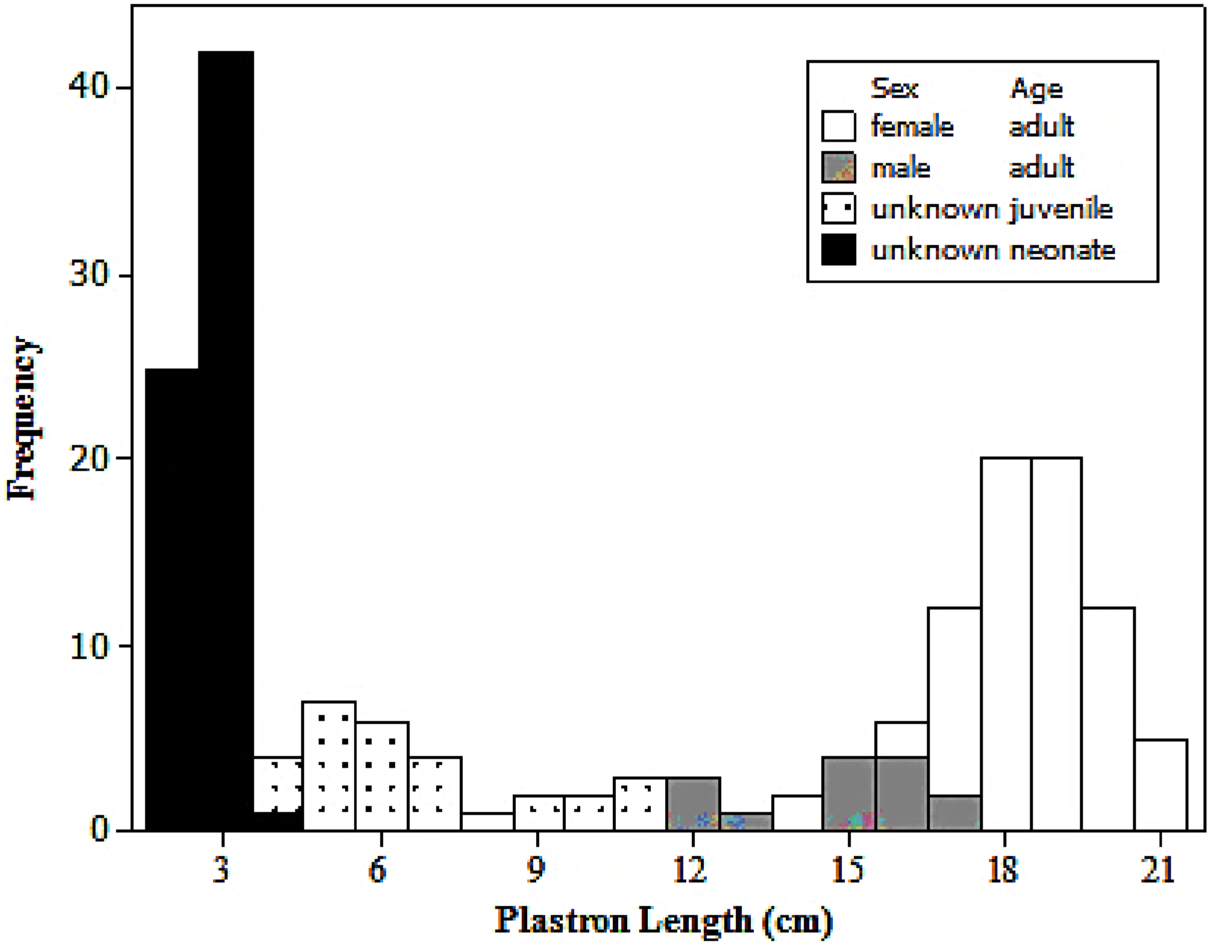

Figure 2-2 Straight-line plastron lengths (cm) of turtles residing in the Upper Arrow Lakes Reservoir, B.C. during the 2010 and 2011 field seasons. * Ninety-nine percent of all neonates were captured at nesting sites and not within the reservoir.

Nesting Locations and Threats

Six nesting sites were identified. All sites were anthropogenic in origin, and all were above the high-water mark (Figure 2-1; N1-N6). Two of these six sites contained the majority of nests (N1 ≥ 30 nests and N2 ≥ 20 nests) where at least one neonate from each nest detected emerged. Both of these sites were in proximity to the AP study site, and adult females demonstrated nest site fidelity as three individuals were detected in both years using the same nesting sites. Only one clutch per female per year was detected. No similar communal nest sites were detected near the MS study site; in fact, only one nest was confirmed at this site. Vegetation encroachment at the main nesting site (N1) was occurring, as I detected root penetration into multiple nests, causing morality to the eggs and neonates.

No movement of adult females was detected from the MS site to the AP site related to nesting and, the maximum distance from the shoreline to all detected nests was approximately 80 m.

A nesting site was suspected at the south end of the MS site across a road. This potential nesting site may experience high mortality rates because during late spring early summers when turtles are nesting water levels are generally higher than early spring when neonates are emerging from their nests and moving towards the water. The distance from this particular nesting site to the shoreline can fluctuate between 80 to 400 metres. At lower water levels, neonates will face a greater distance between them and the shoreline, and thus may face increased risk of predation, desiccation, terrain, vehicles, and disorientation.

Overwintering

Four turtles carried transmitters during the winter of 2010/2011, and 16 were similarly tracked in the winter of 2011/2012. This resulted in 12 turtles being tracked overwinter at the MS site and eight at the AP site. All turtles, except one from AP, overwintered at the same study site where they were captured. Turtles at the AP site did not use a communal hibernation site. Rather, turtles were dispersed over the winter (nearest-neighbour distance between turtles: 187 m; Appendix D - Figure D-2). These sites occurred in various habitat types (pond, and open water next to areas of emergent and submergent vegetation, mainly bulrush) that were characterized by water depths deeper than a metre and in muddy silt substrates.

In MS, a small pond of water encased by the floating vegetation island was used as a communal hibernaculum by all but one of the turtles (n=13) monitored in that site over both years. The one exception occurred during the 2010/2011 season, when a lone female overwintered outside of the communal hibernacula, but then used the communal location in the subsequent winter. The attraction to this pond is not clear, although it appeared to be sheltered from the main channel by the floating vegetation when water levels were high. When water levels were low (particularly in the winter) it still afforded deep water (>2 m; measured at the centre of the pond) with a muddy bottom that turtles appeared to bury into, as suggested by telemetry and visual observations when the bottom of the pond could been seen. The shortest distance needed to reach the pond from the main channel along the shoreline was approximate 5 m.

All overwintering sites had 100% snow cover from November through to February during both years of the study. This suggests ice cover was present, although I could only verify this during January and February when the ice was thick enough to allow tracking off shore.

Hibernating locations for each turtle were located in the same area that the turtle spent the majority of their time during the active season (habitat space use; see section below; MCP). One exception to this rule was one telemetered animal that left the reservoir (AP site) and travelled overland (September 2010) to one of the upland water bodies (Williamson Lake) where it overwintered (a minimum of 400 m straight-line distance). This animal successfully overwintered there and returned to the reservoir the following spring (June 2011).

Mortality

I documented 12 cases of turtle mortality (three in 2010, nine in 2011) within the reservoir during the course of my study. How these animals died is unclear, with the exception of three that were killed by vehicles while crossing the road. The lack of signs of predation and the discovery of their carcasses atop of vegetation, shortly after spring emergence, suggest at least some of these turtles may have emerged from hibernation and died shortly thereafter. The survival rate of the turtles within the reservoir has yet to be determined.

Habitat Space and Turtle Movements

On average, individual turtles occupied 72.0 ha (SE = ±16.0, n = 33) of habitat space. No differences in space use were detected between low (n=16) and high water (n=33) within the study area (U=345, P=0.9), between sites (MS; low (n=9), high (n=15); U=45.5P=00.20; AP; low (n=13), high (n=18) U=108, P =0.7) or between gender (8 ♂♂ : 24 ♀♀; U=84, P =0.6).

The majority of movements detected through telemetry tended to be localized within the study site that each turtle was first captured with very little movements detected between the upland sites and the reservoir. The ADD moved by turtles outfitted with transmitters was 59 m (SE= ± 4.1, n= 620). No difference in this metric was detected between years (U=47113, P=0.68, 2010 n= 165, 2011 n=414) or between sites (U = 84229, P = 0.15, AP n=287, MS n=280) when the years were combined. However a difference in ADD was detected between sites within each year (2010; U= 6887, P=0.03: 2011; U=43261, P=0.001), when turtles moved on average more per day at the MS site (x□= 101.2, n=65) than the turtles at the AP site (x□=59.7, SE=±23.2, n=94) during 2010, while turtles moved on average more at the AP site ($\bar{x}$=70.5, SE=±7.3, n=193) then the MS site during 2011 ($\bar{x}$=50.0, SE=± 5.9, n=215).

Of the two juvenile animals that were outfitted with transmitters, the ADD ($\bar{x}$ = 21.62, SE=±6.0, n = 21) that these turtles moved was significantly shorter than that made by adult turtles ($\bar{x}$=64.59, SE=±7.2, n=287) during the same time period (U = 40317, P= 0.046: Appendix B; Figure B-1 and B-2). Conversely, ADDs demonstrated by adult males ($\bar{x}$=68.6, SE=±8.5, n=129) and females ($\bar{x}$=63.5, SE=±6.9, n=445) were not significantly different from one another (U = 125230.5, P = 0.10).

Turtle Behaviour and Environmental Effects

Mixed effects modelling indicated no significant effects of changing water levels (Level) on ADD, DTS, and Basking (at $\alpha = 0.05$). Conversely, ADD appeared to be influenced by H^2OTemp, Season (a categorical variable), and their interaction. Out of the numerous candidate models, the top model accounted for autocorrelation in time between the locations, and unequal variances between the variable Season (Table 2-3).

The top ranked model illustrated that ADD increased as H^2OTemp increased prior to the nesting Season. This association displayed a somewhat positive exponential relationship in that turtle movements increased as the water temperatures increased, partially when the water temperature reached 15 °C and higher (Figure 2-3); however, the predictive power of the model was very low (Pseudo R^2 = 20%).

My attempts to model the DTS behaviour showed that both H^2OTemp and Season were important explanatory variables, whereas autocorrelation and variance within the seasons had no significance and were subsequently dropped from the models (Table 2-4). As shown in Table 2-4, two models were virtually identical in AIC scores. Both models included H^2OTemp and Season, while also accounting for the repeated measures on each turtle (ID). The only difference in these two models was the inclusion of an interaction effect between H^2OTemp and Season, and the change in AIC score due to this was extremely small; therefore, the model with the least number of parameters was deemed most parsimonious. The top ranked model revealed water temperature and season accounted for only 36% of the variation (Pseudo R^2) with no significant relationship found within these variables (Figure 2-4).

Table 2-3 Summary of AIC and ΔAICc values for the top five candidate models assessing the influence of H^2OTemp, Level (MASL), and Season (pre-nesting, nesting, and post-nesting) on the average daily distance (m) moved by turtles within the Arrow Lakes Reservoir, British Columbia, Canada. Repeated measures on individual animals were accounted for using the ID term as well as autocorrelation between the locations and variance within season.

Explanatory Variables	**AIC**	**ΔAICc**
Season + H^2Otemp + Season* H2Otemp + ID	_947.26_	_0.00_
Season + H^2OTemp + _ID_	952.96	5.70
Level + Season + H^2Otemp + Level* Season * H^2OTemp + _ID_	969.64	22.38
H^2OTemp + Season + _ID_	973.26	26.00
H^2OTemp + Season + _ID_	973.53	26.27
Level+ Season + H^2OTemp + ID	974.89	27.63
Level+ Season + H^2OTemp	995.66	48.39

Italics indicates top model.

* Indicates an interaction between the two variables.

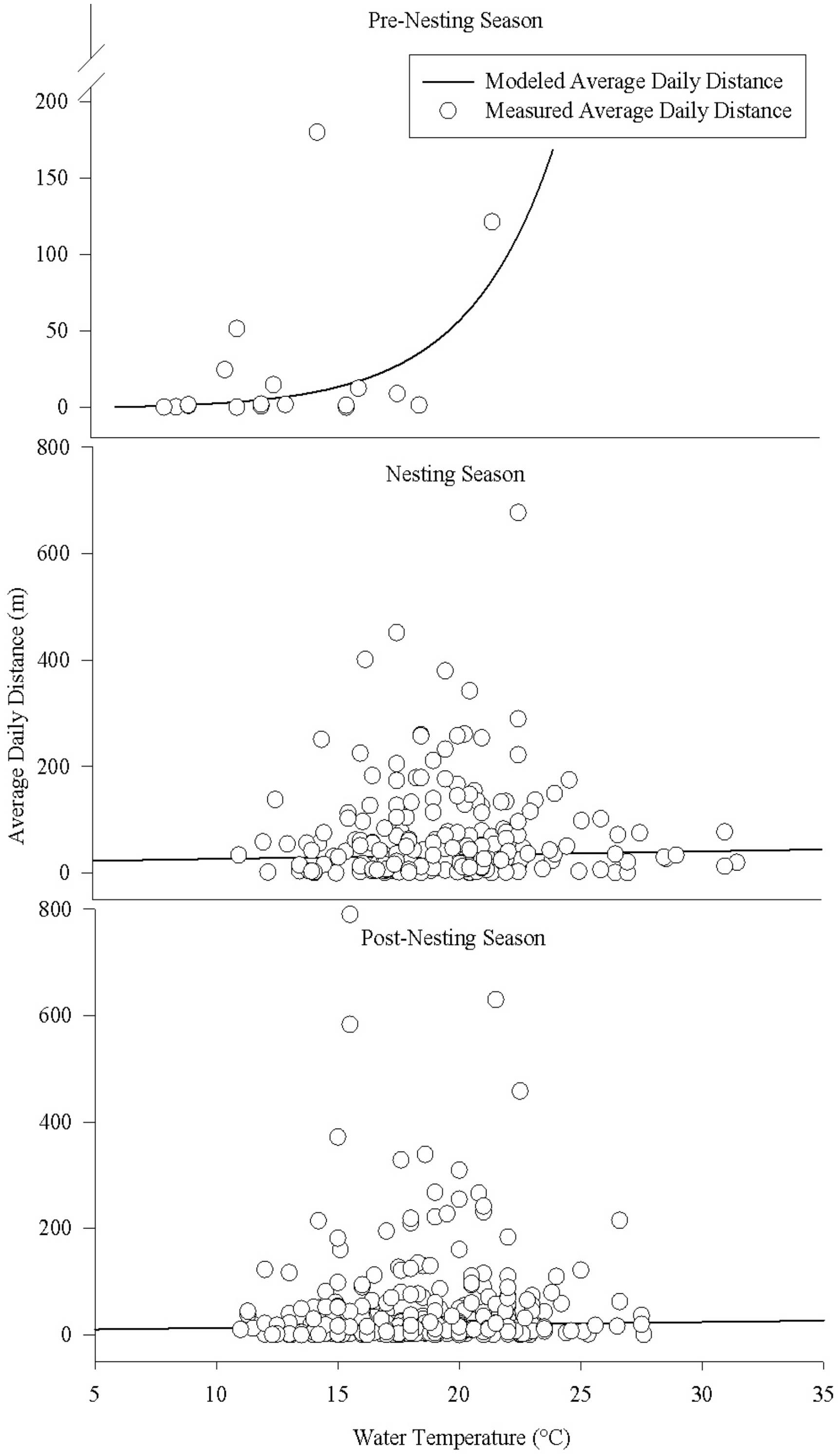

Figure 2-3 Average daily distances (m) recorded for telemetered turtles during three periods of the active season, shown as a function of water temperature (open circle data points). The solid line depicts the predictive relationship determined through mixed-effects modelling. Only during the pre-nesting season (top graph) was a significant relationship detected.

Table 2-4 Summary of AIC, and ΔAICc of the top five candidate models assessing the influence of H^2OTemp and Season on DTS by turtles within the Revelstoke Reach, Arrow Lakes Reservoir British Columbia, Canada. Repeated measures were accounted for using the term ID.

Explanatory Variables	**AIC**	**ΔAICc**
Season+ H^2OTemp + Season * H^2OTemp + *ID*	658.74	0.00
H^2OTemp + Season + ID	*658.82*	*0.08*
Level + Season + H^2OTemp + *ID*	660.78	2.05
Level + H^2OTemp + *ID*	667.23	8.49
Level + SEASON + H^2OTemp + Level *Season* H^2OTemp + *ID*	667.54	8.81

Italics indicates top model.

* Indicates an interaction between the two variables.

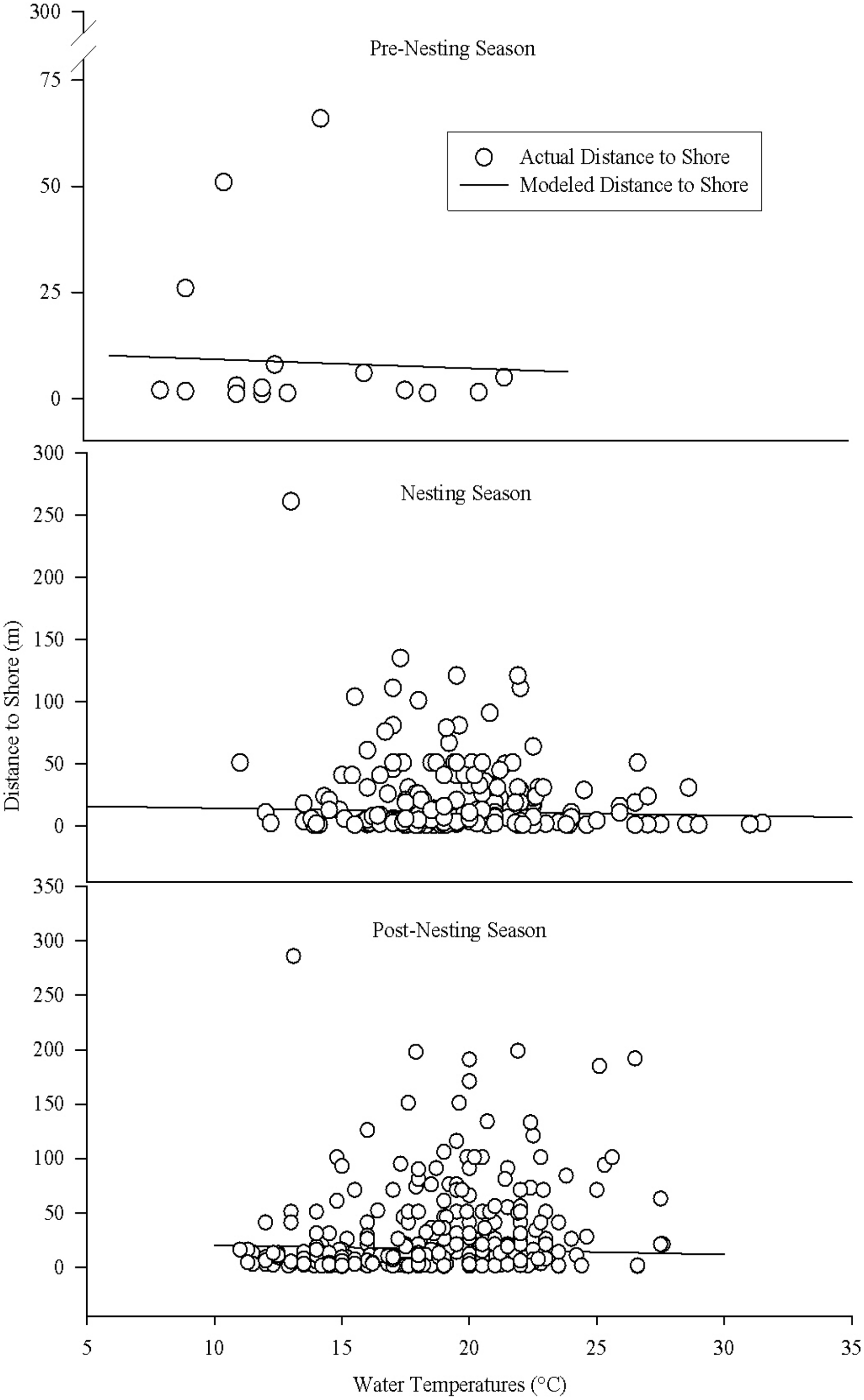

Figure 2-4 Distance to shore (m) recorded for telemetered turtles during three periods of the active season, shown as a function of water temperature (open circle data points). The solid line depicts the predictive relationship determined through mixed-effects modelling no significant relationship was detected.

Modeling basking behaviour as a binary variable revealed Season to be the only significant explanatory variable. The model correctly predicted 86% of the observations (482/559); however, these predictions were bias towards correctly predicating non-basking events at (80% observations) which may be the result of an over-representation of turtle observations during the nesting and post- nesting seasons when water temperatures were higher than the pre-nesting season.

Habitat

A difference in habitat between the two main sites (AP and MS) and the rest of the reservoir was apparent based on the amount of available habitat (MS= 28.3 ha, AP=81 ha), habitat type, the dominate vegetation types observed at each site, and changes in the landscape as water levels fluctuated. Within the AP site, 67% of turtle detections were found within the emergent vegetation that included bulrush (*Schoenoplectus tabernaemontani*), common cattail (*Typha latifolia*), pondweed (*Potamogeton* spp), milfoil (*Myriophyllum* spp) and reed canary grass (*Phalaris arundinacea*). In comparison, the majority of turtles detected at the MS (77.2%) site were on or near the shoreline of the floating vegetation matt dominated by moss (*Sphagnum* spp.), sedge (*Carex* spp.), reed canary grass, and willows (*Salix* spp.). In addition, the fen habitat of the MS site becomes connected to the main channel of the Columbia River during high water and likely experiences a greater influx of colder, faster moving water, where the AP site is relatively sheltered from the reservoir by the earth-filled airport runway. The AP site also floods at a slower rate (having a larger area to flood) and potentially provided superior habitat than the rest of the reservoir. This may at least partially explain why considerably more individual adult turtles were detected during this study in the AP site (n=171) than the MS site (27).

The frequency of basking substrates used by turtles in the reservoir changed with the water level. More turtles were detected basking on wooden substrates as water levels increased (Figure 2-5).

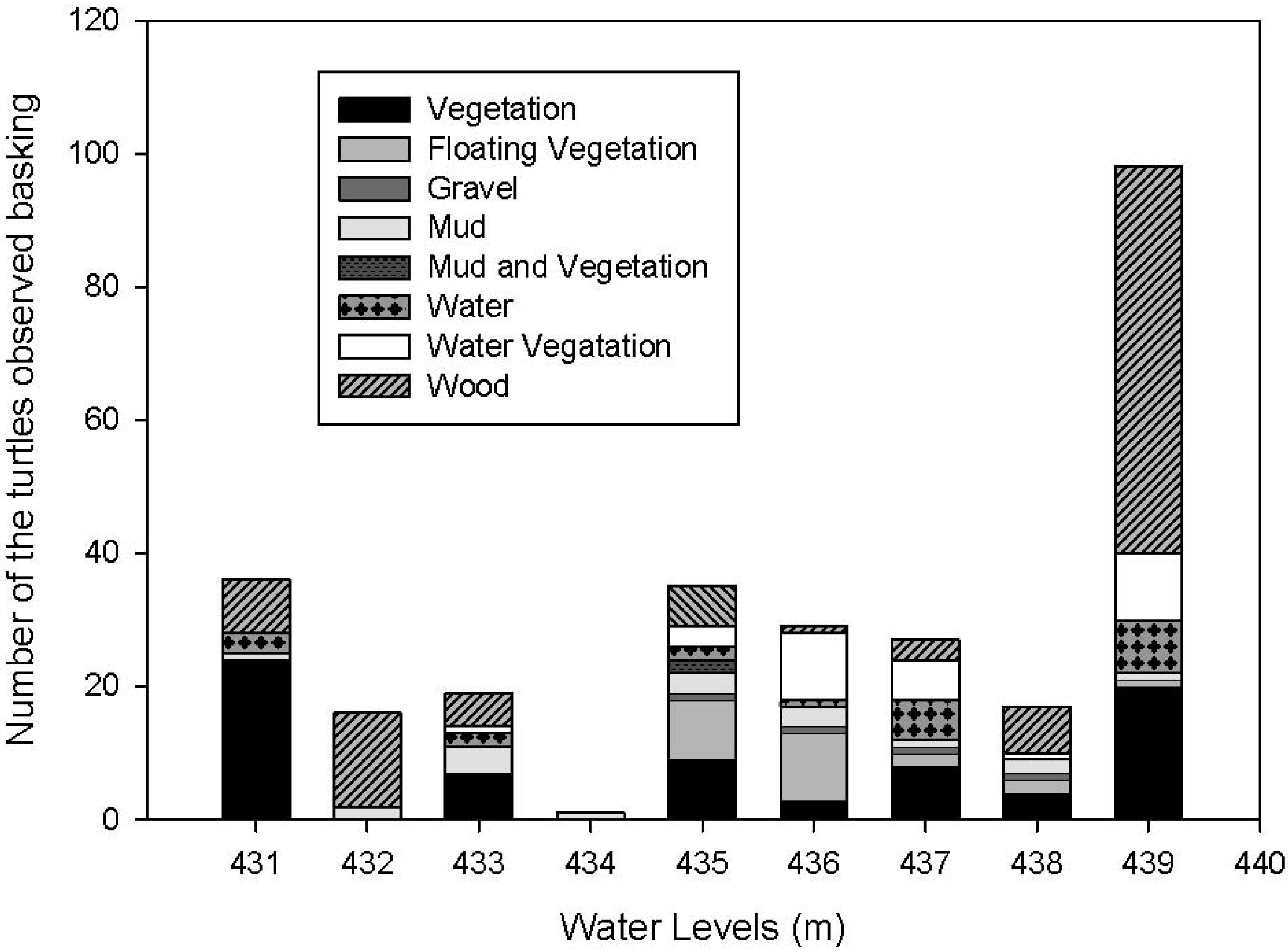

Figure 2-5 Use of different basking substrates by turtles in Revelstoke Reach in relation to changing water levels.

Discussion

This study is the first to focus on the ecology of a northern Canadian turtle population in an environment that experiences dynamic changes in water levels. The results of this study suggest that the turtles occupying the reservoir are able to cope with the local northern environment in a fashion similar to that reported for populations occupying more natural habitat. Overall, extremely little movement of the turtles occurred between the two primary study sites in the reservoir, and even less between the reservoir and the unknown upland areas based on my ability to detect the movement of turtles within the reservoir. Turtles remained within the reservoir to hibernate, with the exception of one, and were found using both scattered locations and a communal location. Changes in the water level of the reservoir did not appear to exert a significant effect on the turtle behaviours measured in this paper, but timing in relation to the nesting season and water temperature did seem to play a role. Changes in water levels also appear to influence the substrates that are used by turtles. The limitations of this study notwithstanding, the plastic behaviour of this animal appears to allow turtles to cope reasonably well with the anthropogenic reservoir environment, although the fortuitous physical structure of the two habitat 'pockets' may be responsible to a large extent in allowing the turtles to persist in the reservoir.

Population Assessment

The density of the reservoir population appears to be comparable to that reported for other populations of northern painted turtles within British Columbia (Kikkomun Creek Provincial Park; populations in six lakes ranged from 0.9 – 7.2 turtles/ha; Macartney and Gregory 1985), but comparative data with other turtle populations in fluctuating water bodies are scant. A study conducted in Ontario (Yagi and Litzgus 2012) investigated the effects of natural flooding (caused by beavers) on a spotted turtle (*Clemmys guttata*) population, and reported a population density of 1.6 turtles/ha prior to the flooding and 0.7 turtles/ha post flooding. It appears that turtle populations and densities can fluctuate dramatically within natural systems and these numbers may be affected by size of the habitat, and the detectability of the turtles. However; at the time of this study it appears that the density of the Arrow Lakes Reservoir population is comparable to that of other northern turtle populations that also deal with natural fluctuations in water levels. However, this density is low in comparison to populations of the same species in more southern latitudes where turtle densities can reach or exceed 100 turtles/ha (Gibbons 1968; Eskew *et al.*, 2010).

The bias in the sex ratio of the reservoir population appears to be related to the sampling methods, as hand captures and basking traps seem more effective at capturing females then males. A female-biased sex ratio appears counter intuitive to what would be predicted for this area; a cooler climate with potentially colder nest temperatures would normally favour a male bias (Schwarzkopf and Brooks 1985). Female-bias sex ratio, which may be the product of the same sampling methods - have been detected in other turtle populations at the northern extent of their range, such as for painted turtles in southern British Columbia (ratios of 1:1.8, 1:1.3, and 1:1.8 at three different lakes - Macartney and Gregory 1985), for stinkpot turtles (0.6:1) and common map turtles (1:2) in the St. Lawrence Islands National Park in Ontario, Canada (Carriére 2007. If a female bias truly exists, future study will be needed to investigate the mechanism responsible.

This is the first assessment of painted turtles in this reservoir and because there is no historical information for comparison, I cannot provide even a tentative comment on the status (increasing, decreasing, or stable) of the population. However, the age and sex class structure of the population contains a relatively large number of reproductive females and neonates. This distribution is similar to other turtle populations that have been studied in southern British Columbia (Macartney and Gregory 1985). Identifying differences in age and sex class structure can be important in determining if a specific sex is being affected and potentially what life stages are being impacted. For example, differences is age class structure could be attributed to lower recruitment rates within an area or a sampling bias resulting from juveniles and neonates being smaller, and more cryptic (Ream and Ream, 1966; Reese and Welsh 1998; Gamble, 2006). Reese and Welsh (1998) identified that lower neonate and juvenile survival in a reservoir population in California may be attributed to fluctuations in water levels that eliminate shallow shoreline microhabitat sites that young animals require. If more detailed studies shared this finding, management recommendations regarding maximum outflow for reservoirs may be established to maintain shallow shoreline habitat during certain times of the year, such as winter emergence or when neonates first exist their natal nests.

My data on the size and age class distribution of this population argues that a demographic collapse in the near future is unlikely, as mature females appear reasonably common, nesting was generally successful during my study, and movements between the upland and the reservoir sites appear infrequent. However, my ability to detect movements was biased towards the movement of the reservoir turtles and not the movement of the upland turtles and the survival rate of the neonates and juveniles is unknown. Therefore monitoring changes in the age and sex class distributions over time are essential in determining the long-term persistence of the population and whether these numbers are influenced by movement between the upland locations.

Nesting Locations and Threats

The majority of turtle species in Canada are semi-aquatic, relying heavily on aquatic habitat with varying degrees of terrestrial habitat use. Akin to many amphibians, this combination of habitat requirements makes populations of these turtles more likely to become threatened and complex management plans may be required. My observations of nesting by turtles occurred in habitat patches above the high-water mark of the reservoir, suggesting that these sites or the nesting efforts of the female turtles are not threatened by reservoir operations. However, potential problems may still exist in the following ways: (1) although communal nesting sites and site fidelity are common in painted turtles and other turtle species (Schwarzkopf and Brooks 1987; Rowe *et al.,* 2005), the predominant use of only two nesting sites by females in the reservoir may reflect a shortage of alternative sites (Yagi and Litzgus 2010), brought on by the creation of the reservoir and its operations, (2) the distance to water a neonate faces when emerging from its natal nest can be greater than that of when the female laid her eggs resulting in an increased risk of predation on the neonates (Marchand *et al.,* 2002), road mortality, desiccation or starvation as the neonates make their way to the water, or (3) these nesting sites could be increasingly impacted by the succession of vegetation and canopy cover that decreases the solar heating of the site. Although succession is a natural process, the negative effects on population with few nesting sites may significantly affect the long-term persistence. (4) Lastly, my sample of female turtles was limited, and therefore I cannot rule out the possibility that at least some animals may be attempting to nest within the drawdown zone leading to subsequent inundation.

Overwintering

My data clearly show that the animals were able to successfully hibernate in the reservoir, but a more striking observation is the differences in hibernation tactics used by turtles in the two neighbouring sites. This seems to reflect the plastic nature of hibernation in these animals: the adoption of the floating mass of vegetation as an overwintering site by turtles in the MS site contrasts sharply with the more dispersed hibernation by turtles in the AP site. Limited overwintering habitat for ectotherms may be common in areas of colder climates (Litzgus *et al.,* 1999), causing communal hibernacula to develop even though individuals do not benefit directly from the presence of their conspecifics (Shine *et al.,* 2004). Or, it is possible that the use of communal hibernation sites aids in the mating process for a species, such as that seen for garter snakes (Gregory 1974). This has been postulated for at least two turtle species (*Clemmys guttata* - Litzgus *et al.,* 1999; *Glyptemys insculpta* - Greaves and Litzgus 2007). From a conservation standpoint, however, communal hibernacula increase the risk of mass mortality occurring over winter. More focused research on the factors that may be causing these different hibernation patterns or tactics in two neighbouring pockets of turtles is underway (Leeming and Larsen, in progress), which will provide a better understanding of the winter ecology of these animals.

Mortality

None of the turtle mortalities detected in this study could be directly attributed the reservoir operations. However, the identification of mortality sources and survival rates over time for age and sex classes will provide insight into the dynamics of the population as well as potentially identifying areas of concern where management can focus.

Habitat Space, Turtle Movements, Turtle Behaviour, and Environmental Effects

The analysis of habitat use by animals such as semi-aquatic or aquatic species like turtles is made difficult by the uncertainty of what habitat is available, given that availability is a function of both landscape and animal behaviour (Brown 2008In addition, pinpointing the location of an individual turtle (and thereby in theory linking it to habitat features) is complicated by the fact that animals are often submerged, and/or the approach by researchers to get visual confirmation will often cause the animals to move (pers. observ.) This movement may be random due to instinctive movement behaviour, or influenced by encountered habitat (Brown 2008). Other attempts to quantify the use of habitat by turtles have focused on terrestrial movement, nesting (Brown 2008), basking habitat (Lambert *et al*., 2013), or the ability to detect turtles according to habitat type (Bury and Germano 2003; Trans *et al*., 2007). Other researchers have made assumptions that all similar habitat in the study is available, and then have looked at multiple habitat scales in order to quantify habitat selection (Edge *et al*., 2010) or have compared turtle locations to random locations (Harden *et al*., 2009). The turtles in my study did not show a difference in habitat space use between high water and low water when all turtles locations in each site were combined or when sites where compared. Future research on the habitat selection of these turtles may benefit from the use of more sophisticated technology

The turtles in my study population demonstrated that basking events were detected more on floating pieces that as water levels rose Turtles residing at the MS Site were most often detected along the shoreline of the mainland or on the floating matt of vegetation, particularly when water levels peaked and completely inundated the area, connecting the MS site to the main stem of the river (Chapter 1; Study Sites). During hibernation, this floating matt of vegetation appears to provide a unique habitat and cover for the turtles. Conversely, in my other study site (AP), areas that were above water at the start of each active season became submerged when water levels rose, but not to the same extent as the MS site, thus creating shallow aquatic habitat in otherwise dry areas. This increase in the wetland system helps explain why turtles within the AP Site were most often detected in marsh habitat, and this seasonal creation of habitat may be beneficial to the population (Yagi and Litztgus 2012). Some variation in movement may be partly due to differences in habitat at the two sites and by the fluctuations in water levels. The shorter movements detected in juvenile turtles may be because the rise in water level eliminated the shallow waters that they utilize (Reese 1996; Reese and Welsh 1998), therefore resulting in decreased movement until they become strong enough swimmers. These differences in habitat could potentially lead to higher energetic costs or risk of predation for the affected turtles (Reese 1996; Grayson and Dorcas 2004), but future work will be needed to elucidate this.

Despite the number of ways that change in the reservoir water level could impact the turtles, I did not detect any significant changes in my measurements of behaviour. The turtles in my study used a wide-array of habitats/basking sites, suggesting a plastic response to not only site-specific differences in habitat but also more sweeping changes brought about by the fluctuating water levels. During low water, the turtles used emergent vegetation to bask, but once water levels rose, they were more frequently found at the surface of the water, using aquatic vegetation or partially-submerged wood to position themselves. These data should not be taken to indicate habitat selection per se: determining selection for these or other habitat features is complicated for this system, given that most turtle detections were underwater or basking. Nonetheless, the data suggests that turtles in MS can be found on the shoreline relatively more often, and that the main population of reservoir turtles exists within these two sites, but the reasons for doing so remain to be determined (i.e. shortage of basking sites versus less suitable aquatic habitat).

Conclusion

Overall, this study indicates that this turtle population seems outwardly capable of coping with the reservoir environment, demonstrating little displacement or shifts in behaviour due to changes in water levels over the course of the active season. Behavioural plasticity also appears to allow them to exist in patches of reservoir habitat that differ at a more local scale. However, as mentioned, the stress exerted on populations of turtles and other aquatic species by reservoir operations will likely vary tremendously from site to site, and through time. Furthermore, the persistence of turtles in this location may be due in some part to the serendipitous formation of habitat ‘patches’ after the reservoir was filled (sites AP and MS) rather than careful planning or engineering (e.g. land contouring) during construction. With little historical inventory data, it is difficult to say whether the reservoir augmented or decreased the amount of habitat available for WPT in this region. In general the continued study of animal populations living in extreme environments (both anthropogenic and natural) is needed to develop long-term, effective management strategies for these populations.

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CHAPTER THREE

MANAGEMENT IMPLICATIONS AND FUTURE RESEARCH

Introduction

The overarching goal of this thesis was to provide an ecological baseline for an extreme-northern population of western painted turtles (*Chrysemys picta bellii*) that inhabits a hydroelectric reservoir in British Columbia Canada. At the same time, I directed my data collection towards understanding the potential effects of reservoir operations on the turtles. Beyond this, it was my intention to provide information to BC Hydro and other organizations that would help in crafting effective management strategies for these animals. Western painted turtles are provincially a Blue-listed species and the intermountain population is listed as “Special Concern” under Schedule 1 of the federal Species at Risk Act (SARA 2008) (COSEWIC 2006). Due to the status of the species, its regional importance, the location of the population at the northern extent of its range, and the increase in the demand for hydroelectric power, the need for understanding the ecology of WPT at my study site may be critical to their long term persistence.

In the preceding chapter, I examined various aspects of turtle ecology and commented that despite the dynamic and anthropogenic nature of the reservoir, the turtle population I studied did not appear noticeably different from other northern population densities, at least within the two main sites within the reservoir that turtles occupy. Water levels altered available habitat in varying degrees and these changes appeared to have no significant effect on turtle behaviours (average daily distance, distance to shore, and basking). However, season and water temperature did appear to have a significant effect of the turtle behaviours as defined in this study. Water levels did appear to influence the substrate upon which turtles were detected basking, although I cannot comment on the repercussions of this apparent forced-change. Finally, no mortalities that were detected over the course of this study could be directly attributed to reservoir operations.

Management Implications and Recommendations

There are a number of management issues that emerged from my study in regards to water level fluctuations, these include;

1. Habitat alternation, including basking sites, when water levels fluctuate
2. loss of quality nesting sites above the drawdown zone;
3. unidentified nesting sites above and below the high water mark; and
4. potentially limited overwintering habitat.

In addition to these issues raised in Chapter 2, I believe there are several other important - perhaps more important - issues that may ultimately affect the persistence of these animals. Observations of nesting turtles occurred primarily in habitat patches above the high-water mark of the reservoir, suggesting that these sites and the nesting efforts of the majority of female turtles are not threatened by reservoir operations. However, these sites are all anthropogenic in nature and occur in areas of high human and vehicle traffic. I also cannot completely rule out that some individual turtles may be nesting within the drawdown zone, leading to the inundation and death of the eggs come high water. All of the nest sites I detected were anthropogenic in nature, suggesting this may be the overwhelming pattern along the reservoir. Further, within these sites vegetation encroachment may be an issue, as I detected a number of situations where eggs or neonates still in the nest appeared to have been killed by the growth of plant roots.

Turtles crossing the road to move between water bodies or to nest are subject to road mortality. Over the course of this study three adult turtles were found killed along the road, which is parallel to the reservoir during the nesting season. One of these animals was confirmed to be a gravid female, and due to the timing of the movements by the other turtles, which were during the nesting season, it is likely that they were also mature females. Because turtles are characterised by low annual recruitment, high adult survival rate, and delayed sexual maturity particularly in northern climates, the mortality of sexually mature turtles, specifically females, can significantly alter the population structure (Steen and Gibbs 2004).

The winter month’s sub-zero temperatures may also be a source of mortality due to hypoxic water conditions and lack of other resources (St. Clair and Gregory 1990) or alteration of the temperature regime to changing water levels that causes freezing. Winter telemetry and early spring surveys revealed that adult and juvenile turtles overwinter within the drawdown zone, that turtles overwinter independently at scattered locations as well as in a communal location, and that some site fidelity was seen. No turtle mortalities could be directly attributed to the reservoir operations, including those deaths suspected to be winter mortalities. Overall my winter results are limited due to my sample size and additional work is needed to comment on the exclusivity of these sites for hibernating. Frequent and detailed locations of WPTs should be collected over the course of the winter (beyond the feasibility of this project), along with data on water depth, flow, temperature, and dissolved oxygen to determine if overwintering habitat is a limiting factor. This work is now in progress (Leeming and Larsen, in progress).

The potential importance of habitat and land-use decisions above the reservoir high-water mark may need to be better incorporated into the current management goals and hypotheses steering turtle research and mitigation efforts in this area. Certainly, turtles from the reservoir move between water bodies upland of the reservoir, nest above the high water mark, and cross roads above the reservoir. Furthermore, there was no historic data that would aid in assessing how the original construction of the reservoir altered the environment and available habitat for the turtles. The magnitude and implications of these observations are not well understood at this point in time, but there is most likely some relevance; for example, the alteration of the two known communal nesting sites and/or increased mortality to dispersing young or reproducing females would impact the reservoir population. Ensuring the long-term persistence of the population of turtles in the reservoir will likely require a partnership between h stakeholders and resource managers to consider the following recommendations:

- removal of encroaching vegetation to maintain current nesting sites;
- research to investigate the utility of artificial nesting sites, their proper placement (e.g., solar radiation, soil type, and distance to water);
- the establishment of artificial basking sites and/or vegetated islands providing permanent habitat for turtles when water levels are high and their traditional basking sites are inundated;
- focused research to determine what turtles are selecting for, diet and food availability in relation to the thermal profiles of the reservoir and upland ponds;
- focused research to determine neonate and juvenile survival and habitat use;
- focused research on hibernation ecology, and protection of hibernating locations with emphasis on communal sites where the animals are at risk of mortality; and
- possible design and construction of artificial habitat in the reservoir that may include vegetated floating island, basking sites, or a berm in areas to create wetland habitat sheltered from the main stem of the Columbia River and water fluctuations.

The Revelstoke WPT population not only faces the challenge of living in one of the most northerly locations for the species, but also in a constantly fluctuating environment due to hydroelectric operation. To identify direct and indirect impacts of reservoir operations on the turtles, a combination of methods must be used to identify population demographics, habitat use, overwintering and nesting locations, and the presence of critical habitat within the reservoir over varying water levels. Results from further research, particulary habitat use of juveniles and neonates may be important in identifying management recommendations in relation to restricting the amount of water being release during the time when neonate turtles are emerging from their nests and juveniles from winter hibernation. Increased water levels may eliminate habitat required by this age class, skewing the age class of the turtle population (Reese 1996; Reese and Welsh 1998). Restrictions to high water levels during this sensitive time may reduce these potential effects. Turtles are a long-lived species, therefore long-term monitoring is needed because of the lag time required to identify more subtle impacts on the population (Reese 1996; Reese and Welsh 1998). My research provides the foundation upon which to develop a long-term strategy for this population and also provides a baseline for future studies. Additional focused work on these and other turtles inhabiting such dynamic environments may provide insight into how populations will be able to persist through subtle and drastic changes in their environment.

Conclusion

Animals occupying atypical environments, such as reservoirs or at the edge of their range, often face stronger selection pressures than animals occupying the region within the core of their range. This therefore will impact their habitat use, movements, recruitment, and survival rates (Lescia and Allendorf 1995; Arvisais *et al.,* 2002). The results of my study identified the basic ecology of the turtles in the reservoir and could not attribute any direct effects of the reservoir operations on the turtle themselves. However; this research identified that there is a high potential for mortality to occur at the nesting sites due to urban development and the succession of vegetation, and management of the population may require strategies that are not necessarily related to reservoir operations. Appropriate management for this species and other semi-aquatic species that reside within drawdown zones is complex, given the reliance on both terrestrial and aquatic habitat, the life cycles of the species, movement between water bodies and sites, the dynamic nature of hydroelectric operations, and the potential impact of freezing temperatures. These factors will all need to be considered in tandem with the life-cycle of the focus species. For example, the release of water in reservoirs further south may have to account for multiple clutches laid by turtles throughout the year, complicating the timing of the water release Management and mitigation plans should focus on determining sources of mortality, boosting recruitment (Reese 1996), and maintaining critical habitat features for each species.

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APPENDIX A. SUMMARY OF RADIO TAGGED TURTLES AND THEIR MOVEMENTS

Table A-1 Summary of radio-tagged western painted turtle (*Chrysemys picta bellii*) with more than one location, in Revelstoke Reach of the Upper Arrow Lakes, British Columbia.

Turtle Name	Number of Locations	Mean	±SE	Distance Travel (m)	Minimum (m)	Maximum (m)
T2	11	141.0	76.6	1409.6	2.2	627.9
T3	11	553.0	147.0	5526.0	58	1299.0
T4	12	187.9	96.7	2066.4	4.5	1105.0
T5	14	158.6	44.9	2061.8	16.2	559.3
T6	10	141.6	54.4	1416.3	1.0	438.0
T7	14	339.5	65.1	4073.9	51.9	660.5
T11	9	83.0	23.7	664.0	1.0	215.6
T12	7	136.6	99.1	819.6	7.1	627.4
T13	6	473.0	278.0	2367.0	8.0	1474.0
T32	29	354.0	104.0	9555.0	1.0	2445.0
T43	14	177.7	53.1	2310.3	5.1	483.4
T47	17	527.0	220	8425.0	2.0	2712.0
T61	36	303.8	98.9	10329.7	3.6	2601.0
T64	37	489.0	194.0	17116.0	1.0	4998.0
T65	11	1174.0	500	11740.0	32	4634.0
T74	28	217.2	35.5	5864.6	0.0	749.7
T79	5	110.8	56.6	443.0	1.0	269.5
T80	17	377.4	92.3	6038.7	12.0	1273.3
T81	17	285.3	66.0	4565.4	24.3	900.9
T82	11	286.0	114.0	2860.0	4.0	997.0
T84	20	309.9	95.5	5888.1	3.2	1415.7
T85	19	120.4	32.3	2168.0	6.7	508.2
T86	19	455.5	93.2	8199.4	8.2	1203.4
T87	18	370.7	96.8	6302.5	3.0	1304.9
T88	20	281.8	83.2	5354.5	1.4	1254.5
T90	16	623.0	229.0	9350.0	2.0	2921.0
T91	18	729.0	259.0	12400.0	6.0	3948.0
T97	17	240.8	59.6	3853.0	4.0	903.7
T98	8	552.0	338.0	4413.0	11.0	2887.0
T99	21	459.0	107.0	9182.0	61.0	1755.0
T104	15	141.9	44.8	1987.1	3.0	591.3
T106	14	301.0	111.0	3913.0	17.0	1270.0
T107	16	152.8	62.5	2292.4	5.4	679.0
T110	15	507.6	89.5	7106.0	47.9	1178.5
T111	13	289.0	70.1	3468.0	48.5	917.1
T114	12	415.0	117.0	4983.0	13.0	1217.0

Turtle Name	Number of Locations	Mean	±SE	Distance Travel (m)	Minimum (m)	Maximum (m)
T2	11	141.0	76.6	1409.6	2.2	627.9
T3	11	553.0	147.0	5526.0	58	1299.0
T4	12	187.9	96.7	2066.4	4.5	1105.0
T5	14	158.6	44.9	2061.8	16.2	559.3
T6	10	141.6	54.4	1416.3	1.0	438.0
T7	14	339.5	65.1	4073.9	51.9	660.5
T11	9	83.0	23.7	664.0	1.0	215.6
T12	7	136.6	99.1	819.6	7.1	627.4
T13	6	473.0	278.0	2367.0	8.0	1474.0
T32	29	354.0	104.0	9555.0	1.0	2445.0
T43	14	177.7	53.1	2310.3	5.1	483.4
T47	17	527.0	220	8425.0	2.0	2712.0
T61	36	303.8	98.9	10329.7	3.6	2601.0
T64	37	489.0	194.0	17116.0	1.0	4998.0
T65	11	1174.0	500	11740.0	32	4634.0
T74	28	217.2	35.5	5864.6	0.0	749.7
T79	5	110.8	56.6	443.0	1.0	269.5
T80	17	377.4	92.3	6038.7	12.0	1273.3
T81	17	285.3	66.0	4565.4	24.3	900.9
T82	11	286.0	114.0	2860.0	4.0	997.0
T84	20	309.9	95.5	5888.1	3.2	1415.7
T85	19	120.4	32.3	2168.0	6.7	508.2
T116	14	267.9	67.8	3482.2	28.3	921.4
T117	12	307.2	85.4	3379.2	12.2	818.0
T120	11	124.1	26.8	1241.4	18.0	267.4
T129	6	54.3	36.1	271.7	8.2	197.6

APPENDIX B. JUVENILE AND ADULT MAPPED LOCATIONS

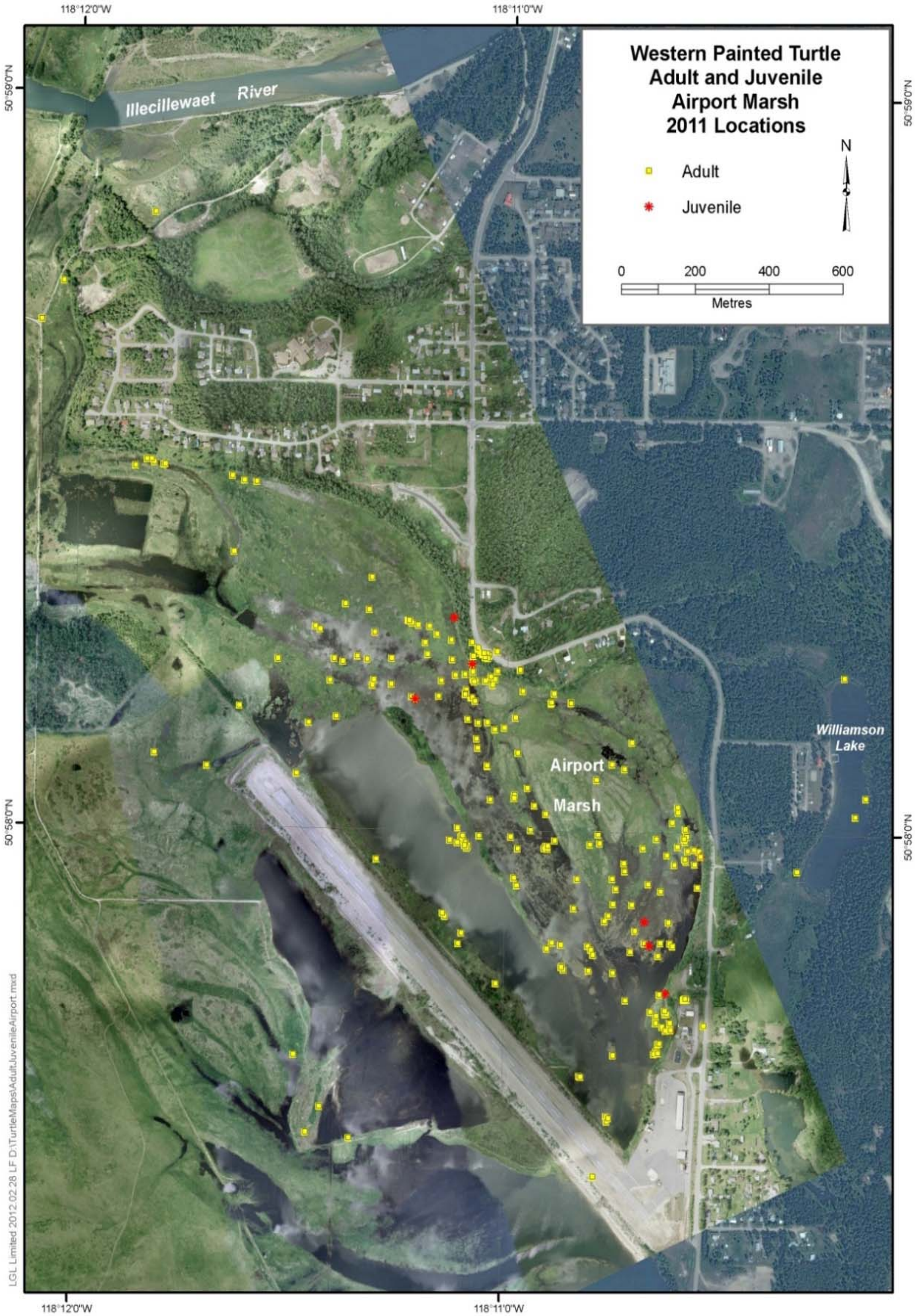


Figure B-1 Adult and juvenile turtle locations during the 2011 season in Airport Marsh, Upper Arrow Lakes, British Columbia, Canada (LGL 2012).

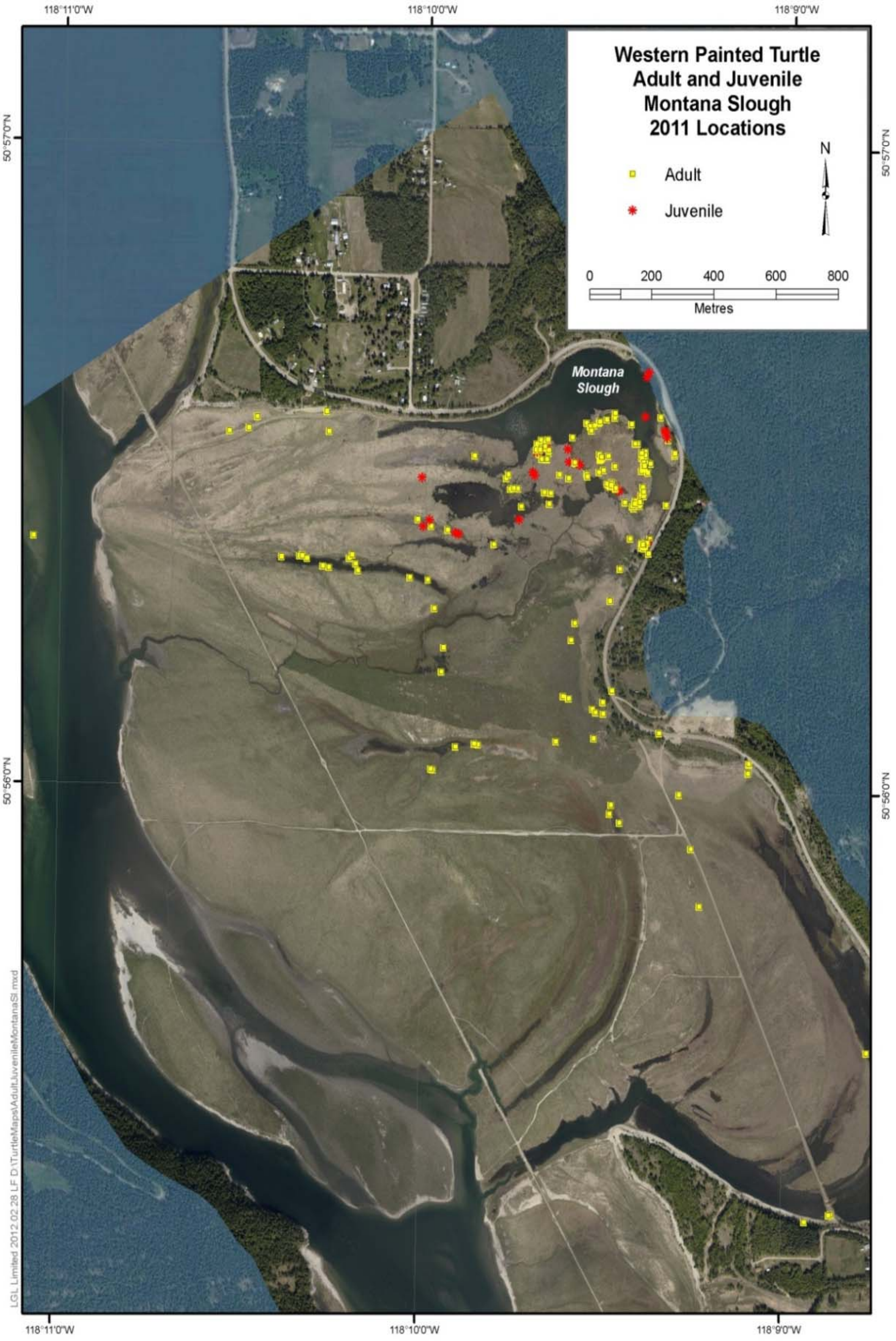


Figure B-2 Adult and juvenile turtle locations during the 2011 season in Montana Slough, Upper Arrow Lakes, British Columbia, Canada (LGL 2012).

APPENDIX C. MALE AND FEMALE MAPPED LOCATIONS BY SITE

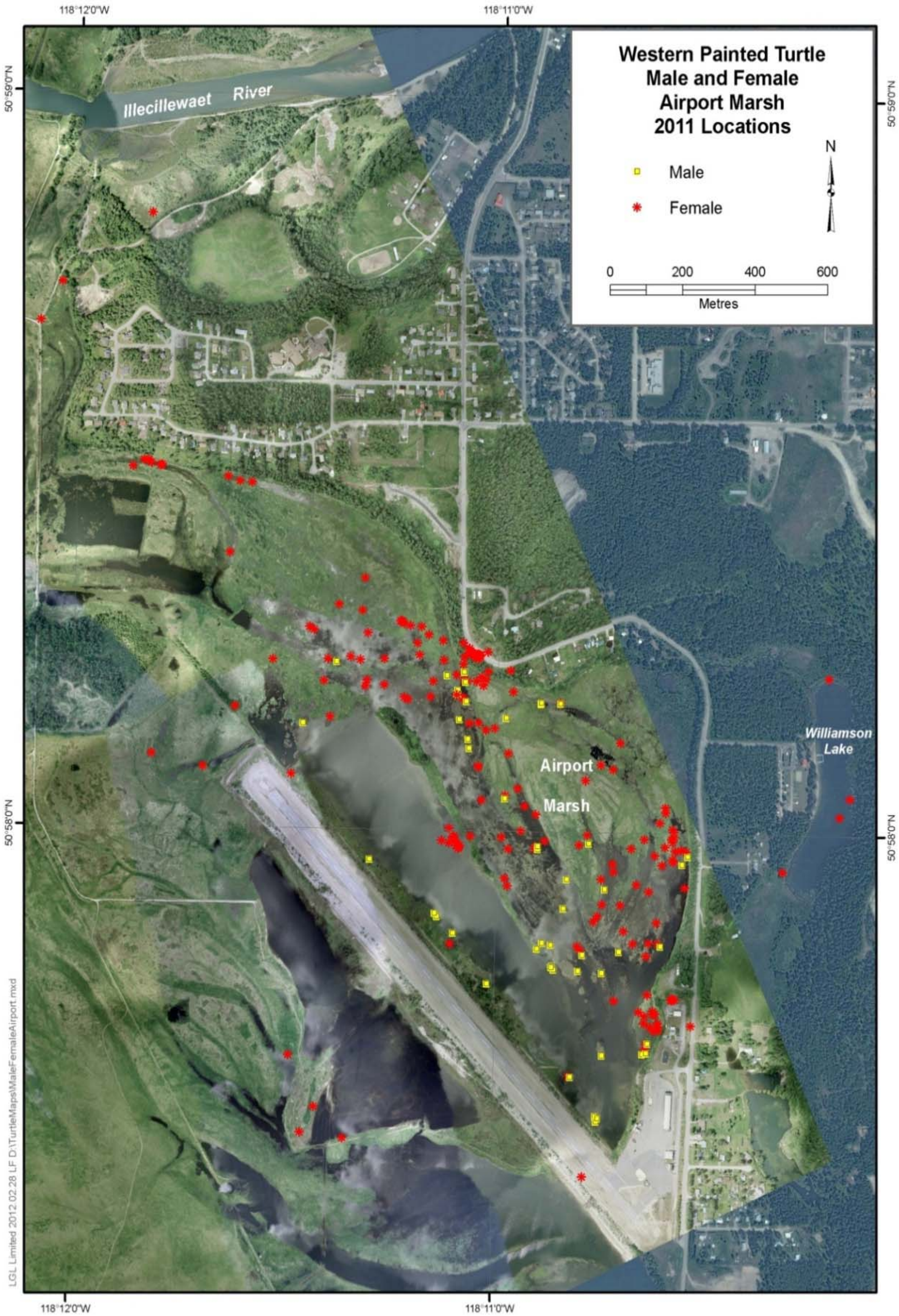
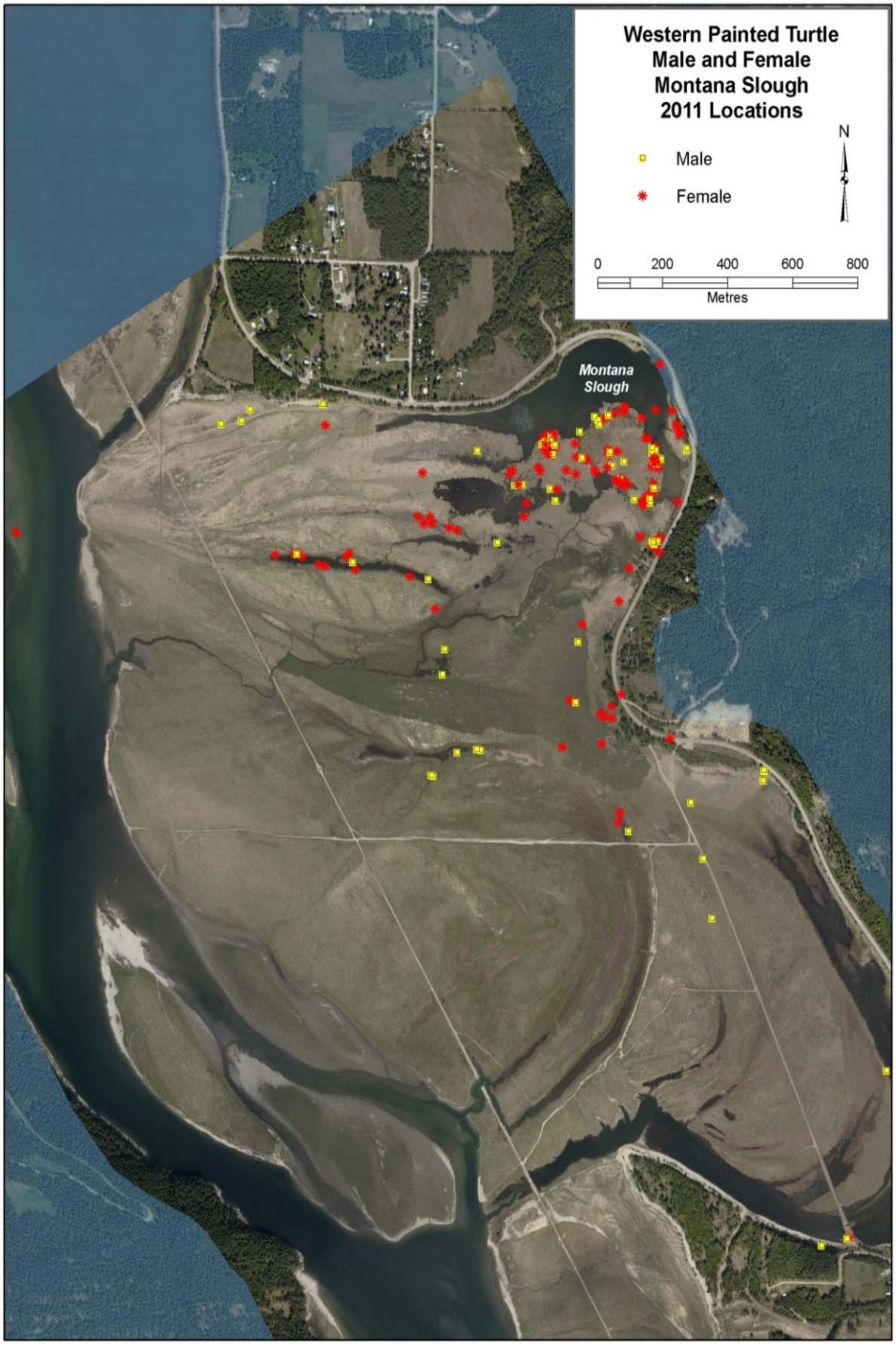


Figure C-1 Adult male and female turtle locations during the 2011 field seasons in Airport Marsh, Upper Arrow Lakes, British Columbia, Canada (LGL 2012).



LGL Limited 2012 02 28 LF D:\TurtleMaps\MaleFemaleMontanaSl.mxd

Figure C-2 Adult male and female turtle locations during the 2011 field seasons in Montana Slough, Upper Arrow Lakes, British Columbia, Canada (LGL 2012).

APPENDIX D. MAPPED OVERWINTERING LOCATIONS BY SITE

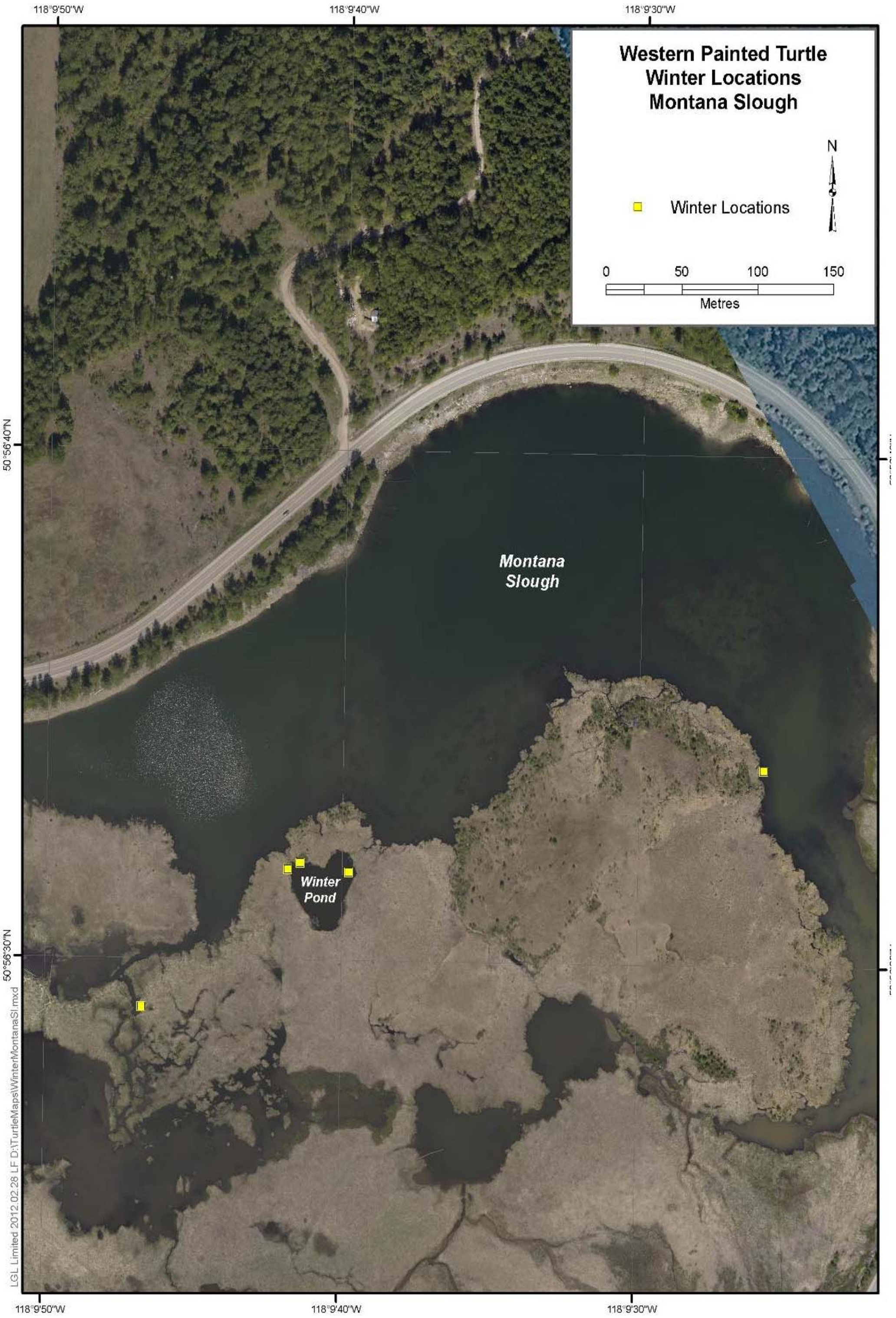


Figure D-1 Overwintering locations identified in Montana Slough during the winter of 2010 and 2011. Communal hibernation site is located in a pond known as 'Winter Pond', Upper Arrow Lakes Reservoir, Revelstoke B.C. (LGL 2012).

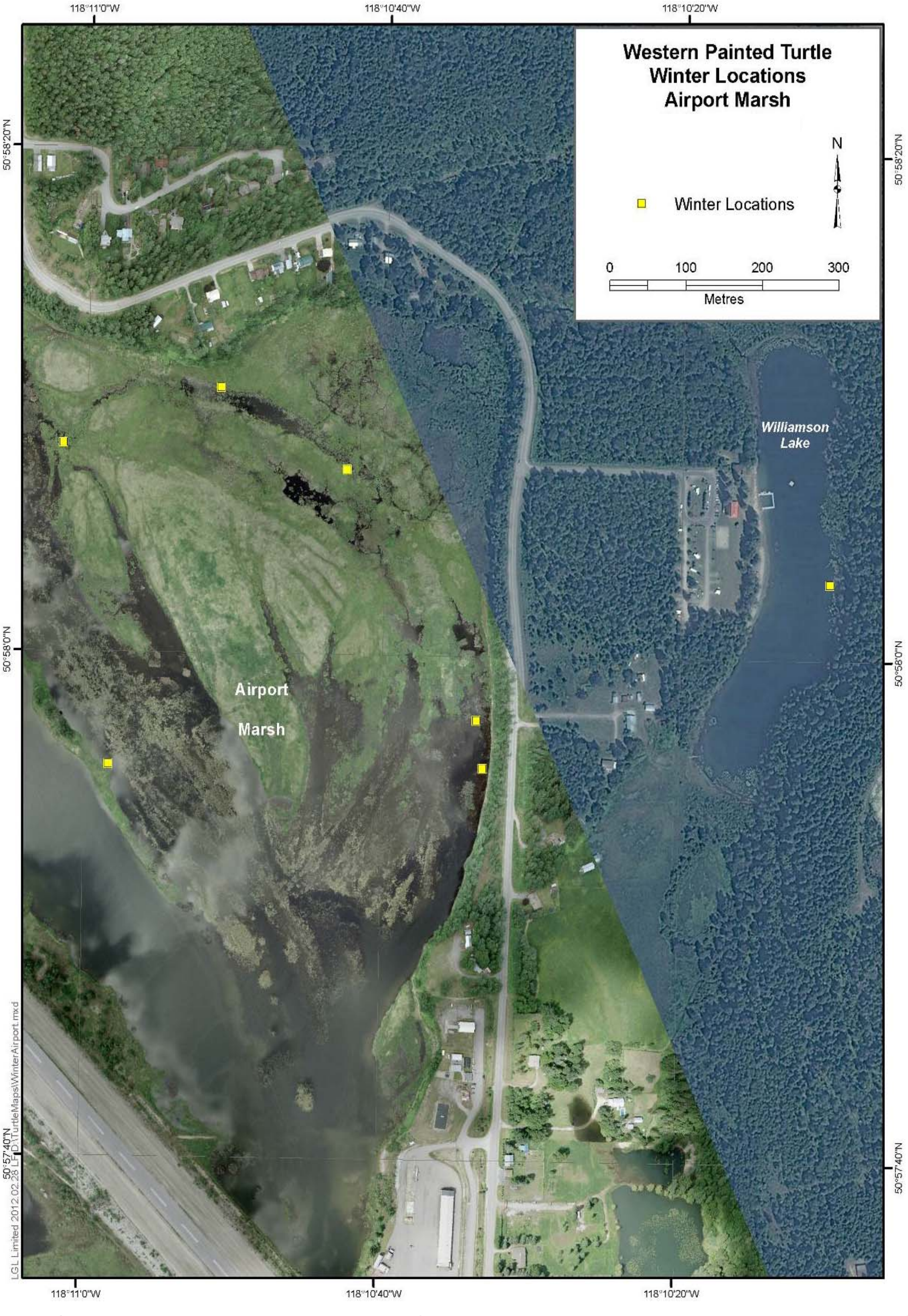


Figure D-2 Overwintering locations identified in Airport Marsh during the winter of 2010 and 2011. One turtle left Airport Marsh and overwintered in Williamson Lake during 2010, Upper Arrow Lakes Reservoir, Revelstoke B.C. (LGL 2012).

APPENDIX E. - REVELSTOKE REACH WESTERN PAINTED TURTLE (*CHRYSEMYS PICTA BELLII*) MONITORING PROGRAM: TURTLE DETECTABILITY IN THE RESERVOIR

INTRODUCTION

The Western painted turtle (WPT) (*Chrysemys picta bellii*) is a species federally listed as Special Concern and Endangered under the Species at Risk Act and provincially listed as ‘Blue’ and ‘Red’ listed (SARA) (COSEWIC 2006). The turtle’s habitat ranges from Ontario to the west coast, and it is the only native freshwater turtle in British Columbia and Alberta. The WPT thus plays a vital role in maintaining the biodiversity for not only these provinces, but also all of Canada (Blood *et al.,* 1998; COSEWIC 2006). WPTs are long-lived reptiles with high rates of juvenile mortality and low nest success (COSEWIC 2006). Turtle populations in the west are believed to be diminishing due to human disturbances such as loss of wetland habitat, road construction, increased recreational activities (Garber & Burger 1995; Blood *et al.,* 1998), and, potentially, hydroelectric operations. The limited knowledge about their populations, demographics and their ecological roles in their environment contribute to the at-risk status of WPTs (COSEWIC 2006).

I conducted research on the WPT at the northern extent of their range in the Columbia River system where this species is recognized as a special conservation concern (Golder Associates 2009). British Columbia Hydro & Power Authority (BC Hydro) funded my main project investigating the population demographics and movements of the turtles within the Arrow Lakes Reservoir near the town of Revelstoke, BC. The animals appear to be confined to a limited area of the reservoir known as Revelstoke Reach. This population is of interest because of the potential impacts reservoir operations may have on turtle survivorship and productivity, and because of the peculiarities of the habitat (northern reservoir at the fringe of their distribution). My project involved a two-year field examination that began in April 2010, assessing the impacts of reservoir operations on these animals and making recommendations for habitat enhancement. A conventional mark-recapture protocol is being used alongside a radio-telemetry program to determine population demographics and impacts, if any, caused by fluctuating water levels on nesting

success and on winter hibernation sites. Additional funding from the Canadian Wildlife Federation (CWF) Endangered Species
Fund permitted us to explore the possibilities of developing a predictive model 'tool' that would aid in census work on the WPT.

Oftentimes, researchers or resource managers are confined by time and or budget as surveys for cryptic species, such as turtles, are time-consuming and often ineffective (Mazerolle *et al.,* 2007). The additional funding provided by the CWF allowed me to take advantage of the animals I was currently radio-tracking as part of the larger project during 2011. Using these animals, I collected data on their activity, and how their 'sightability' related to environmental conditions (i.e. when the animals visible to human surveyors, and how that relates to variables such as time of season, time of day, water and air temperatures, etc.). This information was used to develop a sightability model to aid researchers in determining the best time(s) to conduct surveys aimed at detecting or enumerating turtles within the Arrow Lake reservoir.

I requested support from the Endangered Species Fund to provide an additional summer research assistant to the project (directed in the field by N. Basaraba, an MSc graduate student) and help defer the accommodation costs associated with the hiring. A small portion of the funds were used to purchase temperature data loggers (Maxim Innovation Inc.: iButtons®), wind metres, fuel and other equipment needed to collect data on environmental parameters. My background research in this area provides an opportune situation to collect additional information tailored to aid in the management and conservation of this species.

METHODS

Field work began in May and lasted until the end of August 2011. My ongoing work involved actively searching for WPT throughout the field season by visual surveys and systematic searches. Turtles were observed and or captured whenever possible (i.e. shoreline or terrestrial encounters) and live trapped using basking and hoop traps. Each turtle was assigned to a general size (neonate, juvenile, adult), and behavioural category (basking, swimming, etc.).Each turtle was also measured, weighed and a habitat assessment was conducted.

I used turtles equipped with transmitters (28 turtles; 18 females, 9 males, and 2 juveniles) over the course of the summer and sightings from my systematic surveys from my background project (for a total of 297 locations) to determine whether the animals were capable of being sighted (i.e. basking or stationary in a location where they could, in theory, be observed) or whether the animals were too cryptic to permit detection (i.e. subsurface, or embedded in vegetation).

Each animal was radio-tracked at least once per week. In addition to the weekly location, subsets of turtles (20 of the 28 radioed turtles) were located once a week, at rotating times of the day, to determine whether they were sightable or not. Each week, I selected at least two turtles (paired together for the sake of logistics) that would be more closely monitored over the course of a day (i.e. 0700-1700 hours). The ‘sightability’ of these animals was recorded approximately every 60 minutes, along with more detailed autecology information; permitting better insight into the pattern and process by which the turtles relocate during the course of the day, and how the sightability model might be improved. Initial tracking of the turtle using radio telemetry provided an idea of where the turtle was located; from there, visual scanning (a common method used for detecting turtles) with the naked eyed and or binoculars was used to determine if the turtle was detectable.

At the same time that the above observations were being collected on the turtles, I also collected data on a number of environmental parameters that could potentially be used in isolation or in combination to predict turtle sightability. Such environmental parameters included water and air temperatures at the location where turtles were observed, date, wind speed, precipitation (based on a categorical scale), cloud cover, humidity, aspect (the direction the sun is in respect to the location of the turtle), time of day, activity of the turtle, GPS location, and percent cover of a 5.64 m radius plot (where applicable) of submergent, emergent, and floating leaved-vegetation, grass, shrubs, and trees and if basking sites were present. I also stationed 'dummy' model turtles (rubber replicas, filled with water and equipped with temperature data loggers (iButtons®) that recorded temperature every four hours, on neighbouring basking sites and in other locations (e.g. reed beds) that turtles are known to inhabit (based on my 2010 data). The data from these models were thought to provide a form of 'reference' for the data collected from the real turtles, and (calibration notwithstanding) may be used in future work as an empirical indicator as to whether turtles should be basking or not.

Data were collected on 22 habitat and environmental parameters and model turtle temperatures (closest to the located turtle) to explain turtle sightability using binary logistic regression (detectable=1, not detectable=0; all 'not detectable" locations are considered a false zero; the turtle was present during the survey but not detected; Martin *et al.,* 2005). A correlation analysis was used to detect autocorrelation among the variables. If two variables were highly correlated (R>=0.75 or R<=-0.75) one variable was excluded from the model (Reese 1996). Akaike's Information Criterion (∆AICc and Akaikes weights (AICwt)) was used to determine the 'best' or 'top' model. The model with the lowest ∆AICc was considered the top model given the comparisons; however, models with a change of less than two in the AIC score were considered equivalent models. AICwt, which indicate the level of support in favour of a given model being the most parsimonious, was then used to determine the most parsimonious model (Burnham and Anderson 2002 & 2004). Finally, receiver operating characteristics (ROC) and area under the curve (AUC) were used to evaluate the accuracy of the model variables in determining the detectability of a turtle. Models with areas between 0.5 and 0.7 are considered poor, model areas between 0.7 and 0.9, while model areas greater than 0.90 are considered very good in their ability to measure predictive accuracy (Pearce and Ferrier 2000).

RESULTS

The detectability of the turtles through the use of systematic surveys and telemetry during the 2011 field season was biased toward “not-detectable” (detectable; n=110, not-detectable; n=187, even though the presence of the turtle was confirmed through telemetry.

Of the 103 models evaluated, all models with ∆AICc less than 10 contained habitat and environmental variables and considered basking logs, cloud cover (CC), and date to be influential, while the top seven models included grass and herbaceous vegetation. The top four models have a ∆AICc less than two and are considered equivalent models (Burnham and Anderson 2002). However, the top model (baskingLogs + CC + date.1 + grass.herb) has the most support demonstrated in the AICwt and is considered the most parsimonious model (Table 1), while supporting an ROC score that ranked our top ranked model as reasonable in predicative accuracy (0.76).

Table 1. Summary of AIC, ∆AICc, and AICcWt for the top nine candidate models for predicting the detecting of a turtle within the Revelstoke Reach, Arrow Lakes Reservoir, British Columbia, Canada.

Models	AICc	∆AICc	AICcWt
baskingLogs + CC + date.1 + grass.herb	340.47	0.00	0.48
baskingLogs + CC + date.1 + grass.herb + salix	341.85	1.38	0.24
baskingLogs +CC +date.1 +grass.herb + precipcat	342.57	2.09	0.17
baskingLogs + CC + date.1 + distshore + grass.herb + humidity	344.20	3.73	0.07
baskingLogs + CC + date.1 + totalmin + wtrdepth	346.99	6.52	0.02
baskingLogs + CC + date.1 + totalmin	349.27	8.80	0.01
baskingLogs + CC + date.1 + totalmin + watertemp + windcat + wtrdepth	349.49	9.02	0.01
airtemp + avgwind + baskingLogs + CC + CWDG5 +CWDL5 + date.1 + dew + distshore + eleva + emer + floatleaved + forest + grass.herb + humidity + precipcat + submer + totalmin + watertemp + avgwind + wtrdepth	349.77	9.29	0
baskingLogs + CC + date.1 + totalmin + watertemp	350.08	9.61	0

* totalmin represents the time of day in minutes from midnight

DISCUSSION

My results suggest that the most effective model for predicting the sightability of turtles was that involving basking logs, cloud cover, date, and grass and herbaceous vegetation. The effectiveness of this model suggests it has reasonable potential as a tool for selecting specific times to maximize the chances of sighting a turtle. However, it is important to note that this particular model may not necessarily be as effective when applied to another ecosystem. Variables important to sightability at this location may have less effect elsewhere, or be totally absent.

Research conducted on the basking behaviour of turtles found that turtles optimize body temperature by using the available environmental temperatures, such as air and water temperatures, and that basking is a non- random event (Crawford *et al.,* 1983; Schwarzkopf and Brooks. 1985). Boyer (1965) found that high air temperatures and low water temperatures promote basking. My study looked at the detectability of a turtle in relation to their environment, which included activities other than basking. Crawford *et al.,* (1983) and found that total radiation (solar), air temperature, wind speed, and substrate temperature influenced the environmental temperature of where a turtle was found basking. In my study I found that cloud cover, date, the presence and absence of basking logs, grass and herbaceous vegetation influenced environmental temperatures and the detectability of turtles. Although other environmental and habitat variables were not included in my ‘top’ model, these variables will still have an effect on the environmental temperature as displayed by the global model, which was ranked eighth in my study. Depending on the area being surveyed, these other variables may have varying degrees of influence and should be considered when designing a study.

Vegetation has an important role in the ability to locate a turtle as well as environmental temperature as it provides shelter from predators and the elements, such as wind. Within my study, reed canary grass (*Phalaris arundinacea)* was the dominate vegetation within the reservoir sites and an important factor in detection. A decrease in the surrounding vegetation allowed for an improved probability in turtle detection (Table 2). The presence of basking logs is an important feature for turtles, but turtles may be basking within wetland vegetation, as observed frequently at my sites, and go undetected. Cloud cover plays another important role in air temperature. Solar radiation is reflected off clouds and into space, therefore the greater the cloud cover the less solar radiation reaching the surface decreasing the air temperature, and thus decreasing the probability of detecting a turtle (Table 2). It is not a surprise that date plays an important role in turtle detection as it greatly influences air and water temperatures as well as the growth of the vegetation and should be the top consideration when surveying for turtles (Table 2).

Table 2 Summary of the ‘top’ model variables and their coefficients, standard error and 95% confidence interval s for predicting the detecting of a turtle within the Revelstoke Reach, Arrow Lakes Reservoir, British Columbia, Canada.

Variable	Coefficients	SE	95% CI
Basking Logs: not enough	0.75	0.78	0.19 - 3.52
Basking Logs: sufficient	1.87	0.32	-0.82 - 2.34
Cloud Cover	-0.013	0.0045	-0.023 - -0.0053
Date	-0.010	0.0044	-0.018 - -0.0022
Grass and herbaceous vegetation	-0.38	0.011	-0.062 - -0.017
Intercept	1.84	0.86	0.19 - 3.52

Through the use of telemetry my study was biased towards the detection of turtles, however, my results indicate that turtles were still difficult to detect even with the advantage of knowing the approximate location of the animal. This is important to note because my data likely overestimates the detection of turtles and should be considered when surveying for these cryptic species. In addition, visual surveys are not an effective technique for determining an estimate of the size of a turtle population (Refsnider *et al.,* 2011).

The behaviour of thermoregulation in turtles and other species (Charland 1995) that use their environment to thermoregulate is multifaceted and highly correlated to their environment. Variation arises in habitat and seasonal heterogeneity, gender and age (Crawford *et al.,* 1983; Schwarzkopf and Brooks 1985; Reese 1996; Boulinier *et al.,* 1998; Grayson and Dorcas 2004). Understanding the environmental temperature allows us to better predict the detectability of turtles and thus can be an important tool for resource managers in planning and surveying.

The development of this tool to aid in the detection of turtles will make a valuable contribution to the methods and tools used by biologists and resource managers. Ultimately, the full effectiveness of the selected model has yet to be determined until it can be tested on other populations, or at least on the same population in subsequent years. Further testing of the model will take place within Revelstoke Reach through the continuation of the long-term monitoring strategy for the turtles set forth by BC Hydro, as well as being published in the peer-review literature.

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