Revisiting the Nesting Ecology of the Western Grebe after 40 Years of Changes at Delta Marsh, Manitoba

by **Nicholas LaPorte**

A Thesis submitted to the Faculty of Graduate Studies of
The University of Manitoba
in partial fulfillment of the requirements for the Degree of

Master of Natural Resource Management

Natural Resources Institute
Clayton H. Riddell Faculty of Environment, Earth, and Resources
University of Manitoba
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FACULTY OF GRADUATE STUDIES

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Abstract

Since the 1970s, artificially stabilized hydrology, increased presence of Common Carp (*Cyprinus carpio*), and invasion by a highly competitive cattail hybrid (*Typha x glauca*) have changed the nesting ecology of Western Grebes at Delta Marsh, Manitoba. To evaluate the impact of stressors within Delta Marsh on Western Grebes, I repeated surveys originally conducted by Nuechterlein (1975) on the nesting ecology of Western Grebes at Delta Marsh, and compared 2009/2010 breeding success and nesting ecology data with 1973/1974 data. Reductions in breeding success during 2009 and 2010 were primarily due to increases in rates of nesting losses from wave action. Nests destroyed by spawning Common Carp, and depredations by River Otters (*Lontra canadensis*) further contributed to nesting losses. Reestablishing stands of emergent bulrush around nesting islands and reducing the abundance of carp within the marsh might help return Western Grebe breeding success to rates recorded in the 1970s.

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1.0 INTRODUCTION

"…the call of the grebe is, by some peculiar authority, the sound that dominates the marsh-land chorus. Perhaps, by some immemorial authority, he wields the baton for the whole biota. Who beats the measure for the lakeshore rollers as they build reef after reef for marsh after marsh, as age after age the waters recede to lower levels? Who holds sago and bulrush to their task of sucking sun and air, lest in winter the muskrats starve, and the canes engulf the marsh in lifeless jungle? Who counsels patience to brooding ducks by day, and incites bloodthirst in marauding minks by night? Who exhorts precision for the heron's spear, and speed for the falcon's fist? We assume, because all these creatures perform their diverse tasks without admonition audible to us, that they receive none, that their skills are inborn and their industry automatic, that weariness is unknown to the wild. Perhaps weariness is unknown only to grebes; perhaps it is the grebe who reminds them that if all are to survive, each must ceaselessly feed and fight, breed and die."

Aldo Leopold on the Western Grebes of Delta Marsh, *in* A Sand County Almanac, 1949

The Western Grebe (*Aechomophorus occidentalis*) is the largest waterbird in the grebe family. It is a graceful black and white grebe, easily mistaken for a Clark's Grebe (*Aechomophorus clarkii*), with its slender neck, red eyes, and a long pointy bill for capturing small fish while diving underwater. Often comprised of several hundred nests, colonies of Western Grebes are found in beds of emergent vegetation on the fringes of large lakes and within freshwater wetlands in Western North America. The Delta Marsh, located on the southern shore of Lake Manitoba, has historically been a highly productive habitat for Western Grebes with an initial nesting success rate of 84% and chick-to-adult ratio of 0.88 in 1974 (Nuechterlein 1975). The local population of this species has persisted despite a number of potentially detrimental changes occurring within this coastal wetland ecosystem. Future management strategies being considered for Delta Marsh must take into account their effect on Western Grebes as this species is considered a species of high concern in the Northern Prairie and Parkland Region (Beyersbergen et al. 2004).

The 11,000 ha Delta Marsh Wildlife Management Area was established in June 2006 to protect and enhance natural habitat, conserve biodiversity, provide opportunities for low-impact recreational activities while allowing the continuance of traditional activities such as hunting, fishing, trapping, and agricultural uses (Manitoba Conservation 2011). It is a unique wetland ecosystem that has great potential for eco-tourism and recreation. It is visited by nature enthusiasts because of its biodiversity, lack of motorized water-crafts, and proximity to Lake Manitoba's Delta Beach. Due to its proximity to the urban centers of Portage la Prairie and Winnipeg, Delta Marsh lends itself to the development of further eco-tourism and educational opportunities.

Delta Marsh has been a major nesting area for the Western Grebe in Manitoba. Koonz and Rakowski, (1985) counted 5135 nests from province-wide aerial surveys in 1979; though Western Grebe nests were not detected on Delta Marsh. In 1973 and 1974 at Delta Marsh there were 654 and 585 nests detected, respectively (Nuechterlein 1975). Following Nuechtelein's (1975) study on the nesting ecology of the Western Grebe, information regarding the population at Delta Marsh has been deficient, with a lack of monitoring activities until the 2005 nesting season (Underwood & Rasmussen, 2005). Ducks Unlimited Canada (DUC) and the Canadian Wildlife Service (CWS) conducted one-day colonial waterbird surveys from an airboat, in selected areas of Delta Marsh, during June of 2005, 2006 and 2007. These surveys resulted in counts of 346 Western Grebe nests in 2005 (Underwood & Rasmussen 2005, unpublished data), 307 in 2006 (Bazin et al. 2006, unpublished data), and 588 in 2007 (Bazin et al. 2007, unpublished data). Delta Marsh may generate a significant proportion of the Western Grebe nests produced annually in the province of Manitoba.

Nuechterlein (1975) determined that three primary variables impacted nesting success: wave exposure, water depth and emergent vegetation stem density. Sufficient water depths allow nesting pairs to penetrate farther into nesting islands, thus decreasing the degree to which nests are exposed to waves, while emergent stem densities affect the amount of energy waves can carry to nests (Denny 1988), thus increasing the odds of a nest succeeding. Since the 1970s, nesting success may have declined if changes in the marsh ecosystem have caused nests to be increasingly exposed to wave action, or provide insufficient water depths or sparse emergent vegetation at nest sites.

Declines in nesting success or the availability of nesting habitat in Delta Marsh could impact the provincial population of Western Grebes. Western Grebes, and other wetland birds, are useful indicators of ecosystem function and health because they are acutely sensitive to disturbance (Storer & Nuechterlein 1992), and therefore are useful to assess and monitor environmental change (Caro & O'Doherty 1998). They are likely, then, to respond to changes in habitat structure in Delta Marsh. Delta Marsh continues to be under pressure from invasive hybrid cattail (*Typha* x *glauca*), invasion by Common Carp *(Cyprinus carpio*), and artificially stabilized water levels, which all represent serious threats to the marsh ecosystem (Goldsborough & Wrubleski 2001). Changes in the plant and fish community and reduced variability in marsh water levels may be negatively impacting Western Grebes at Delta Marsh. In light of these ecological changes in the marsh, it is important to re-evaluate the current status of Western Grebes at Delta Marsh.

Long-term fluctuations in water levels are important for wetland conservation and regeneration, as periodic high levels open up areas of dense and overgrown vegetation, and allow for the re-growth of emergent vegetation, particularly bulrush during low water years (Squires & van der Valk 1992). Within Delta Marsh and other coastal marshes of southern Lake Manitoba, the long-term stabilization of water levels may have impacted the composition and structure of emergent vegetation preferred by Western Grebes for nesting (Nuechterlein 1975).

For the most part, inflows from Lake Manitoba regulate the water level within Delta Marsh (Jones 1978). Since the construction of the Fairford River Dam in 1961, Lake Manitoba and Delta Marsh water levels have been managed at the target level of 247.6 masl and have reduced natural hydrological fluctuations to less than ±0.6 m (Shay et al. 1999, Squires & van der Valk 1992; Figure 1). Reduced wetland water level variation increases monotypicity of emergent vegetation (Keddy & Reznicek 1986, Wilcox et al. 1992). This relatively stable hydrological state thus prevents regeneration of the coastal marshes of southern Lake Manitoba (Shay et al. 1999) and possibly reduces the value of the marsh for nesting waterbirds (Koonz & Rakowski 1985, Craigie et al. 2003).

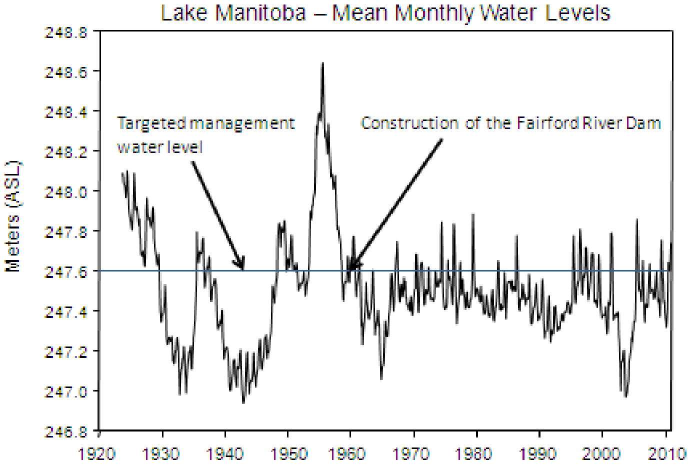

Figure 1. Water levels of Lake Manitoba from 1923 to 2010 (Steep Rock gauging station 05LK002, Environment Canada).

Reservoirs with seasonally fluctuating water levels are considered poor breeding areas for Western Grebes (Storer & Nuechterlein 1992). At the Lake Mead reservoir in Arizona, severe fluctuations in water levels decreased available nesting habitat, giving researchers the impression that Western and Clark's Grebes were not breeding that year (Parmelee & Parmelee 1997). Instead of abandoning the site, Grebe courtship began later that summer near renewed plant growth initiated by raised water levels. However, the first eggs of the season were laid during exceptionally high temperatures in mid-August, and more eggs were laid in the coldest period of mid-December, thus increasing the risk of nest failure (Parmelee & Parmelee 1997). Western Grebes at Old Wives Lake in Saskatchewan unsuccessfully nested on dry land, due to a drop in water levels that made the small lake uninhabitable during the nesting period (Nero 1958). In the long run, hydrological variability is essential in maintaining coastal wetland ecosystems and for the provision of high quality nesting sites; however, production of Western Grebes is likely to be poor during years with low water levels (Nuechterlein 1975) or during seasons with rapid fluctuations in water level (Storer & Nuechterlein 1992).

Over the last four decades other changes in habitat that may influence the nesting ecology of Western Grebes have also been recorded at Delta Marsh. For example, an aggressive hybrid cattail (*Typha x glauca*; Kuehn & White 1999, Goldsborough & Wrubleski 2001) is spreading rapidly throughout Delta Marsh and is out-competing native shoreline vegetation (Shay et al. 1999), which is exacerbated by reduced water level variability (Keddy & Reznicek 1986, Wilcox et al. 1992). Generally, invasive *T.* x *glauca* grows in dense monotypic stands (Boers 2006), as compared to the native *T. latifolia,* which only grows in dense stands when nutrient conditions are high (Day et al. 1988). *T.* x *glauca* also tolerates a wider range of water depths than both *T. augustifolia* and *T. latifolia*, and is a superior competitor in water depths tolerated by its parent species (Waters & Shay 1991, Kuehn & White 1999). Research by Shay et al. (1999) found that continued stable water levels would lead to the eventual in-filling of the smaller bays at Delta Marsh by cattails. As an example of the major changes in the plant community at Delta Marsh from 1964 to 1997, cattail cover (ha) in the isolated Center Marsh increased by 819%, bulrush cover declined by 97%, and open water area declined by 19% (Goldsborough & Wrubleski 2001). An 8% decline in the extent of open-water area in the large bays throughout the East Unit of the marsh from 1974 to 1997, along with the erosion and disappearance of islands of emergent vegetation, has also been recorded (Goldsborough & Wrubleski 2001).

Vegetation structure can influence nesting success in Western Grebes. During the summers of 1973 and 1974, at Delta Marsh, Western Grebes preferred to nest in the densest clumps of bulrush (*Scirpus* spp.) available, and nest stability was related to the number of vertical stems supporting it (Nuechterlein 1975). Western Grebes may be forced to select less than ideal nest sites, especially if water levels change (Davis 1961, Nero 1958, Stirling 1964). Nero (1958) found dry-land Western Grebe nests constructed of grass, sticks, and feathers that were unsuccessful. On reservoirs in Colorado, Davis (1961) indicated low nest success in nest platforms constructed in shrubs and forbs where persistent emergent vegetation was lacking due to the reservoir failing to reach capacity. The quantity and quality of preferred nesting vegetation structure may be increased when water levels are high because dense areas of cattails and reeds (*Phragmites*) become flooded and therefore useful as nesting habitat. At the Bear River Migratory Bird Refuge in Utah, nesting platforms were situated on rafts of pondweed (*Stuckenia* sp.) which Lindvall & Low (1982) recognized would disintegrate from wave action.

The Western Grebe may construct nest platforms on banks of dredged channels immediately adjacent to open water or on dried out islands of emergent vegetation bordering flooded channels. This allows them to swim to the site and hop onto the nest, yet these nests at the Bear River Migratory Bird Refuge were only successful when human disturbance and depredations were minimal (Lindvall & Low 1982). Furthermore, a reduction in water level during the nesting period may affect success of channel bank nests by making it difficult to swim to and enter nests. Change in the quantity and quality of vegetation structure at Delta Marsh, therefore, may affect Western Grebe nesting success.

In addition to changes in the plant community in Delta Marsh, there have also been changes in the fish community, particularly the increase in the presence of the Common Carp (*Cyprinus carpio;* hereafter referred to as carp), a non-native invasive fish species (Goldsborough & Wrubleski 2001). Carp were first introduced in the late 1950s (Badiou & Goldsborough 2010) and by 1998-99, became the dominant fish species in terms of biomass, and second most abundant fish species in Delta Marsh (Goldsborough & Wrubleski 2001). With the arrival of the Koi herpes virus in Lake Manitoba, the size of the carp population decreased considerably in 2008 from 1998-99 levels, but has probably returned to earlier population sizes (D. Wrubleski pers. comm.).

The presence of carp is known to contribute to water turbidity by resuspending sediments (Anderson et al. 1978, Keen & Cagliardi 1981, King et al. 1997, Hamilton & Mitchell 1997), and by uprooting marsh vegetation through foraging and spawning behavior (Crivelli 1983, Breukelaar et al. 1994, Chow-Fraser 1998). At Delta Marsh, increases in water turbidity since 1974 are thought to be caused primarily by the increased presence of carp (Goldsborough & Wrubleski 2001, Badiou 2005). The increased water turbidity at Delta Marsh (Goldsborough & Wrubleski 2001) may impact the foraging success of Western Grebes as they are visual feeders that search for and pursue their prey under water (Storer & Nuechterlein 1992). Increased water turbidity has been found to decrease prey capture rates of colonial waterbirds (Cezilly 1992). In an experimental 6 x 3 m pool filled to a depth of 10 cm designed to test ecological solutions to limiting the impact of fish-eating birds on fish farms, increasing water turbidity decreased the foraging efficiency of Little Egrets (*Egretta garzetta*) by reducing the predator's visual detection of prey (Cezilly 1992). A decrease in prey capture rates may negatively affect the health of breeding Western Grebes and their young, thus decreasing birth and growth rates.

Carp consume macrophytes and damage plants while foraging, by uprooting or damaging plants (Crivelli 1983), and often reduce overall submerged macrophyte cover (Havens 1991, Breukalaar et al. 1994, Loughheed et al. 1998). In an experiment to investigate the effects of Common Carp on a shallow lake in Utah, Miller and Crowl (2006) found that carp can significantly decrease species abundance and diversity of macrophytes including bulrush (*Scirpus validus*). Similar small scale experiments within Delta Marsh performed by Hnatiuk (2006) found that by excluding carp, small peripheral ponds that previously had carp present returned to a clear, macrophyte dominated state from a turbid, phytoplankton-dominated state in a year. As the majority of Western Grebes nests at Delta Marsh historically were situated in emergent bulrush (Nuechterlein 1975), excluding carp from the Delta Marsh may be beneficial to nesting Western Grebes if carp exclusion contributes to the reestablishment of extensive beds of bulrush.

As a multi-stakeholder initiative, the Delta Marsh Rehabilitation Project's overall goal is to restore the ecological health of Delta Marsh to enhance habitat for fish and wildlife (DUC 2009). Future management actions for the Delta Marsh Rehabilitation Project, such as screens that prevent spawning carp from entering Delta Marsh in the spring, are proposed to be placed at the four outlets to Lake Manitoba, to revitalize the marsh ecosystem (Figure 2; DUC, 2009). This would not be the first attempt at excluding carp from Delta Marsh. During Nuechterlein's (1975) study, there were carp barriers at outlets from Delta Marsh to Lake Manitoba. However, these carp barriers were removed in 1982 after their condition deteriorated considerably (G. Goldsborough, pers. comm.). Following the removal of the former carp barriers, Western Grebes continued to nest within Delta Marsh (R. Bazin, pers. comm.). Screens blocking Western Grebe movements between Delta Marsh and Lake Manitoba are likely to have the unnatural effect of impounding Western Grebes and their broods within the marsh. These proposed carp screens may impact the movement of Western Grebe broods that are likely pursuing concentrations of prey from Delta Marsh to Lake Manitoba (G. Nuechterlein pers. comm.). As the Western Grebe's feet are set at the posterior end of the body, adults and chicks are poorly adapted to terrestrial movement (Storer & Nuechterlein 1992). The literature contains no evidence of parents possessing the ability to transport chicks overland. Sustained flight by Western Grebes is seldom observed during the summer months at Delta Marsh (Nuechterlein 1981). Furthermore, limited data from a small sample of Western Grebe flight muscles (*pectoralis* and *supracoracoideus*) suggest that adult Western Grebe flight muscles become severely atrophied during the nesting and post-nesting periods, indicating a period of temporary flightlessness (Nuechterlein 1988). The prospect of adult Western Grebes flying their chicks over the forested beach ridge is most certainly impossible. It is important to note however that Western Grebes nested within Delta Marsh before (Leopold 1949), during (Nuechterlein 1975) and after (Underwood & Rasmussen 2005, Bazin et al. 2006, Bazin et al. 2007) the presence of these carp screens.

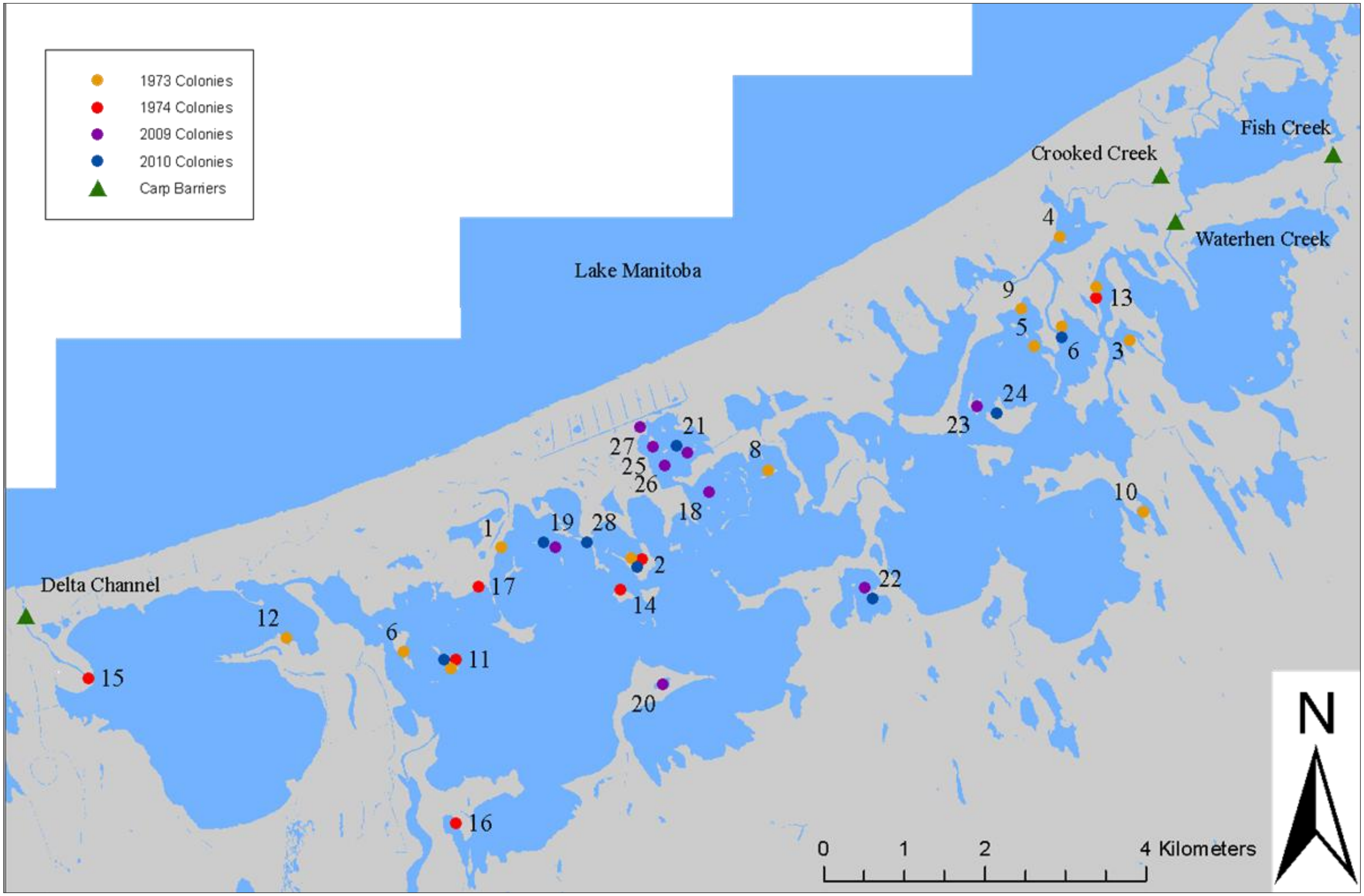

Figure 2.Western Grebe colony locations at Delta Marsh during 1973, 1974 (Nuechterlein 1975), 2009, and 2010, and the proposed locations of carp exclusion screens. Numbers refer to colony names (Table 1).

While their flight muscles remain atrophied, and the proposed screens to exclude carp from Delta Marsh are in place, Western Grebes will not be able to pursue their prey of small fish migrating to the adjoining Lake Manitoba in late summer (Wrubleski 1998). As Allen et al. (2007) observed at Lake Christina, Minnesota, during a season lacking sufficiently high concentrations of fish, Western Grebes might depart from the marsh before autumn migration, to relocate to areas where prey is potentially abundant. In such events breeding adults may abstain from nesting altogether (Allen et al. 2007).

This study will help contribute to the conservation of Western Grebes in Manitoba by determining the current breeding success rates of Western Grebes in Delta Marsh and by evaluating how the nesting ecology in Delta Marsh had changed since the early-1970s. Initial nesting success, chick-to-adult ratios, proportions and causes of nesting losses were compared with Nuechterlein's (1975) data from 1973 and 1974. I compared changes in marsh habitat over time, the reasons for any changes, and evaluated the effects of habitat structure on nest site selection and breeding success.

To further examine the effects of nest site selection on nesting success, I compared nesting ecology data between years with similar water levels at the beginning of the nesting season. Average daily water level in June was 247.6 masl in 1973, 247.5 masl in 2010, and 247.8 masl in both 1974 and 2009 (Environment Canada). Although this is only a difference of roughly 30 cm, for the purposes of this study 1973 and 2010 are considered low water years, while 1974 and 2009 are considered high water years. Nuechterlein (1975) concluded that the primary reason for differences in breeding success between 1973 and 1974 was water level. During the nesting season of 1974, the quantity and quality of available habitat was higher, nest structures were characterized with higher densities of emergent stems, and mean distance to open water was larger, compared to the low water year of 1973 (Nuechterlein 1975). Consequently, nests in 1973 were more exposed, less stable, more vulnerable to high winds, and were thus less successful than nests in 1974 (Nuechterlein 1975).

Comparing nesting ecology data between low water years and high water years should enhance the power of the study and produce ecologically meaningful comparisons. If Western Grebe breeding success is related to habitat composition and structure, then changes in the Delta Marsh habitat since the 1970s (Shay et al. 1999, Goldsborough & Wrubleski 2001) may have altered Western Grebe nesting ecology, which in turn, may have negatively impacted breeding success.

This project will make an important contribution to future research on the effects of carp and the carp exclusion screens at Delta Marsh, by providing pre-screening Western Grebe nesting ecology and brood movement baseline data, which can later be compared to post-screening data. This study will also assist in the planning, design, and implementation of the carp screens, to optimize impacts on the health of the marsh ecosystem while minimizing negative impacts on Western Grebes. This will help ensure that future carp management actions in Delta Marsh do not negatively impact the local population of Western Grebes.

Western Grebes have not yet received sufficient conservation attention in Manitoba. Due to their natural charisma and beauty, the Western Grebe has the capacity to capture the public’s attention to the conservation and eco-tourism opportunities of Delta Marsh, and the benefits of

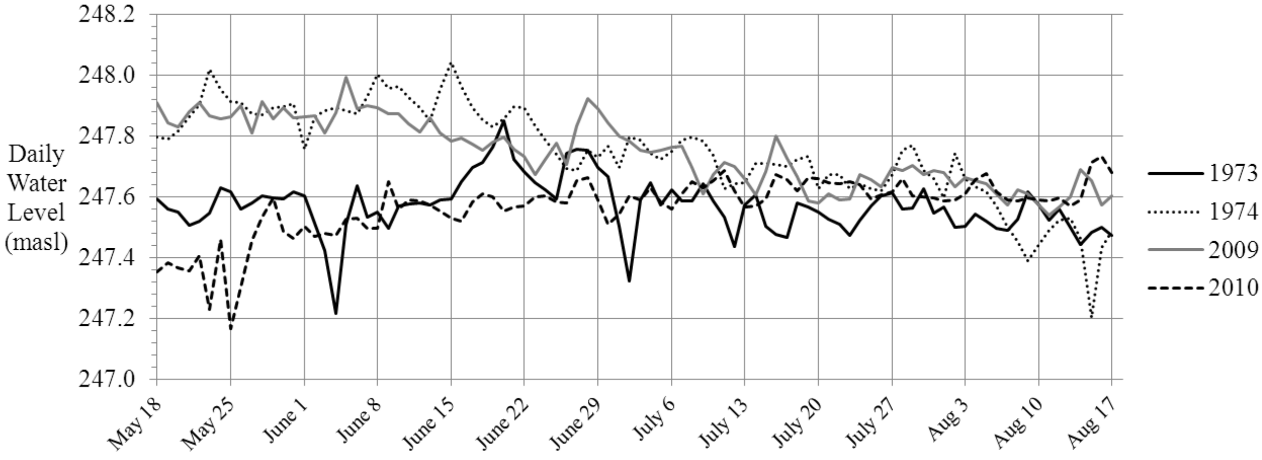

Figure 3. Daily water levels at Delta Marsh for 1973, 1974, 2009, and 2010 (Westbourne gauging station 05LL012, Environment Canada).

increased attention may extend beyond this species alone. Focusing conservation attention on this species will also help bring attention to the need to conserve and manage wetland habitat at Delta Marsh. This research will therefore make a critical contribution in informing the management and conservation of Delta Marsh.

1.1 Purpose statement

The purpose of this study is to contribute toward our understanding of the ecology of the Western Grebe and the impact of various factors on this species within Delta Marsh, with the purpose of conserving this important species in decline. Using baseline data from Nuechterlein's (1975) study on Western Grebe nesting ecology at Delta Marsh, I studied changes in Western Grebe nesting ecology, and examined how this relates to negative stressors within Delta Marsh. These data will add to our knowledge of the nesting ecology of Western Grebes, and will help identify and prioritize actions to improve the management and conservation of Western Grebes and other wildlife in Delta Marsh and similar coastal marshes.

1.2 Research Objectives

The objectives of this study were to (1) determine the current nesting ecology of Western Grebes in Delta Marsh, (2) compare 2009/2010 breeding success and nesting ecology data with 1973/1974 data, (3) examine changes in habitat structure between 1973/1974 and 2009/2010, and suggest reasons for these changes, (4) understand the effects of habitat structure on nest site selection and nesting outcomes, and (5) provide baseline information for evaluating the impacts and effectiveness of future management activities on Delta Marsh. The long-term goal is to provide management recommendations for Western Grebes in coastal wetlands of Lake Manitoba and similar lakes.

1.3 Justification of Research

The Western Grebe is a waterbird of interest, as it is identified as a waterbird species of high concern in the Northern Prairie and Parkland Region (Beyersbergen et al. 2004), which includes Southern Manitoba. There is a substantial need for further research on Western Grebes in Delta Marsh. Other than brief surveys during 1979, 2005, 2006 and 2007 (Koonz & Rakowski 1985, Wrubleski et al. 2005, Underwood & Rasmussen, 2005, Wrubleski et al. 2006, Bazin et al. 2007, Underwood & Rasmussen 2005), there has been no research on Western Grebe nesting ecology in Delta Marsh, or Manitoba, since the 1973 and 1974 surveys by Nuechterlein (1975). Nuechterlein’s (1975) Western Grebe nesting ecology data at Delta Marsh provides the rare opportunity for evaluating changes in Western Grebe nesting ecology over time. It is important to re-evaluate the status of this species in Delta Marsh because numerous environmental changes, such as water level stabilization, changes in vegetation composition, and changes in the fish community, have taken place in the last three decades (Shay et al. 1999, Goldsborough &

Wrubleski 2001), which may have influenced the nesting ecology and population status of Western Grebes. Research on the status of this species in this area is overdue. This research will contribute to the protection and restoration of wetlands, particularly Delta Marsh. This project provides an opportunity to do a comparative study that will contribute further literature on Western Grebe nesting ecology and also provide important baseline information useful for evaluating the impact of the Delta Marsh Rehabilitation Project on Western Grebes. The results of this study should assist in the planning and design of carp management structures to minimize any potential impacts on Western Grebes within Delta Marsh. This research will therefore make a critical contribution in informing the management and conservation of Delta Marsh.

More than any other waterbird in Manitoba, the Western Grebe captures the imagination of bird enthusiasts, eco-tourists and casual observers. Their showy open-water displays are among the most complex of any bird species (Storer & Nuechterlein 1992). In terms of eco-tourism, no other bird species at Delta Marsh has a comparable profile and attraction to the public. As a flagship species, the potential of this bird for education on wetland conservation, as well as for the promotion of ecotourism at Delta Marsh, Manitoba, is substantial.

2.0 LITERATURE REVIEW

2.1 Taxonomy

Until 1985 (Monroe et al. 1985), Western (*Aechmophorus occidentalis*) and Clark's Grebes (*Aechmophorus clarkii*) were considered colour phases of the same species, with the Clark's Grebe as the light morph. The taxonomic separation of the Western and Clark's Grebe is supported by differences in breeding behaviour (Nuechterlein 1981) and analysis of DNA-DNA hybridization (Ahlquist et al. 1987). The subspecies *Aechmophorus occidentalis occidentalis* and *Aechmophorus clarkii transitionalis* breed from Canada, south through the western United States to northern Baja California, while the other subspecies *Aechmophorus occidentalis ephemeralis* and *Aechmophorus clarkii clarkii* breed on the Mexican Plateau (Storer & Nuechterlein 1992).

2.2 Legal status

Aechmophorus grebes receive protection under the Migratory Birds Convention Act (Environment Canada 1991). This Act states that no person shall possess a live or dead bird, nest or egg, or destroy or take a nest or egg, or cause nest abandonment through human disturbance (Environment Canada 2011). Though currently unlisted, the Species Specialist Subcommittee Candidate List of the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has included the Western Grebe as a high priority candidate for upcoming assessments (COSEWIC 2011). In British Columbia, the Western Grebe is a candidate for endangered or threatened status because of population declines, and the vulnerability of the few remaining breeding sites to habitat erosion and anthropogenic disturbance (Burger 1997). In Alberta, the Western Grebe is considered a sensitive species (Hanus et al. 2002a). The Northern Prairie and

Parkland Waterbird Conservation Plan (Beyersbergen et al. 2004) also identified the Western Grebe as a species of high concern due to loss and degradation of wetlands and their surrounding upland habitats.

2.3 Description

The Western Grebe (*Aechmophorus occidentalis*) (Figure 4) is a large (55-75 cm long; 800-1,800g) waterbird with a narrow body, long neck, black and white plumage and a sharply pointed yellow bill (Storer & Nuechterlein 1992). The black upper parts continue from the base of the bill to the tail, white under parts continue from the chin to the belly; the cheeks are white while the black on the crown extends below red eyes and to the triangular crest which when raised, spreads laterally in display (Storer & Nuechterlein 1992, Bezener & DeSmet 2000). The sexes of Western Grebes are similar, though the female is smaller, has a shorter and much thinner bill that appears slightly upturned, making sexes separable based on bill size and shape (Storer & Nuechterlein 1992).

Figure 4. Male Western Grebe with chick at Delta Marsh, 2010 (Photo by Anna Gonzalez).

The Western and Clark's Grebe are distinguished by the yellowish green bill and the black on the crown extending below the eyes of the Western Grebe (Storer & Nuechterlein 1992). Clark's Grebes have a yellowish-green bill, with the white of the head extending above the eyes and tend to have more white in their wings and flanks, which varies and is never in a defined patch for either species, though there is much overlap in this characteristic (Storer & Nuechterlein 1992).

2.4. Geographic Distribution

The breeding range of the Western Grebe occurs from south-central British Columbia, along the Pacific Coast to southern California, across central Alberta and Saskatchewan, and southern Manitoba, south to north-west Iowa, Colorado, New Mexico, Arizona, and on the Mexican Plateau (Figure 5; Storer & Nuechterlein 1992). The Western Grebe generally winters along the Pacific Coast from southern British Columbia to southern Baja California, as well as inland open water areas east of California to Southern Texas and Mexico; this species is rare on the Texan coast-line, Florida, the New England Coast, and southern Alaska (Storer & Nuechterlein 1992).

2.5 Life History

2.5.1 *Habitat requirements*

The breeding habitat of Western Grebes consists of fresh water lakes and marshes characterized by large areas of open water bordered by emergent vegetation (Storer & Nuechterlein 1992), and rarely on tidewater marshes (Weber & Ireland 1992). Common winter habitat includes salt or brackish bays, estuaries, and sheltered sea coasts, less commonly on fresh water lakes and occasionally on rivers (Storer & Nuechterlein 1992).

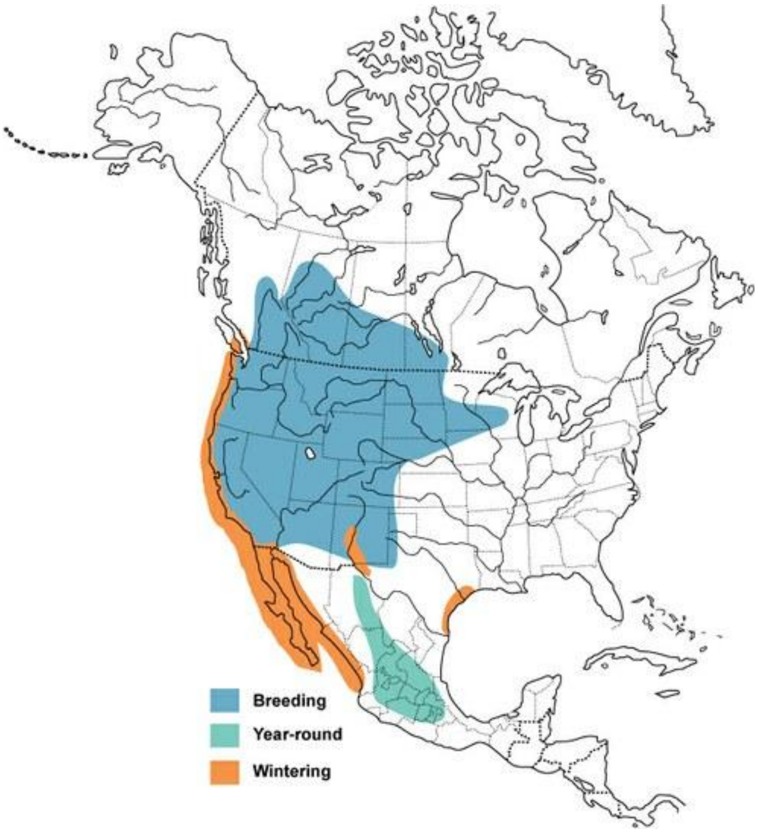

Figure 5. Breeding and wintering range of the Western Grebe. (Map used with permission from Birds of North America Online http://bna.birds.cornell.edu/bna maintained by the Cornell Lab of Ornithology)

Extensive beds of emergent vegetation provide favourable nesting sites and attract the largest breeding colonies of Western Grebes, which are often recolonized in later years. Colony site selection may, however, diverge from traditional sites due to complex conspecific interactions including the influence of prey abundance, availability of shelter from high winds and waves, nesting substrate structure, locations of early nests, as well as local water conditions (Nuechterlein 1975, Storer & Nuechterlein 1992). Most Western Grebe nests are in colonies consisting of hundreds, or even thousands of nests; Koonz and Rakowski (1985) recorded a colony of 2,400 nests on the eastern shore of Lake Manitoba.

Western Grebes commonly build floating nests anchored to emergent plants that are constructed of emergent vegetation found near the nest. These nests are continuously maintained throughout the season by the addition of new emergent stems, algae or sodden material brought by both the male and female, and can hold eggs after 1 to 3 days (Storer & Nuechterlein 1992). Nest platforms are most commonly located in hardstem bulrush (*Schoenoplectus acutus*), but have also been observed in other emergent vegetation such as alkali bulrush (*S. maritimus*), cattatil (*Typha* spp.), giant bur-reed (*Sparganium eurycarpum*), Baltic rush (*Juncus balticus*), common reed (*Phragmites australis*), reed canarygrass (*Phalaris arundinacea*) saltgrass (*Distichlisspicata*) and water smartweed (*Polygonum amphibium*) (Storer & Nuechterlein 1992, Burger 1997, Ivey 2004). Submergent plants employed in Western Grebe nest construction include sago pondweed (*Stuckenia pectinata*), curly pondweed (*Potamogeton crispus*), long-leaf pondweed (*P. nodosus*), broad-leafed pondweed (*P. natans*), bladderwort (*Utricularia vulgaris*), water milfoil (*Myriophyllum* spp.), and muskgrass (*Chara* spp.; Storer & Nuechterlein 1992, Ivey 2004).

Changes in water level may force Western Grebes to use other vegetation such as willow (*Salix* spp.), tamarisk bushes (*Tamarix* spp.), and rose (*Rosa* spp.; Davis 1961, Nero 1958, Stirling 1964, Lindvall & Low 1982). Nero (1958) observed unsuccessful dry-land Western Grebe nests constructed of grass, sticks, and feathers, situated as far as 23 m away from water following a drop in water level at Old Wives Lake, Saskatchewan.

At Delta Marsh, Western Grebes preferred bulrushes (*Schoenoplectus* spp.) over reeds (*Phragmites*) or cattails (*Typha latifolia*.) for nesting. Nesting vegetation preferences, however, reflected the depth of water below the nest more than the structure of the vegetation. At Delta Marsh, 99% of nests (n=315) at the time of clutch initiation had water depths of over 25 cm, with mean depths of 41 cm (Nuechterlein 1975). Other studies have reported nests occasionally situated in very shallow water (<20 cm; Ivey 2004).

2.5.2 *Reproductive ecology*

Western Grebes exhibit a social system of colonial nomadism where nest sites are selected based on social attraction to conspecific pairs that have established a nest site (Nuechterlein 1975). Based on Nuechterlein's (1975) observations at Delta Marsh, it is clear that colony locations and sizes change each year, suggesting a lack of fidelity to specific breeding sites.

Western Grebes are monogamous, and the pair bond is maintained until the chicks are a few weeks old, at which point the pair may split the brood (Storer & Nuechterlein 1992). A male-biased sex ratio is suggested (Storer & Nuechterlein 1992) due to unpaired males outnumbering females in late courting groups. While courting, two or more males will dip-shake, rush across the water surface, and barge into one another, to display their fitness to a female (Storer & Nuechterlein 1992). In the pair formation display, the male and female face each other in mutual dip-shaking, rush across the water surface, dive for weeds then bring them together in the "weed-dance", and end with ritualized "bob-preening" (Storer & Nuechterlein 1992). During nest selection displays, the male leads the female to the potential nesting site, then stays in a low arch display before the site; if the site is suitable both the male and female begin arranging vegetation into a pile (Storer & Nuechterlein 1992).

Territorial behaviour serves to disperse nest locations within the colony. Through these behavioural interactions, nests are non-randomly spaced within the colony, radiating out from the first selected nest sites (Nuechterlein 1975). Average nearest neighbour distances for nests among several colonies at Delta Marsh was 3.4-5.0 m (Nuechterlein 1975). At the Bear River Migratory Bird Refuge in Utah, nearest neighbour distances of nests in colonies greater than ten nests averaged 10 m, while nests in colonies with fewer than ten nests were spaced an average of 30 m from each other (Lindvall & Low 1982).

Western Grebes have an extended nesting season, the dates of which vary by location. At Delta Marsh they arrive in early May and nest from late May to early August (Nuechterlein 1975). Usually there is one brood per season, though, if the nest is lost, renesting is common (Storer & Nuechterlein 1992). For the first day or two, eggs are unmarked pale blue, later becoming white with brown stains from sodden nest material (Storer & Nuechterlein 1992). Mean size of 174 eggs in Utah was 57.4 mm (SD = 2.2) long, and 38.8 mm (SD = 1.1) in breadth (Ratti 1979). Eggs are laid in mid-morning, and there may be 3-6 days between laying the first and last egg of the clutch; hatching occurs after 22-24 days of incubation (Storer & Nuechterlein 1992). Incubation is nearly continuous, beginning between the first and second egg of a clutch being laid, and is performed by alternate bouts of several hours by both sexes (Storer & Nuechterlein 1992). Unattended or abandoned nests may become ‘dump nests,’ where a series of females will lay additional eggs, continuing to parasitize the nest even though the host has abandoned it (Lindvall & Low 1982). Brood parasitism of Western Grebe nests has been observed among Pied-billed Grebes, American Coots, and Forster’s Terns (Storer & Nuechterlein 1992).

Chicks are precocial and once hatched, they immediately climb onto their parents backs and remain there until they are two to four weeks old. Chicks remain dependent on parents for six to seven weeks (Storer & Nuechterlein 1992). Back brooding (Figure 3) is done by both parents, though newly hatched young are more frequently carried by males (Storer & Nuechterlein 1992). Following back brooding, parents split the brood, separating for long periods while foraging (Storer & Nuechterlein 1992). It is worth noting, however, that parental care may be performed by an additional adult in addition to the breeding pair. Forbes (1985) reported an instance of a third adult (male) feeding young.

2.5.3 *Demographics*

Breeding is presumed to begin at the age of one year; however, nonbreeding birds are not unusual (Storer & Nuechterlein 1992). At Delta Marsh, clutch size ranged from 1 to 6 eggs, decreasing through the breeding season with means of 3.70 in May, 3.11 in June, and 2.16 in July (Storer & Nuechterlein 1992). Clutch size may vary with location as seen in a study at the Bear River Migratory Bird Refuge in Utah, where clutch size ranged from 1 to 4 with a mean of 2.6 eggs per clutch (Lindvall & Low 1982).

The longevity record for Western Grebes is between 13 and 16 years old; recovered banded birds have been between six and eight years old (Eichorst 1992).

2.5.4 *Feeding ecology*

The Western Grebe is primarily a fish-eating bird. Western Grebes search for their food from the water surface by peering into water with their eyes submerged below the water surface (which may also assist in the identification of potential predators), then pursue prey while underwater (Storer & Nuechterlein 1992). The Western Grebe may laterally spear small deep-bodied fish with its bill (Lawrence 1950), but most prey are captured by forceps-like action of mandibles (Storer & Nuechterlein 1992). Fish are reported to comprise 81% (Lawrence 1950) to 100% of the diet (Whetmore 1992). Stomach contents of 27 grebes at Clear Lake, California, were 81% fish 27-88 mm long, 17% insects, and 2% plants (Lawrence 1950). Lawrence (1950) found that the impact of Grebe depredation of sport fish was minor as the contents of Grebe stomachs were predominately non-game species. The wide variety of fish species taken suggests opportunist foraging behaviour in Western Grebes (Storer & Nuechterlein 1992). Although uncommon, crustaceans, polychaete worms, insects, and salamanders (*Ambystoma* spp.) are included in their diet, indicating Western Grebes may forage along the bottom of water bodies (Storer & Nuechterlein 1992). Feathers that come out during preening activities are actively eaten, and have been found in the stomachs of Western Grebes, which are thought to protect the gastro-intestinal tract from being injured by swallowed fish bones (Storer & Nuechterlein 1992), or possibly assist in the expulsion of indigestible material in pellets, and reducing the potential build-up of gastric parasites (Piersma & Van Eerden 1989).

2.5.5 *Migration*

Western Grebe populations migrate nocturnally, probably in flocks, from breeding grounds to the Pacific Coast from early September to early November. In late April to early May they return to their northern breeding grounds (Nuechterlein 1975, Storer & Nuechterlein 1992). Twenty eight Western Grebes banded at Delta Marsh, were recovered in winter along the Pacific Coast from southern British Columbia to San Diego, California (Echorst 1992). Though a few inland recoveries were made in Nevada and Mexico, the recovery data demonstrated that most of the breeding population at Delta Marsh migrates west, and south-west to overwinter along the Pacific Coast from B.C. to Southern California (Echorst 1992). Banding data also suggest that in subsequent winters, some individuals may return to the same wintering sites; in later breeding seasons, some may return to the same or nearby marshes, while some disperse to marshes that are more distant (Echorst 1992). During migration, Western Grebes usually stop on large open bodies of water and occasionally on small fishless bodies of water (Storer & Nuechterlein 1992). Small (1994) reported 50,000 Western Grebes at the Salton Sea in California, indicating the importance of this area for staging or wintering.

2.5.6 *Sounds*

Young of the year are not known to vocally advertise before they leave their breeding grounds. Adults, however, have a wide variety of calls that do not vary geographically (Nuechterlein 1981). The *creet-creet* advertising call is given by lone, courting birds spontaneously, or in response to potential courting partners; it is also given by a paired bird separated from its mate or by parents seeking their young (Storer & Nuechterlein 1992). Within colonies, Western Grebes respond individually to their mate’s call (Nuechterlein 1981). The loud trill of the Ratchet call is given alternately with another bird when they are facing each other during the ratchet-pointing display (Storer & Nuechterlein 1992). The repeated *tuk-tuk-tuk* threat call is given when defending the nest, or when defending temporary concentrations of fish in a feeding area (Storer & Nuechterlein 1992). Towards the egg-laying period, a guttural *tuk* is given by the female to draw feeding by the male in mate-feeding bouts (Nuechterlein & Storer, 1989). The copulation duet, performed upon the nest platform, is the loud trill given by the male accompanied by interspersed shorter notes by the female (Storer & Nuechterlein 1992). Other calls in the courtship displays include tick-pointing, barge-drilling, neck-stretch trilling, and arch-clucking (Storer & Nuechterlein 1992). Clucking food calls and ticking alarm calls are given by parents to their young (Nuechterlein 1988). The non-vocal sound of rapid foot movements across the water surface, during the rushing display can be heard from several hundred yards away on a calm day (Storer & Nuechterlein 1992).

2.5.7 *Movement*

The rare occurrence of Western Grebes moving on land is difficult due to their posteriorly placed legs. In such rare cases, they propel themselves slowly forward on their belly by kicking their feet, and are capable of standing and running short distances (Nero 1958). While in flight, their movements are fast and direct with rapid beating of wings, neck stretched with their head slightly lower than the body, and with their feet stretched out behind them (Storer & Nuechterlein 1992). While swimming above the surface, Western Grebes alternate strokes of their feet, and use a simultaneous foot stroke when they are swimming below the water surface (Storer & Nuechterlein 1992).

Lawrence (1950) described four types of diving behavior: when the water surface is smooth, the “feeding dive” is a “deliberate forward and downward thrust of the head and a vigorous stroke of the feet, which propels the grebe beneath the surface in an effortless appearing dive;” on rough waters a “springing dive” begins with a “vigorous leap forward and downward,” and the fore body surging out of the water; in an “alarm dive” it thrusts “its wings outward and virtually push the body below the surface;” a second type of alarm dive, the “surface dive” is when the bird dives with only its head and neck protruding from the water. Lawrence (1950) reported a mean period below the surface in feeding dives of 30.4s, with a mean interval between dives of 21.3 s. While feeding in deep water, springing dives are more common, and may be linked with deeper dives (Storer & Nuechterlein 1992). Western Grebes alternate disproportionally long and short periods at the surface between dives while foraging, with lighter work periods corresponding to foraging for fish schools, and with heavy periods of work while they exploit a sighted school (Ydenberg & Forbes 1988).

2.5.8 *Nesting losses and mortality*

The foremost cause of nesting and egg losses is from wave action caused by storms. These losses are most extensive in low water years when dense emergent vegetation is inaccessible to nesting Western Grebes, and may affect entire colonies (Storer & Nuechterlein 1992). Western Grebe nests and eggs located on Lake Mead, Arizona, were mostly destroyed by high winds and strong wave action (Parmelee & Parmelee 1997). Allen et al. (2008a) found that Western Grebe nests were more successful when storms were less frequent and intense, and when nests were located within the more central tuber-mat of the colony, nearer to the center of bulrush islands. In addition, nests on the leeside of a vegetation stand gain more protection than if they were located in dense vegetation, and are at least three times more likely to have successful nests than more exposed nests (Allen et al. 2008b). Furthermore, storms and waves can be considerable sources of chick mortality; after violent windstorms on Lake Manitoba, hundreds of young washed up on the beach shore (Storer & Nuechterlein 1992).

Slight differences in water level at the beginning of the nesting season can have significant effects on breeding success. Low or unstable water levels are considerable problems for nesting Western Grebes. Following a three-week 38 cm decline in water levels at the Bear River Migratory Bird Sanctuary, 25% of nests were abandoned (Lindvall & Low 1982). At Delta

Marsh, breeding success in a low water year was ~50% less than during a high water year, when water levels were only ~30 cm higher at the beginning of the nesting season (Nuechterlein 1975).

Mink (*Mustela vison*) and Raccoon (*Procyon lotor*) both prey on nesting adult Western Grebes and their eggs. Once a colony is located, Mink will continue exploiting nesting colonies (Storer & Nuechterlein 1992). Nuechterlein's (1975) evidence of mink depredation is based on finding decapitated adult grebes, which is characteristic of mink depredation (Burkholder 1955), however, Great Horned Owls (*Bubos virginianus*) also decapitate birds (Olmsted 1950). In order to differentiate between depredations by these two species, additional evidence such as feathers or pellets of scat would be required. Ivey (2004) reported finding one decapitated Western Grebe on a nest at Eagle Lake, California, that in his opinion, was probably taken by a Great Horned Owl.

Although documentation of nesting Western Grebes depredated by River Otters could not be found in the literature, Nuechterlein (pers. comm.) saw an otter causing a lot of commotion among the nesting grebes in a colony on Lake Osakis, Minnesota, and also had reports that otter depredation was a problem for Western Grebes on Davis Lake, Oregon.

Though rarely observed, Western Grebes may be vulnerable to underwater predators. Other than one record of an adult Western Grebe being attacked and killed by a Common Snapping Turtle (*Chelydra serpentine*;Igl & Peterson 2010), the only other reported instance of a predator taking a Western Grebe by an underwater approach, was a Sea Otter (*Enhydra lutris*;Riedman & Estes 1988). In contrast, chicks may be vulnerable to large fish such as bass (*Micropterus* spp.) and pike (*Esox* spp.; Storer & Nuechterlein 1992). Fortunately for Western Grebe broods, bass have not expanded their range into Delta Marsh (Wrubleski 1998) and northern pike (*Esoxlucius*) move out of the marsh and into Lake Manitoba in mid-July when water temperatures exceed 25°C (Lapointe 1986) and are not present in large numbers during the peak in hatching, in late July.

Anthropogenic disturbances near colonies pose a serious problem for nesting Western Grebes. At Delta Marsh, 22 of 42 nests in a colony situated along the Delta Channel, which provides the few recreational paddlers access into Delta Marsh, were abandoned due to human disturbance (Nuechterlein 1975). At Bear River Migratory Bird Refuge in Utah, increased depredation was documented when adults flushed from nests following disturbance from automobiles, airplanes and helicopters (Lindvall & Low 1982). Following a disturbance, avian predators that take advantage of unoccupied nests include gulls (*Larus spp.*), American Coots (*Fulica americana*), Forster's Terns (*Sterna fosteri*), crows (*Corvus* spp.), and Common Ravens (*Corvus corax*) (Nuechterlein 1975, Lindvall & Low 1982, Storer & Nuechterlein 1992).

If humans approach a nest too quickly, parents may abandon the nest without adequately covering the eggs with nesting material, which may cause hyperthermia or hypothermia of eggs from exposure to wind, rain or sun, and increase opportunities for avian depredation (Storer & Nuechterlein 1992). When large mammalian predators are spotted approaching the nest by nesting adults, Western Grebes will often cover the nest with nesting vegetation and leave the nest.

Gill-nets used in fisheries are another source of mortality (Burger 1997). In the late 1970s, Nuechterlein (1981) salvaged approximately 100 Western Grebes from fisheries by-catch on Lake Manitoba in a single week (O'Donnel & Fjeldsa 1997). Mortality can also be caused by entanglement in old fishing lines, and discarded plastic or rubber rings (Storer & Nuechterlein 1992).

As is the case for many seabirds overwintering on the Pacific coast (Carter 2003), Western Grebes are vulnerable to oil spills. Large numbers of Western Grebe mortalities have been documented after catastrophic oil spills (Smail et al. 1972, Speich & Thompson 1987, Bayer 1988). Burger (1993) reports that chronic low volume oil spills contribute to small numbers of dead Western Grebes found on the beaches of Southern British Columbia.

2.6 Population Trends

Based on The Audubon Society's Christmas Bird Counts (CBC), current population estimates are 110,000 Western Grebes (Kushlan et al. 2002). Ivey's (2004) analysis of CBC data from 1984-2003 for the region where the majority of Western Grebes winter (British Columbia, Oregon, Washington State and California) showed evidence of a 5.3% annual decline in population. Trends from each state and province except California showed similar results to regional trends; however, when the province of B.C. was analyzed separately a significant annual decline of 12% was shown.

The literature contains additional evidence that Canadian Western Grebe populations are declining. In British Columbia, the decline has been attributed to human disturbance, as well as habitat change from industrialization and urbanization (Burger 1997). Human disturbance, habitat loss, and declining water levels are negatively impacting Western Grebe populations in Alberta (Hanus et al. 2002b). Koonz and Rakowski (1985) suggested that Manitoba's Western Grebe population in 1979 had declined due to artificially maintained stable water levels resulting in the stagnation of provincial wetland habitats (Koonz & Rakowski 1985).

2.7 Population Threats

Western Grebe populations were severely impacted by human activities in the late 19th and early 20th centuries. Until the Migratory Bird Treaty Act of 1918, Western Grebe populations suffered from egg collection, as well as hunting to supply the plume trade with grebe “fur” used in the construction of capes, coats and hats (Storer & Nuechterlein 1992).

At the landscape scale, the availability of alternative breeding sites is critical for maintaining regional populations (Hanus et al. 2002b). Changes in precipitation patterns causing extreme droughts or floods can lead to major changes in breeding habitats. In such cases, breeding populations must either relocate to other more suitable areas or suffer the consequences of poor breeding success if they remain. For example, during one year in the late 1970s, many Western Grebes were present in Delta Marsh early in the spring, but then suddenly departed, shifting the Delta Marsh population to other nearby wetlands (Nuechterlein pers. comm.). Nuechterlein (pers. comm.) believed this relocation to be caused by insufficient fish populations within the marsh.

Habitat loss and degradation continues to threaten populations. Extensive drainage of wetland habitats for agricultural development has reduced the amount of habitat available to breeding Western Grebes (Cogswell 1977). Development on shorelines near colony sites has also reduced breeding habitats (Burger 1997, Hanus et al. 2001ab). Nesting habitat in emergent vegetation can also be degraded by grazing cattle (Burger 1997). Degradation of wetlands due to eutrophication, pollution, and invasive fish species also threaten the health of breeding habitats (O’Donnel & Fjeldsa 1997).

As over-water nesters, stable water levels are critical for Western Grebes during the breeding season, however, some hydrological variability is required to maintain nesting habitat over the long term. Although no threshold has been determined, locations where severe fluctuations in water level occur are considered unfavorable for nesting grebes (Storer & Nuechterlein 1992), and may even cause extreme postponement of breeding activities (Parmelee & Parmelee 1997). Rapidly declining water levels are also recognized as being detrimental as nests may be abandoned once becoming inaccessible on dry land (Nero 1958). However, water levels should be managed to manipulate growth patterns of emergent vegetation for the benefit of nesting birds. High water levels drown areas with overgrown vegetation while low waters expose mudflats, thus stimulating the dormant seed bank and increasing diversity in the plant community (Squires & van der Valk 1992). Provision of high quality breeding habitats from water level manipulation should offer archipelagos of dense clumps of emergent vegetation (i.e. bulrush and cattail), with open water channels that provide access to inner, wave protected, areas for nesting (Storer & Nuechterlein 1992).

The colonial nesting behavior of Western Grebes augments their sensitivity to disturbance by humans (Forbes 1988). When colonies are closely approached or entered by humans, adults temporarily vacate the colony leaving eggs and chicks vulnerable to avian predators and exposure (Storer & Nuechterlein 1992).

It is widely recognized that boat wakes can cause distress to birds (Carney & Syderman 1999). In addition, Western Grebe nests can be swamped and destroyed by boat wakes, though the density of emergent vegetation between the nest and the water craft can mediate this effect (Allen et al. 2008b). Burger (1997) implicated powered water-craft disturbances in the loss of nesting areas in British Columbia. Entire colonies may be abandoned if repeatedly visited by boaters during early stages of colony development (Storer & Nuechterlein 1992).

Because Western Grebes are piscivorous they can biomagnify many persistent contaminants, including organochlorine pesticides, heavy metals, polychlorinated aromatic industrial chemicals, and radionuclides which are likely to affect individual survival and reproductive fitness, as has been shown in the common loon (*Gavia immer*; Evers et al. 2001). At the Bear River Migratory Bird Refuge in Utah, various concentrations of DDE, DDD and PCBs were detected in Western Grebe eggs (Lindvall & Low 1979). The bioaccumulation of these toxicants reduced Western Grebe eggshell thickness, although this did not result in detectable effects on reproduction (Lindvall & Low 1982). Since the introduction of DDT in the 1940s, the thickness of grebe eggshells nesting in Manitoba declined, but have partially recovered following the ban on DDT in 1972 (Forsyth et al. 1994).

2.8 Western Grebes as Biological Indicators

In light of the logistical and financial difficulties of identifying and measuring all of the components, functions and values of complex ecosystems, biologists and managers often use a single species to indicate many types, and magnitudes, of exposure and/or effect. Species used in this manner are referred to as biological indicators, or bioindicators.

The potential of Western Grebes for indicating changes in ecosystems is not yet well understood, but there are indications that for certain conditions they may be useful. As a predator specializing in small fish (Lawrence 1950, Whetmore 1992), Western Grebes are potentially good indicators of high densities of fish (O'Donnel & Fjeldsa 1997). For example, Allen et al. (2007) observed a lack of colony formation and early departure of Western Grebes from Lake Christina, Minnesota, after fish abundance decreased following an autumn rotenone treatment. In this case, the effect of Western Grebes not nesting and departing well in advance of the fall migration indicated low densities of fish.

Like many high trophic level waterbirds, the biology of Western Grebes makes them favourable indicators of exposure to persistent contaminants on their feeding grounds (Kushlan 1993). Due to atrophied flight muscles (Nuechterlein 1988), Western Grebes usually remain on the breeding grounds throughout the entire breeding season. Western Grebe movements are restricted within a specific breeding site, so effects of contaminant exposure, including eggshell thinning, altered behavior, reduced growth, reduced reproductive performance, and mortality may indicate the presence of contaminants within the breeding habitat.

Flagship species are often charismatic species that can draw public attention to the importance of wildlife conservation in a particular habitat (Mallinson 1991). Flagship species, used in a sociopolitical context, help focus the public’s attention and funding on a single species, rather than the more difficult to communicate complex concepts of ecology. They are species that when conserved locally result in benefits to other locally present, and possibly less charismatic, species across a range of taxa (Dietz et al. 1994).

Western Grebes are potentially effective flagship species for the conservation of wetlands because they are large, conspicuous birds with highly visible courtship displays (Storer & Nuechterlein 1992). These courting rituals, most notably the spectacular ceremonies of rushing, when two birds lunge out of the water and run across the water surface side by side, and weed-dancing, have been featured in numerous nature films and television programs, and photographed for countless nature magazines. Although Western Grebes are not considered at risk in Manitoba, conservation status often affects the criteria for the selection of a flagship species (Dietz et al. 1994), as threats to at risk species may elicit strong reactions from the public. As a wetland formerly famous for the production and staging of waterfowl (Goldsborough & Wrubleski 2001), species favoured by hunters have been the informal flagships of Delta Marsh. However, as the declining health of the marsh impacts waterfowl populations, its appeal to hunters has waned considerably (Peter Ward pers. comm.). In comparison, the Western Grebe population at Delta Marsh has not declined (Wrubleski et al. 2005, Underwood & Rasmussen 2005, Bazin et al. 2007, Wrubleski et al. 2006). Western Grebes at Delta Marsh are abundant, conspicuous, and charismatic, and could potentially be a strong candidate as a flagship species for this unique wetland ecosystem.

2.9 Flightlessness

Flightlessness is understudied and not well understood in Western Grebes, but is significant for the conservation of this and other species that become flightless due to atrophied flight muscles. In general, birds are highly mobile because of their ability to fly. A lack of mobility, due to flightlessness, makes them vulnerable to predators, and may restrict movements within their home range, which may also increase their vulnerability to catastrophic events.

Changes in body composition are not unusual for grebes. Research by Jehl (1997) showed that major body constituents of Eared Grebes (*Podiceps nigricolis*) experience 3-6 cycles of atrophy/hypertrophy annually. This results in several periods of the year when Eared Grebes are incapable of sustained flight due to flight muscle mass being atrophied below the ~11% of body mass necessary to sustain flight (Jehl 1997). Atrophic flight muscles have also been described for Great Crested Grebes (*Podiceps cristatus*) by Piersma (1988) and Pied-billed Grebes (*Podilymbus podiceps*) by Storer (1960) and are possibly widespread in the grebe family. Some species in this family: the Titicaca Flightless Grebe (*Rollandia microptera*), the Junin

Flightless Grebe (*Podiceps taczanowskii*), and the Atitlán Grebe (*Podilymbus gigas*) (extinct; Hunter 1988) evolved to be permanently incapable of sustained flight with relatively small flight muscles mass (Storer 1960). Attempts to track changes in major body constituents across an annual cycle are limited in the grebe family to Eared Grebes (Jehl 1997).

To provide further support concerning the mechanics of breast muscle atrophication in Great Crested Grebes (*Podiceps cristatus*), Piersma (1988) published a summary table of average monthly flight muscle mass of Western Grebes collected by Nuechterlein (1988) in the 1970s. Nuechterlein's (1988) data is the only information in the literature regarding the mass of Western Grebe flight muscles. Although the sample size was small, these data indicate that in June, the mass of flight muscles of both male and female Western Grebes underwent a large reduction from their post-migratory muscle mass indicating an inability to support sustained flight during the nesting and post-nesting periods (Nuechterlein 1988). During the month of August, the mass of Western Grebe flight muscles increased to post-migratory levels. Because Nuechterlein's (1988) Western Grebe flight muscle mass data is based on a small number of samples collected from gill-nets and carp-traps in the south basin of Lake Manitoba, his results may not be generalizable to other areas of the breeding range. Furthermore, because the monthly sample sizes were small, the timing of changes in Western Grebe flight muscle mass during the breeding season remains uncertain. Data on Western Grebe migratory (in flight) flight muscle mass is not available in the literature.

The timing of recovering the ability to fly in grebes may vary. Jehl (1997) suspected that providing food densities remain at exploitable levels, pre-migratory Eared Grebes will postpone departure to late fall or early winter. However, when densities of food decline to unexploitable levels, flight muscle mass may be regained in a matter of two to three weeks to allow early departure from fall staging areas (Gaunt et al. 1990). Allen et al. (2007) documented Western Grebes departing from a shallow lake by mid-June when prey was scarce. This suggests that when the prey base decreases to unexploitable levels, Western Grebes can regain the ability to fly.

The limited mobility of flightless birds increases their vulnerability to attacks by predators, as well as to environmental disasters. During molt, ducks that become temporarily incapable of flight are at increased risk of being attacked by predators (Wishart et al. 1981, Oring 1963, Reid et al. 1994). For birds to survive attacks from predators, becoming airborne and gaining height is crucial (Bednekoff 1996). Lacking both of these courses of action, flightless birds can only dive, swim, or run across the water surface, to escape from predators, and depending on the predator, this may not be sufficient to ensure an individual's survival. In the event of an environmental disaster, flightless birds may have limited opportunities to disperse, and may not be able to avoid contaminant exposure. For example, for Flightless Cormorants (*Nannopterum harrisl*) and the Galapagos Penguin (*Spheniscus mendiculus*), oil spills are acknowledged as a threat to populations when populations and spills are confined within limited areas (Valle 1986).

3.0 METHODS

3.1 Study Area

The Delta Marsh in Manitoba is a wetland of historical, local and international importance. Approximately 2,500 years ago, the lacustrine wetland known as Delta Marsh was produced, as one of the largest marshes on the Canadian prairies it currently covers an area of approximately 18,500 ha, depending on water level, at the south end of Lake Manitoba (Figure 2; Last 1980). Delta Marsh received the distinction of being named a wetland of international importance under the International Union for the Conservation of Nature's (IUCN) Ramsar Convention in 1982 (Ramsar, 2009). Provincially, the marsh was recognized as a Heritage Marsh in 1988, and nationally as an Important Bird Area in 1991due to its significance to staging waterfowl and migrating songbirds (Goldsborough & Wrubleski 2001). The conservation of Delta Marsh is extremely important in a provincial, national and global context.

The Delta Marsh is located along the southern shore of Lake Manitoba (Figure 2). It is composed of a series of channels connecting a network of shallow (0.3-2.0 m deep) open-water bays. A narrow forested beach ridge separates the marsh from the lake. Water exchange between Lake Manitoba and Delta Marsh takes place through two channels in the East Unit of the marsh that cross the ridge. Many channels formerly connected the lake to the marsh but have since been blocked naturally with sand and silt, or purposely obstructed in the early twentieth century (Shay et al. 1999).

Delta Marsh and Lake Manitoba water levels are highly correlated (de Geus 1987); marsh levels are maintained by inflows from the lake (Jones 1978).Water levels of the lake and marsh have been regulated at the targeted mean water level of 247.6 masl, and have fluctuated less than

0.6 m since 1961 (Figure 1) (Shay et al. 1999, Squires & van der Valk 1992). The shorelines of the marsh's bays are largely fringed by stands of cattail (*Typha* spp.), and bulrush (*Schoenoplectus* spp.) bounded by mono-dominant stands of *Phragmites* (Shay et al. 1999). Mixed stands of these three species form small islands and peninsulas in the shallow waters of the marsh (Shay et al. 1999). In the marsh, cattail and bulrush are found primarily at permanently flooded areas less than 247.5 masl, while *Phragmites* are found at seasonally flooded areas over 247.5 masl (Squires & van der Valk 1992). The climate at Delta Marsh is cool continental, with warm summers and cold winters (Michalyna & Smith 1972). The mean annual air temperature is 2.5°C (max. 33.0°C, min. -37.5°C), while the total annual precipitation is 522 mm (daily max. 61 mm), with 77% falling as rain (Goldsborough 1995).

Delta Marsh has formerly been recognized as an area of high productivity for breeding birds (MacKenzie et al. 1982). For example, waterfowl production at Delta Marsh used to be high in the 1930s and 1950s, with annual production of waterfowl estimated at 27,000, but has since become unappealing to breeding waterfowl. Production has subsequently decreased to 8,000-10,000 ducks in good to average production years (DUC, 1986). The importance of Delta Marsh to staging waterfowl, especially for diving ducks (Jones & Bazin 1991) has also declined (Jones 1978, DUC 1986). Estimates of the duck population during fall surveys have decreased steadily from 607,560 in 1956 to a meager 17,592 in 2001 (Delta Waterfowl Foundation 2003).

3.2 Study design

Several of the methods used by Nuechterlein (1975) are replicated in the present study in order to facilitate comparisons with Nuechterlein's data collected during the breeding seasons of 1973 and1974.

3.2.1 *Local distribution & status of nests*

A preliminary survey of Delta Marsh was done to determine the general location of Western Grebe colonies as the locations of colonies change from year to year (Storer & Nuechterlein 1992). This preliminary survey was done in early May from an airboat by looking for Western Grebe courtship activities and listening for their distinct advertising call, which can be heard up to a distance of 3 km (Nuechterlein 1975). Since Western Grebe aggregations are visually and audibly conspicuous, all of the colonies during the study can confidently be assessed as being located. Western Grebes preferentially select nest sites that are close to existing nests (Nuechterlein 1975). Therefore, by identifying early nest and colony sites, the preliminary air-boat survey identified the location of developing colonies (Nuechterlein 1975). Following the preliminary survey, a kayak was used to travel through the marsh, and to identify the precise locations of colonies.

Once colony sites were found, the locations of individual nest sites were identified. Nesting structures that were not yet initiated (no eggs), and were still under construction were not recorded. Nests were primarily located by kayaking though emergent vegetation. Nests were accessed by wading through the vegetation when emergent vegetation was too dense for kayaking.

Nests in the colonies were checked at weekly intervals (Nuechterlein 1975). Follow-up colony checks were conducted to record the number and distribution of nests and were performed rapidly and only on sunny, warm, calm days, so as to minimize the distress of nesting Western Grebes and their clutches (Nuechterlein 1975) and to prevent the flushing of adults from nests when wave action due to high winds may upset the stability of unattended nests. To minimize disturbance to colonies, nests checks were performed at intervals of seven or more days. This minimized the amount of disturbance and ensured that the colony was left undisturbed for the majority of each week.

3.2.2 *Breeding success*

Nest sites were numbered and marked using a small piece of flagging tape. In an experiment testing the effects of nest markers on nesting success of ducks, no difference in depredation rates were observed between flagged and naturally marked duck nests (Greenwood & Sargeant 1995).

At each nesting site, clutch size was recorded, and each egg was numbered by black marker (Nuechterlein 1975). Care in handling eggs and nests, careful training, and vigilant monitoring ensured that nests and eggs were protected from damage by the researcher. I determined the age of eggs using a flotation method, which uses the angle of flotation and buoyancy of eggs floated in a cup of water to determine egg age, and to aid in distinguishing between successful and unsuccessful nests (Nuechterlein 1975). Because 3 to 6 days can elapse between laying the first and last egg of a clutch (Storer & Nuechterlein 1992), and because the floatation method is only accurate to 3-7 days (Nuechterlein 1975), it was necessary to assess the age of each egg independently. Examined eggs were returned to their nest immediately after age determination. Eggs in nests were covered by dry vegetation regardless if they were found in this condition to minimize depredation risk.

During the ongoing weekly follow-up nest checks, outcomes of nests were evaluated by observing evidence of hatching (such as tiny eggshells left in the nest), the presence of eggs in advanced stages of incubation (22-24 days, vocalizing), or evidence of depredation, such as shell remains with the membrane attached (Mabee 1997). Nests that were empty at a stage prior to when they could have conceivably hatched were confidently assessed as failed. The maximum clutch size for Western Grebes is six eggs (Storer & Nuechterlein 1992); therefore, nests that contain over six eggs are likely dump nests that have been parasitized by another, or several, adults, when the nest was left unattended, or after it was abandoned. Eggs in nests that contained over six eggs were always cold providing further evidence that these eggs were not being incubated and were in fact parasitized by conspecifics.

Calculating rates of nesting success and losses is challenging as Western Grebes persistently re-nest (Storer & Nuechterlein 1992, Hanus et al. 2002b). Western Grebes will build atop of abandoned or damaged nests (this study) although it is difficult to known if this is the same breeding pair that originally selected the site or another pair. Western Grebes will also reuse nests that have hatched young and subsequently been abandoned by the initial nesting pair (Nuechterlein 1992).

Consistent with Nuechterlein's methods, I used the outcomes of the first laid clutch in nests for calculating nesting success. Subsequent clutches in the same nests were not included in calculations of the success of these initial nests. The total number of nests is less than counts of nesting losses because nests were counted on a nest by nest basis, while rates of nesting losses were calculated from the outcomes of each clutch.

To facilitate comparisons with 1970s data, two major colonies during 2009, along with the largest 2010 colony, were periodically examined to determine the cause and magnitude of nesting losses throughout the nesting season. I did not include the largest colony of 2009 (Sioux Point Lake) in comparisons with the 1970s because nests within this colony were located late in the season, and were likely to have sustained nesting losses before observation began. Data from 1973 and 1974 were not available separately; data from four major colonies (1973-Division Bay and Cook’s Creek, 1974-Waterhen Arm and Division Bay South) were combined by Nuechterlein (1975).

To test whether change in rates of nesting losses between the 1970s and 2009 were statistically significant, we combined both 2009 and 2010 data and collapsed probable causes of nesting losses into a dichotomous variable χ^2-test of pooled depredation-caused losses and storm-related losses, which was required to meet the minimum criterion of a χ^2-test. Accidentally broken shells, malformed eggs, nests becoming inaccessible due to seasonal water level drops, and carp destruction of nests, were omitted from the test because they were unique to either the 1970s or 2009-2010 data. The minimal effects of researcher disturbance were omitted from the test because they do not reflect differences in habitat conditions between the two survey periods.

Following the peak of hatching in early August, brood surveys were conducted on all of the major bays of Delta Marsh, and along the southern shore of Lake Manitoba, to obtain further information on Western Grebe productivity and brood movements. Brood surveys by Nuechterlein (1975) were limited to the marsh, as water control structures blocked access by Western Grebes to the lake, while our surveys included southern Lake Manitoba as the formerly blocked channels were now open, and provided Western Grebes with access to the lake. The Western Grebe population within the marsh, and surveyed off the southern lake-shore, probably did not receive additional inputs of birds from other areas. The single channel that connects the neighbouring Lake Francis to Lake Manitoba is covered by a culvert making it highly improbable that Western Grebes travel through it (Nuechterlein pers. comm.). The nearest area with suitable nesting habitat that could theoretically be contributing Western Grebes to the

Southern Lake Manitoba survey estimates are over 30 km away to the North, and are unlikely to be contributing to count data.

Brood surveys were timed to match the post-hatch lag of Nuechterlein's (1975) surveys. Otherwise, if hatch rates were the same, an earlier survey with younger chicks would show a higher chick-to-adult ratio than a later survey with older chicks (Nuechterlein pers. comm.), as full sized hatch year birds are nearly indistinguishable from after hatch year birds. Observation points of Lake Manitoba were spaced 2 km apart along the southern lake-shore from Clandeboye channel at the east end of the marsh to the University of Manitoba's Delta Marsh Field Station at the west end of the marsh. Western Grebe adults are large and chicks are dependent upon them for a minimum of six weeks (Storer & Nuechterlein 1992), making their broods very conspicuous in the open water areas which they occupy to rear their chicks. Although complete coverage of the marsh was not possible, a large sample for calculating chick-to-adult ratios was obtainable. The numbers of adults, numbers of chicks, and chick age class (Nuechterlein 1975), were recorded. Back brooded chicks could not be counted with confidence, as adults with raised wings may or may not be concealing a chick, and were not included in calculating ratios (Nuechterlein 1975). Surveys were performed from one hour after sunrise to the early afternoon on very calm days.

Volunteers and I performed brood movement observations at the four channels where the carp screens are proposed to be located (Figure 2), to investigate whether Western Grebes and their broods move between the marsh and Lake Manitoba. Observations were conducted sporadically, when time permitted, from July 13 to August 21, 2009, from shortly after sunrise to mid-afternoon.

3.2.3 *Colony exposure & wind*

Vegetation maps of the marsh in 2009 (DUC 2009) were used to determine the fetch of open water (distance to nearest wavebreak or shoreline) in eight compass directions for each of the 17 colonies of 2009 and 2010, as an index to wave exposure.

To examine differences in high wind intensity and frequency between 1973/1974 and 2009/2010, I calculated average maximum daily wind speeds from May 18 to July 31 for each year. Because wind speeds on days with maximum daily wind speeds below 31 km/h were not recorded (Environment Canada), these days were assigned the value of 16 km/h for calculating average maximum daily wind speed. Using Welch's *t*-test, I compared average maximum daily wind speed between all years. Using χ^2-tests, I also compared frequencies of high wind events between all years, though counts of high wind events greater than 70 km/h were omitted to meet the minimum criterion of the χ^2-test.

3.2.4 *Colony mapping*

To map the locations of individual nests in the largest colonies, an aerial photography technique was employed. After hatching in the largest colonies was completed, and the colonies were uninhabited by nesting birds, I tied white plastic bags to the emergent vegetation above each remaining nest to provide visible markers on aerial photographs, which were taken the following morning. Only those nests remaining present after hatching was complete were included in the maps. Evidence of many nests was absent by then, and I was unable to quantify habitat variables for these nests, which were predominately positioned near the perimeter of the colony, and they were therefore omitted from the sample of nests included in the maps. Due to difficulties in photographing the entire length of Gibby's island (Figure 6), I only used the largest part (southern part) of the island for mapping in the GIS; I was able to photograph, and enter into the GIS, the entire Blackfox North Island. Photographs of the Northern and middle portions of Gibby's Island could not be entered into the GIS because the projection of the photographs was warped. Photos were taken using a Panasonic DMC-T25 10.7MP digital camera from a small fixed-wing aircraft (<200 km/h, 300 m altitude). After the flight, nest identification numbers were matched to nest sites on the aerial photograph and the plastic bags were then removed. The colony photos were then geo-referenced into 2009 satellite imagery of Delta Marsh (DUC) using ArcGIS v.9.2.

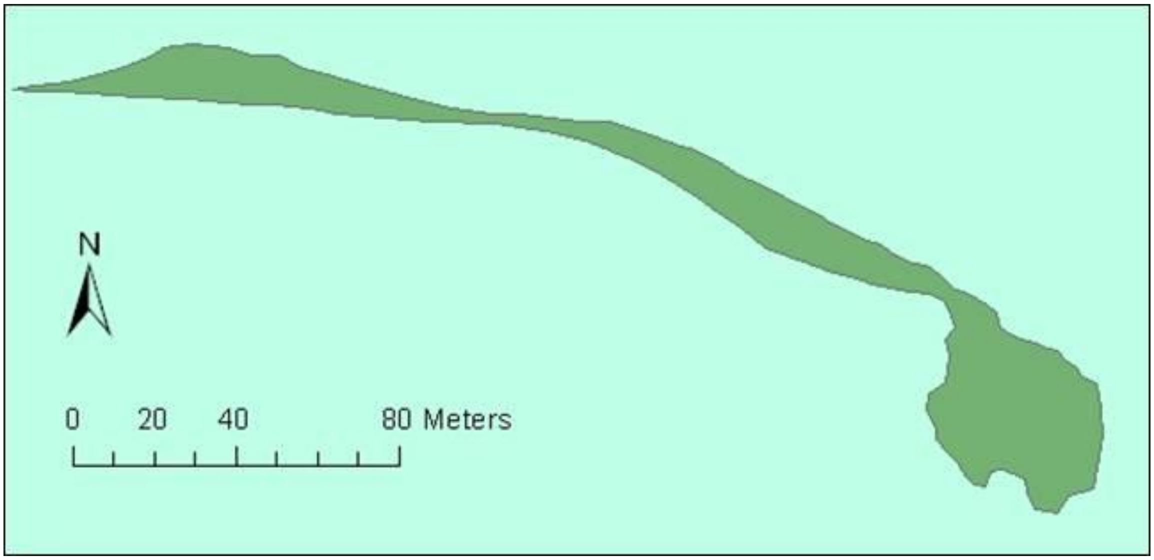

Figure 6. Overview of Gibby's Island, at Delta Marsh, 2009 (See Figure 1. for location within Delta Marsh).

Using the digital colony maps, the shortest distance to the open-water edge of the nesting island, and fetch of open water (distance to closest wave break), was measured for all marked nests in the aerial photographs. The area (m^2) of the southern portion of Gibby's and Blackfox North Islands was calculated from the aerial photographs. Because I was only able to photograph the southern portion of Gibby’s island, this is the only portion of the colony for which area was calculated.

During spring and summer at Delta Marsh, the predominant wind directions are from the northwest (Environment Canada). Nests were categorized as being either on the wayside (northwest) or the leeside (southeast) of nesting islands by bisecting the islands using a straight line from the south west to the north east across the center of each nesting island.

Nearest neighbor distances of contemporary nests in these two large colonies were calculated using Hawth’s Analysis Tools (Beyer 2004) for ArcGis v.10 to compare with nearest neighbor distances among nests in the 1970s.

3.2.5 *Statistical Analysis*

Effects of habitat structure on nesting success were modeled using a logistic regression approach that has been modified to accommodate the unique characteristics of nesting success data (Dinsmore et al. 2002, Shaffer 2004). I used logistic exposure modeling (PROC NLMIXED, SAS Institute 2008) to analyze how odds of nesting success were affected by year (2009 or 2010), date of nest initiation, distance of each nest to the open-water edge, fetch of open water adjacent to each nest, and whether or not nests were on the wayside or leeside of the island. Nests included in the model were limited to nests included in the colony maps.

In order to determine whether the effect of colony should be included in the nesting success model (success=1, failure=0), I used generalized linear modeling (PROC GENMOD, SAS Institute 2008) to determine whether nesting success was significantly different between the two 2009 colonies. There was no significant difference between the two 2009 colonies ($\chi^2 = 0.02$, $p>0.1$, df = 1, $n=196$), thus the colony variable was omitted from the final model.

The year variable represented all causes of variation in nesting success among years. I hypothesized that the primary reason for these differences would be water level, but I acknowledge that there may also have been other causes of variation in nesting success among years.

To determine whether effects of nest initiation date on nesting success were nonlinear, nest initiation dates were modeled using a quadratic function. Because Julian nest initiation date and Julian nest initiation date squared were strongly correlated ($r>0.99$, $p<0.001$) there is a high risk of multi-collinearity in the model. To minimize problems of multi-collinearity, Julian nest initiation dates were centered by subtracting the median nest initiation date prior to adding the polynomial term (Quinn & Keough 2002). The distribution of the independent predictor variable distance (m) of nest to the open-water edge of nesting islands was normally distributed (Table 1). Nests on the leeside (n=166) or wayside (n=133) of the islands were expressed binomially.

Table 1. Descriptive statistics of covariates used in a logistic regression model examining odds of nesting success of Western Grebes at Delta Marsh during the 2009 & 2010 breeding seasons.

Variable	Mean	Median ± SD	Minimum	Maximum
Nest initiation Julian date		164^{*} ± 15.2	$146^{§}$	$221^{€}$
Distance to edge (m)	8.1	6.78 ± 4.8	0.49	21.42
Fetch of open water (m)	525.1	280.5 ± 445.3	121	2879

*June 13, §May 26, $^{€}$August 9

I transformed effect sizes and 90% confidence limits by using Euler's $e^{(\beta)}$ to calculate odds ratios for effect sizes, which are more easily interpreted. For example, an odds ratio of 0.4 for fetch of open water would indicate that the odds of a nest being successful are 60% less likely for every increase of one unit change (100 m) in fetch of open water ((1-odds ratio)*100). An odds ratio of 1.4 would indicate that the odds of a nest being successful are 40% more likely for every increase of one unit change (100 m) in fetch of open water ((1-odds ratio)*100).

The complete model was represented by the equation: NESTING SUCCESS = YEAR + ADJUSTED NEST INITIATION JULIAN DATE+ ADJUSTED NEST INITIATION JULIAN DATESQUARED + DISTANCE TO EDGE + FETCH OF OPEN WATER + LEESIDE or WAYSIDE.

3.3 Flightlessness

To continue Nuechterlein’s (1988) investigation into atrophied flight muscles in Western Grebes during the breeding season, I investigated flight muscle mass in 64 birds that were accidentally drowned in gill-nets in 2009 and 2010. These gill-nets were associated with ongoing research on the fish population within Delta Marsh (Wrubleski, unpublished data). Necropsies were undertaken to examine if, and to what degree, flight muscles were atrophied. All the specimens I examined died less than 24 hours before collection, and were stored in freezers maintained at constant -30°C until they were processed.

Methods were consistent with previous examinations into the body composition of Great Crested Grebes (Piersma 1988), Western Grebes (Nuechterlein 1988), and Eared Grebes (Jehl 1997). Total body mass was determined by weighing each bird and subtracting the mass of their gastrointestinal contents. Using a scalpel, each bird was dissected to remove a single breast muscle (*pectoralis* and *supracoracoideus*), along with the contents of the stomach and intestines. After as much surficial fat as possible was removed, breast muscles and the gastrointestinal contents were weighed to the closest 0.01g. Sex and evidence of molting were noted. Because only one breast muscle was removed and weighed, I doubled the mass of the removed muscle to estimate total mass of flight muscles for each bird. Because Nuechterlein's (1988) data is only available as a summary table reporting average flight muscle mass from May through August, I also calculated monthly averages.

I calculated monthly average percentage of total body mass for flight muscles of both male and female Western Grebes collected by Nuechterlein (1988) from the months of May, June, July and August. I also calculated monthly average percentage of total body mass for flight muscles of both male and female Western Grebes collected in June, July and August of 2009 and 2010, by dividing monthly average mass of flight muscles by monthly average total body mass. By using average percentage of total body mass for flight muscles, these data were standardized, which controlled for possible changes in Western Grebe body mass since the 1970s. This allowed for comparisons between monthly average percentage of total body mass for flight muscles of male and female Western Grebes between the 1970s (Nuechterlein 1988) and recent data.

I compared recent Western Grebe flight muscle mass data to Nuechterlein's (1988) data to examine whether the timing of Western Grebe flight muscle atrophication and recuperation during 2009 and 2010 was different from Nuechtelein's (1988) data. Using χ^2-tests, I compared average percentage of total body mass for flight muscles of male and female Western Grebes collected at Delta Marsh in the months of June, July and August (Nuechterlein 1988), to recent average percentage of total body mass data from the same months.

4.0 RESULTS

4.1 Spatial Distributions

The locations and sizes of colonies varied between the 1970s and the 2009/2010 (Figure 2). There are also differences between colony locations and sizes between 1973 and 1974, and between 2009 and 2010 (Table 2).

During the breeding season of 2009, 1314 Western Grebe nests in nine colonies were initiated on Delta Marsh, whereas in 2010 there were 1428 nests in eight colonies, including one solitary nest 3 km from any contemporary colonies. In 1973 there were 654 nests in thirteen colonies, and in 1974 there were 585 nests in seven colonies (Table 2). In 2010, three colonies were initiated in locations where Western Grebes nested in the 1970s: Division Bay North, Goldeye Pond, and West Simpson Bay (Figure 2, Table 2). Three 2009 colony sites (22 Bay Islands East, High Point Lake, and Gibby’s Island) were re-selected in 2010. However, the 22 Bay Islands East colony only had four nests in 2010, which represents a decrease from 162 nests in 2009. In 2010, High Point Lake contained one unsuccessful nest and cannot be considered a colony. The Gibby’s Island colony contained 20% of the total number of nests initiated during 2009; the same island was recolonized in 2010 and contained 65% of the total number of nests initiated that year.

In 2009, 90% of the nests were distributed among six small colonies, whereas 94% of nests initiated during 2010 were distributed among three large colonies: Division Bay North, Gibby's Island, and Bluebill Bay North. During both 2009 and 2010, no Western Grebe colonies were located in Cadham Bay, the most westerly bay of the East Unit of the marsh (Figure 2). During the breeding season of 1974, one colony was situated in Delta Channel, and during 1973,

Table 2. Counts of nests within Western Grebe colonies at Delta Marsh during 1973, 1974 (Nuechterlein 1975), 2009, and 2010.

		Nests With Eggs			
Map Location (Figure 2)	Colony Name	1973	1974	2009	2010
1	Cook's Creek	226*			
2	Division Bay North	90	5		264
3	Waterhen Peninsula	88			
4	Small Bluebill Bay	55			
5	Gadwell Island	48			
6	Naegley's Point	33*			
7	Goldeye Pond	32			18
8	Blackfox	31			
9	Gadwell North	16*			
10	East Bluebill	15*			
11	West Simpson	9	20		29
12	The Gap	8			
13	Waterhen Arm	4*	239*		
14	Division Bay South		261		
15	Delta Channel		42		
16	Portage Creek		22		
17	Cook's Creek West		5		
18	Blackfox North			239	
19	Gibby's Island			264	927
20	Sioux Point Pond			284*	
21	22 Bay islands, East			162	4
22	High Point Lake			133*	1
23	Bluebill Bay North(a)			102	
24	Bluebill Bay North(b)				151
25	22 Bay Islands, North			61	
26	22 Bay islands, West			54	
27	22 Bay, North Shoreline			14	
28	Moses Creek				34
	Total Nests	655	594	1313	1428

* Does not represent a complete count

one colony was situated at The Gap, both of which were located on Cadham Bay. Adjacent to Cadham Bay are the most developed areas in the vicinity of Delta Marsh; this area includes the highway that provides access to Delta Beach, and many lake-front summer cottages.

4.2 Colony Exposure

Most colonies were protected from the prevailing northwest winds (Figure 7) by being situated near northern shorelines or within small sheltered bays (Figure 2). There were no fetch measurements greater than 1 km in the north-northwest to west-southwest directions (Table 3), suggesting that colonies were unlikely to be exposed to large waves originating from these directions. Similar to the 1970s, south-southeast and east-northeast exposures during 2009/2010 (Table 3) showed the greatest variability in fetch measurements and therefore in exposure indices.

4.3 Temporal Distribution

Western Grebes at Delta Marsh during 2009 and 2010 continued to exhibited a long nesting season similar to the 1970s (Nuechterlein 1975). Nest initiation during 2009 extended for 68 days from May 27 to August 2, and for 67 from May 20 to July 25 in 2010 (Figures 8 & 9). Nest initiation during 1973 occurred for 61 days from May 18 to July 19, and 67 days from May 30 to Aug 4 in 1974.

4.4 Distribution of nests within colonies

Temporal and spatial distribution patterns of nests within colonies were studied within the two largest 2009 colonies (southern part of Gibby’s Island and Blackfox North; Figure 8),

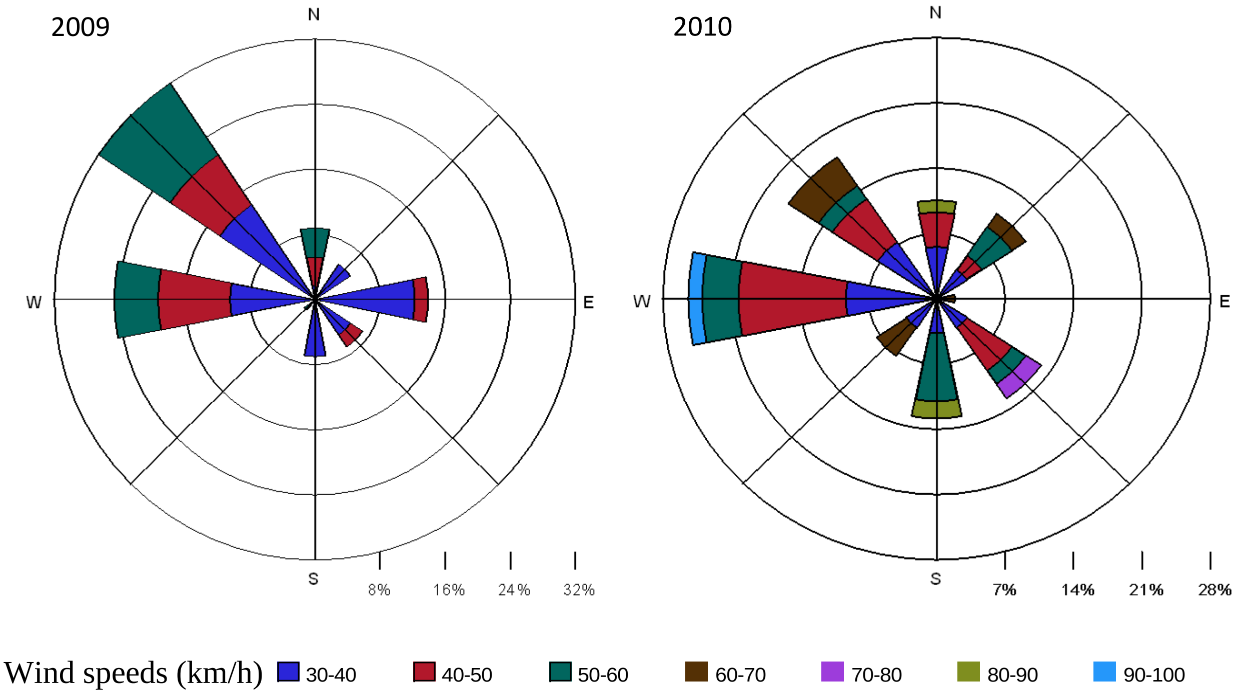

Figure 7. Daily maximum wind speeds and directions from May 18 to July 31, 2009 and 2010. Wind speeds <31 km/h were not recorded (Portage la Prairie, Environment Canada).

Table 3. Distributions of fetch distances for seventeen Western Grebe colonies within Delta Marsh during 2009 and 2010.

	Number of measurements				
Fetch distance (km)	North-Northwest	West-Southwest	South-Southeast	East-Northeast	Total
0.00-0.49	27	31	24	28	110
0.50-0.99	7	3	3	3	16
1.00-1.49	0	0	3	2	5
1.50+	0	0	4	1	5
Totals	34	34	34	34	136

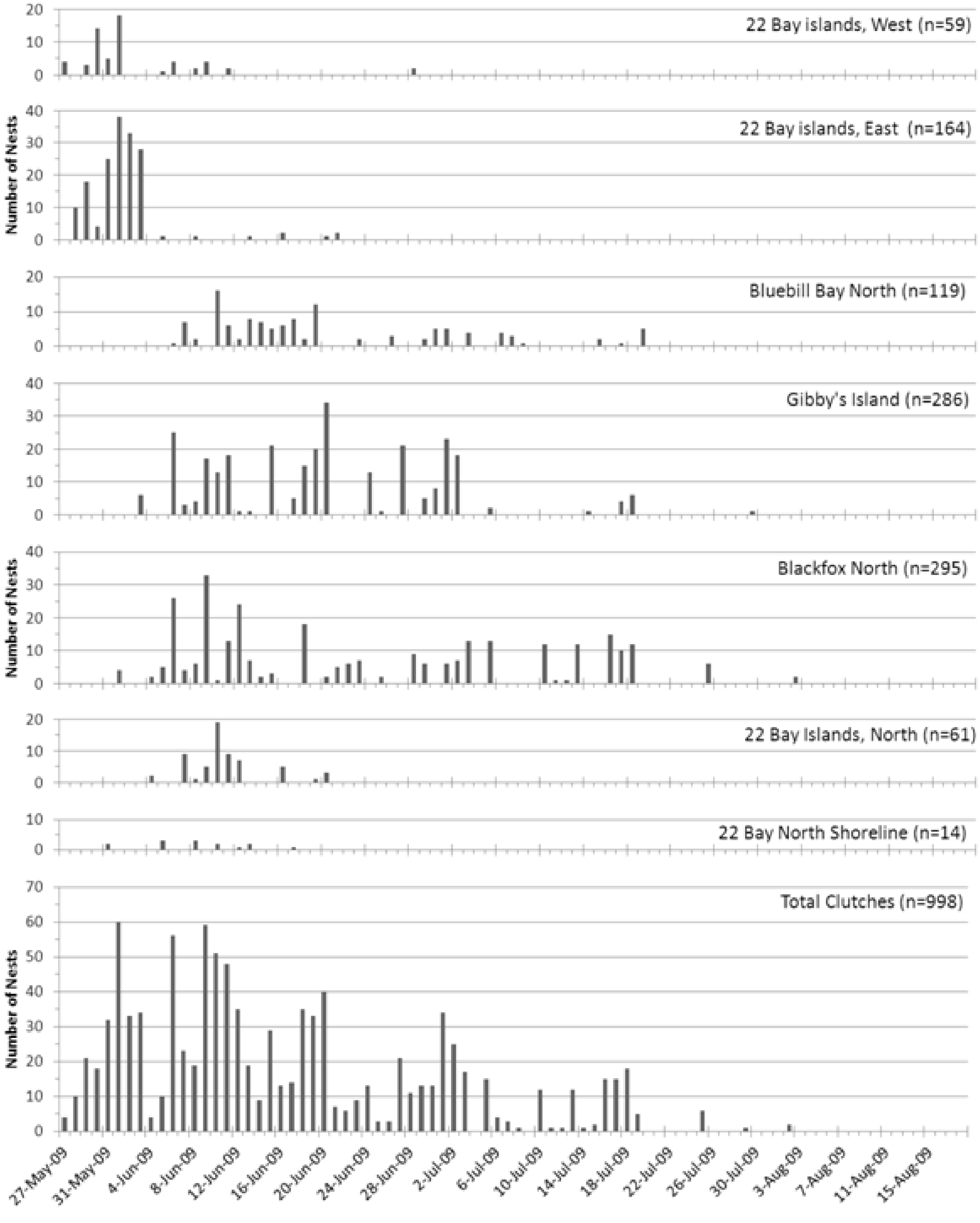

Figure 8. Temporal distribution of Western Grebe nest initiations at Delta Marsh during 2009.

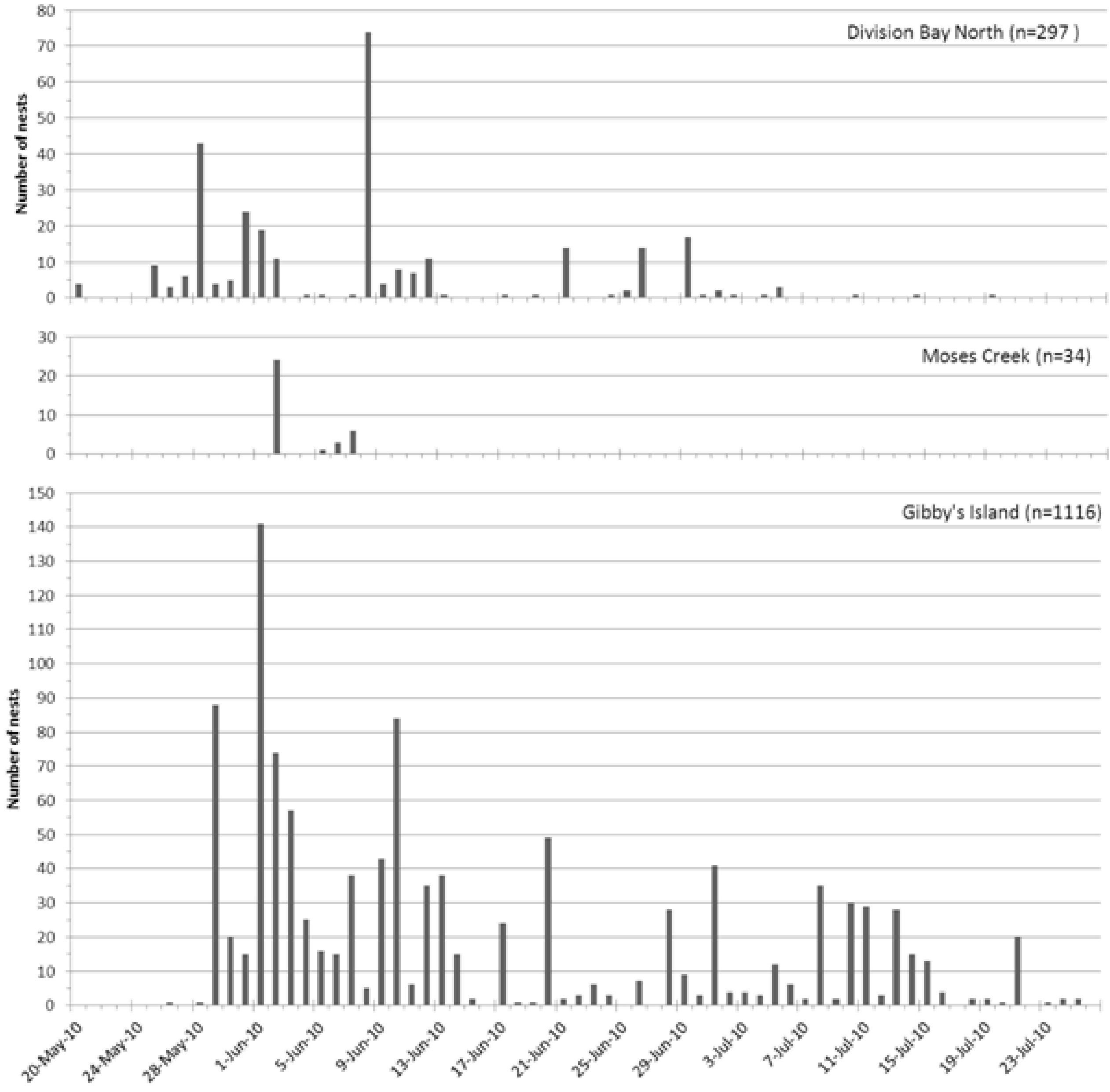

Figure 9. Temporal distribution of Western Grebe nest initiations at Delta Marsh during 2010.

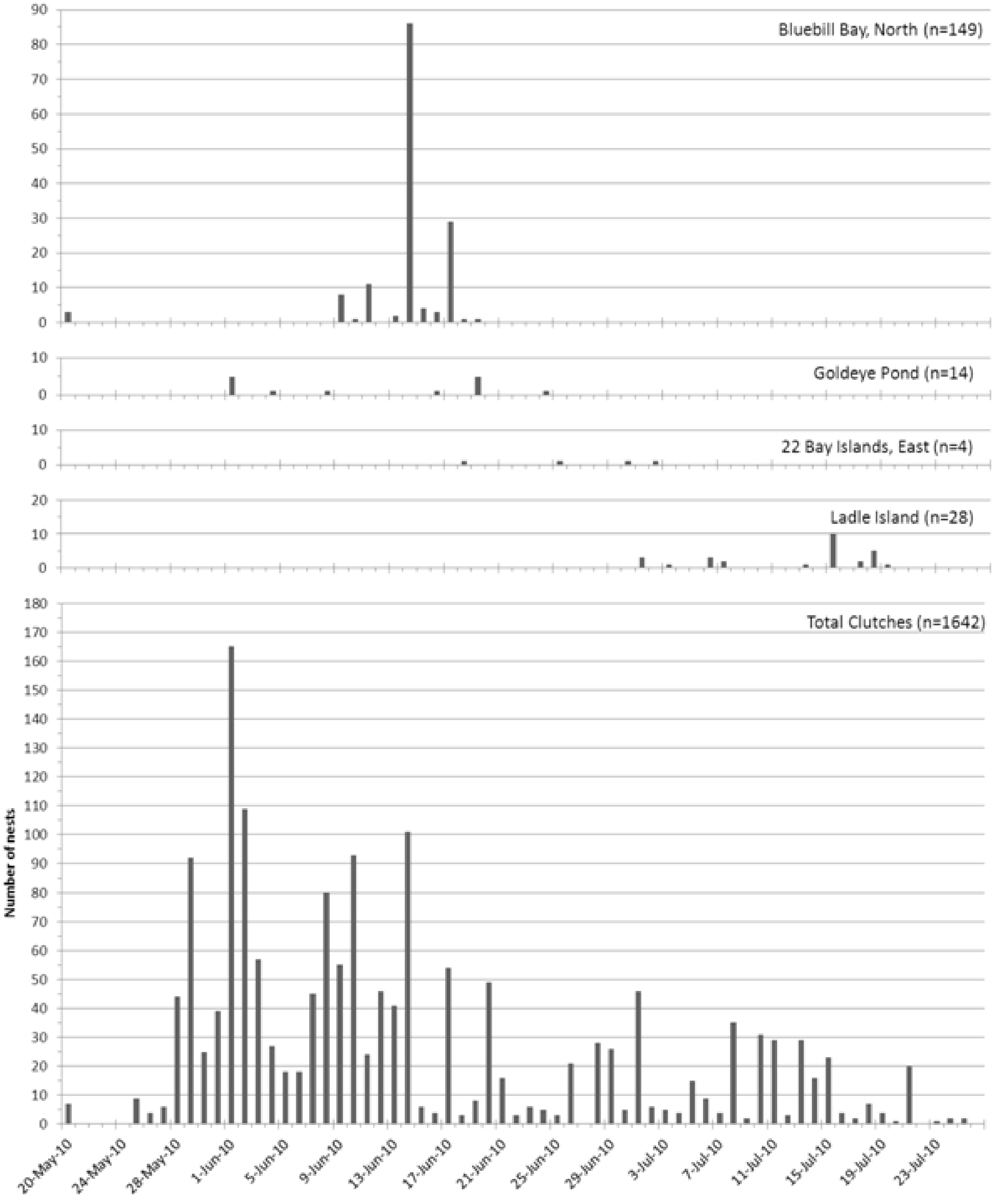

Figure 9. Continued.

and the southern portion of the largest 2010 colony (Gibby's Island) (Figure 9). The distance of nests to the open-water edge of the nesting islands was greater in 2009 than 2010 (Table 4). These distances to edge, however, are a function of the size and shape of the nesting islands; nests within larger islands have potentially greater distances to the open-water edge. The Blackfox North colony was 53% larger than the southern portion of the Gibby's Island colony in 2009, and 63% larger than the southern portion of Gibby's Island colony in 2010 (Table 5). In 1974, the largest nesting island (Division Bay South; Nuechterlein 1975) covered 464% more area than the Blackfox North colony in 2009, and 764-823% more area than the southern portion of Gibby's Island during 2009 and 2010.

At the beginning of the 2009 nesting season, water levels were sufficiently high (Figure 3) to allow Western Grebes to penetrate central areas of islands to select nest sites. Initial nests were primarily located near the center of islands (Figure 10), with later nesting efforts radiating outward due to gradually decreasing water levels and increasingly dense cattail stands. As the 2009 nesting season advanced, mean distances to open-water edge decreased (Table 4). Selected nest sites shifted to the periphery of the island, thus increasing nest exposure to wave action and contributing to nesting losses. In 2010, low water conditions early in the nesting season (Figure 3) that exposed dead cattail litter at the centers of nesting islands, and impenetrable stands of cattails, caused Western Grebes to nest near the open-water edge (Figure 10). Mean distances from nests to the open-water edge in 2010 did not significantly change as the nesting season advanced ($p<0.01$; Table 4). Nest sites in 2010 were located nearer to the open-water edge of nesting islands than during 2009 (Table 4).

In the largest colonies of both 2009 and 2010, the mean distance to the open-water edge decreased from distances documented for the largest colony (Division Bay South) during the high water year of 1974 (Table 4). Distances of nests to the open-water edge are not available for the low water year of 1973.

Table 4. Distances of nests to the open-water edge (m) within the largest 1974 colony (Nuechterlein 1975), and the southern portion of Gibby's and Blackfox North Islands during 2009 and 2010.

Colony	Year	Clutch Initiation Date	# of Nests	Mean Distance (m) to Edge
Division Bay South	1974	June 1 - June 17	75	20.6 ± 1.9
		June 18 - July 5	122	21.2 ± 1.6
		July 6 - Aug 10	64	18.3 ± 2.4
Blackfox North	2009	June 1 - June 17	72	12.7 ± 0.8
		June 18 - July 5	42	10.0 ± 1.3
		July 6 - Aug 10	29	8.6 ± 1.2
Gibby's Island	2009	June 1 - June 17	25	9.8 ± 1.5
		June 18 - July 5	28	6.7 ± 0.9
		July 6 - Aug 10	0	*NA*
Gibby's Island	2010	May 26 - June 17	68	3.4 ± 0.3
		June 18 - July 5	15	3.5 ± 0.5
		July 6 - July 21	19	5.0 ± 0.8

Table 5. Area (m^2) of Division Bay South in 1974 (Nuechterlein 1975), Gibby's Island (South), and Blackfox North Island colonies during 2009 and 2010 at Delta Marsh, Manitoba.

Colony	Year	Area (m^2)
Division Bay South	1974	~13000
Blackfox North	2009	2304
Gibby's Island (south)	2009	1505
Gibby's Island (south)	2010	1408

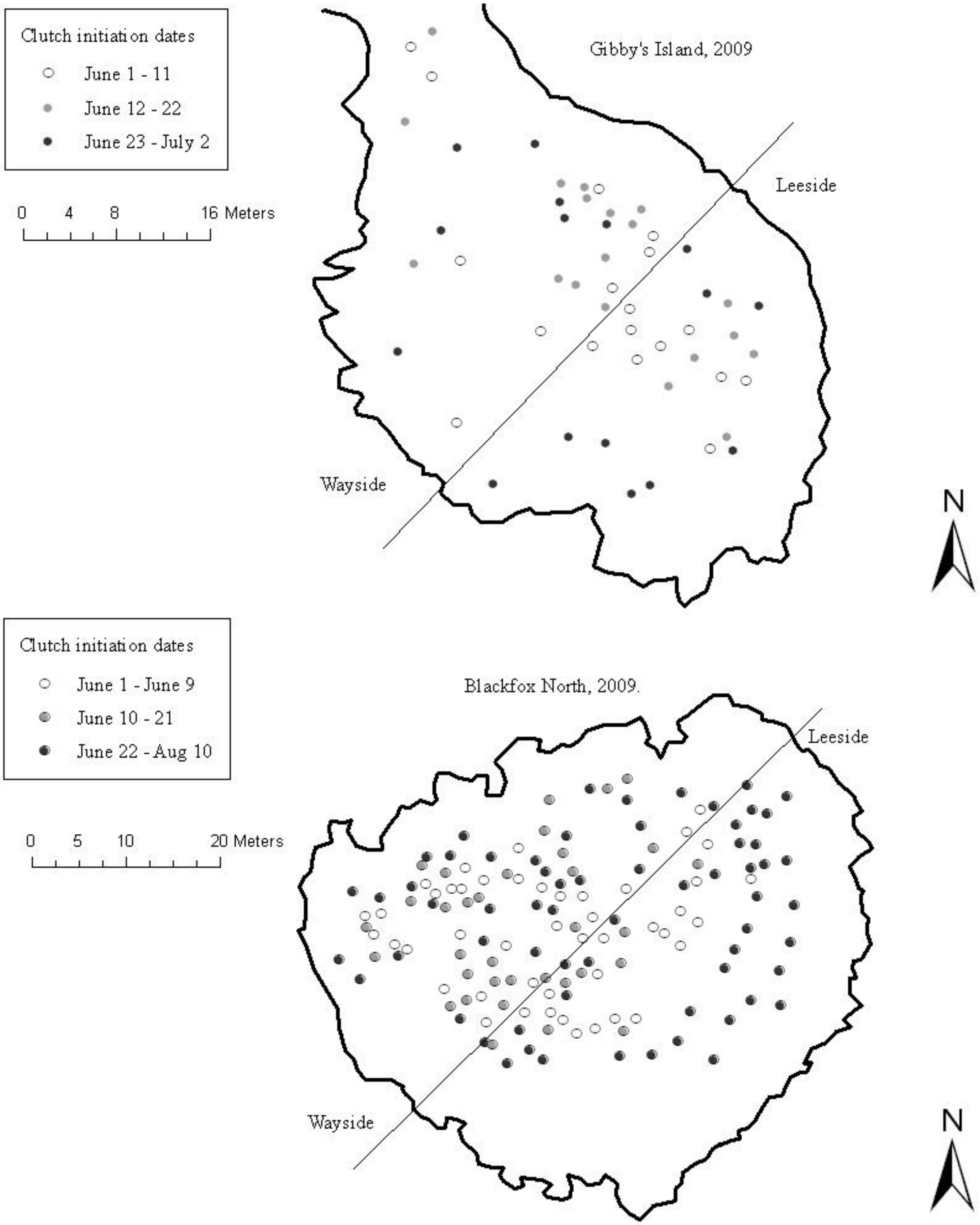

Figure 10. Spatial and temporal distributions of nests at Gibby's Island and Blackfox North Island during 2009 and 2010 at Delta Marsh, Manitoba.

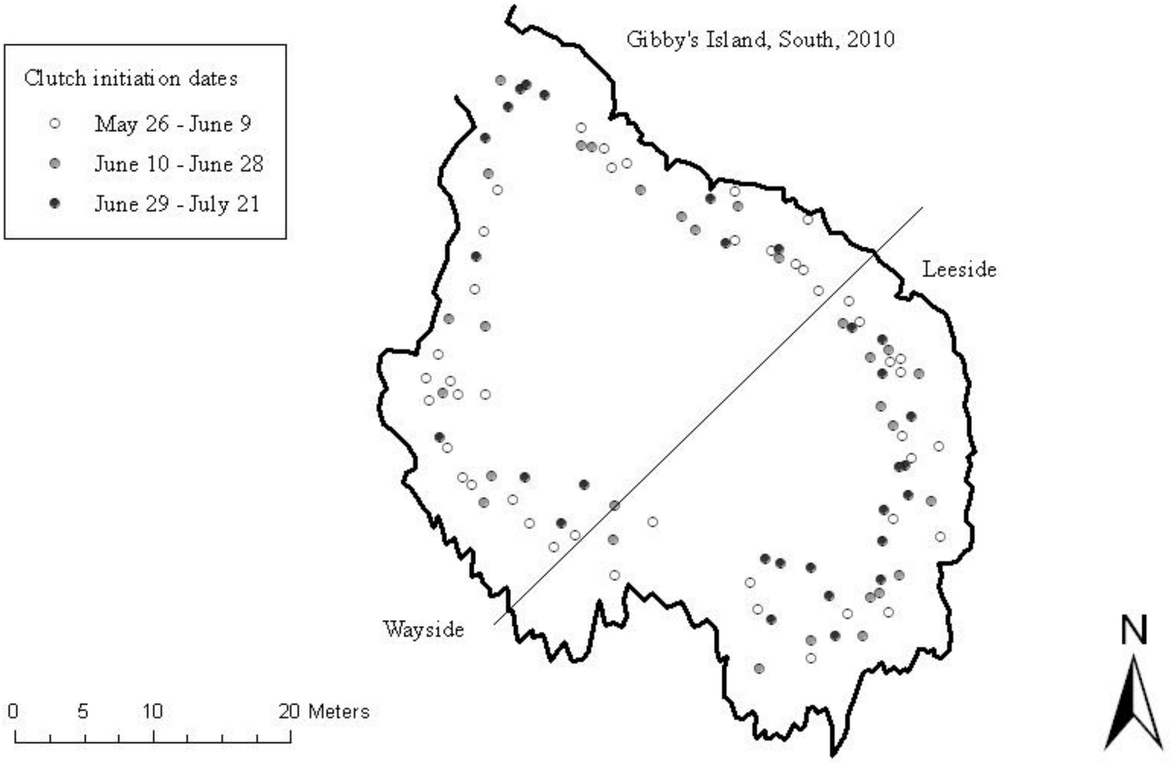

Figure 10. Continued.

4.5 Nesting Habitat Characteristics

During 2009, all nests were located in stands of cattail (*Typha* x *glauca*). In 2010, all but 18 nests were located in stands of emergent cattail; the remaining 1.3% of nests were located in a small stand of hardstem bulrush (*Schoeonoplectus* spp.). In contrast, during the high water year of 1974 (*n*=518), 59% of nests were established in phragmites, 30% in bulrush, and 11% in cattail, while during the lower water levels of 1973 (*n*= 654), 98% of nests were established in bulrush, 2% in cattail, and no nests in phragmites (Nuechterlein 1975).

During 2009/2010, in deep water areas within cattail nesting islands, nests were built of cattail stems piled on top of clumps of cattail rhizomes (Figure 11). Nests in shallower areas were constructed of cattail stems piled on the marsh bottom (Figure 11). The 18 nests situated in

Figure 11. Non-floating Western Grebe nests with eggs in shallow water built up from the marsh bottom or anchored in clumps of hybrid cattail (*Typha x glauca*) at Delta Marsh, 2009.

Figure 12. Floating Western Grebe nest with eggs in a deep water stand of emergent hardstem bulrush (*Scirpus lacutris* spp. *glaucus*) at Delta Marsh, 2010.

the relatively deeper waters of a stand of emergent bulrush were built of piled floating bulrush stems (Figure 12).

During 2010, the mean water depth of freshly initiated nests situated in stands of cattail was 24.8 cm (min=3.4, max=45.8, *n*=134). Water depth below nests was not measured in 2009. The mean water depth below nests situated in bulrush was 53.4 cm (min=43.6, max=63.2, *n*=14).

In 1973/1974, mean water depth below nests was 41 cm (*n*=315), and 99% of all nests had depths greater than 25 cm (Nuechterlein 1975).

4.6 Nearest Neighbor Distances of Nests

The distances between nests of 1.43 to 2.49 m (Table 56) within the largest colonies of 2009/2010, were less than the distances of 2.2 to 5.0 m (Nuechterlein 1975) between nests within the 1973/1974 colonies. In both 1973/1974 and 2009/2010, nests were spaced farther apart during high water years than during low water years. Mean nearest neighbour distances among nests in 2009 (1.94, 2.49, 1.43; Table 6) were less than mean nearest neighbour distances of 3-5 m during the high water year of 1974 (Nuechterlein 1975). During the low water year of 1973, when 98% of nests were situated in stands of bulrush, Nuechterlein (1975) indicated that if all nests in the island with the highest density of nests had been evenly spaced, the maximal nearest neighbor distances would have been 2.2 m. Because there was less nesting habitat available during the lower waters of 2010, mean nearest neighbor distances were less than mean nearest neighbor distances during 2009 (Table 6).

Table 6. Mean nearest neighbor distances among nests within the largest colonies at Delta Marsh during 2009 and 2010.

Colony	Year	Number of Nests	Mean Nearest Neighbour Distance (m)
Blackfox North	2009	145	1.94 ± 0.11
Gibby's Island	2009	54	2.49 ± 0.38
Gibby's Island	2010	103	1.43 ± 1.3

*Data are ± 2 SE

4.7 Clutch Size

Western Grebe mean monthly clutch sizes of 4.17 in May, 3.45 in June, and 2.84 in July of 2009/2010 were significantly greater (p<0.01) then mean monthly clutch sizes in the 1970s (Nuechterlein original data, *in* Storer & Nuechterlein 1992). Clutch sizes diminished through the nesting season (Figure 13).

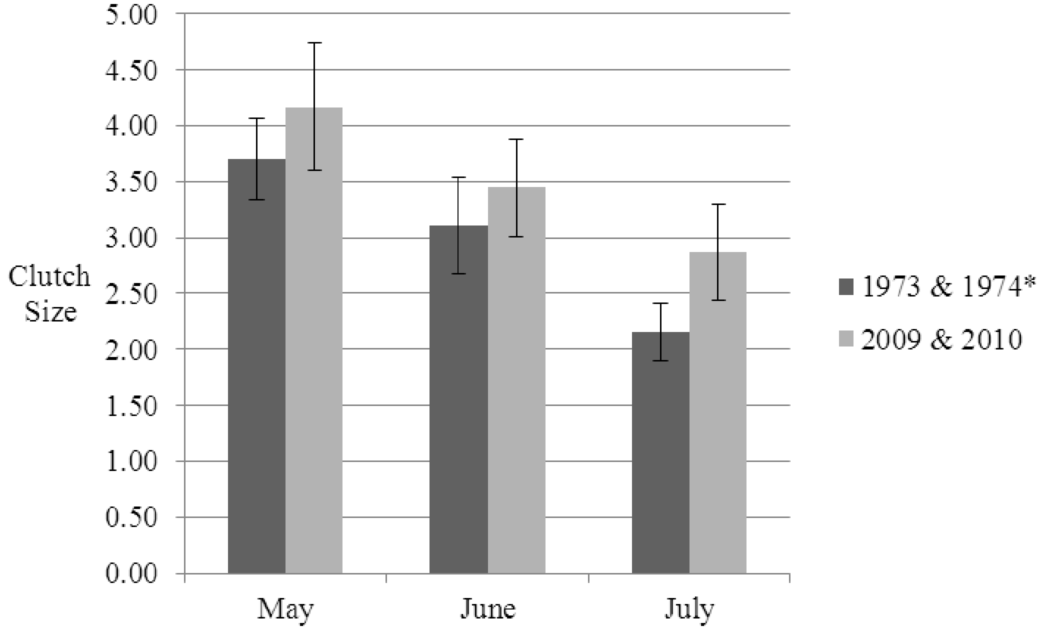

Figure 13. Monthly clutch sizes and of Western Grebes at Delta Marsh during the late 1970s* (G. Nuechterlein original data, *in* Storer & Nuechterlein 1992), and 2009/2010.

4.9 Breeding Success & Relative Abundance

Nesting success (84%) in a sample of 181 initial nests in the two largest colonies during 1974 was significantly greater than the rate of nesting success (49%; Table 7, Figure 14) of initial nests in the two largest colonies during 2009 (χ^2= 55.18, p< 0.001, df=1, n = 211) and nesting success (43%; Table 7, Figure 14) of initial nests in the largest 2010 colony (χ^2= 345.53, p< 0.001, df = 1, n = 445). Nesting success was 42% lower in 2009 and 48% lower in 2010, compared with 1974. Nesting success in 2009 (Table 7, Figure 14) was not significantly different from nesting success (46%) in 1973, (χ^2= 2.18, df = 1, n = 211), indicating that nesting success in 2009 was the same as it formerly was during the low water year of 1973. Nesting success in 2010 (43%; Table 7, Figure 14) was significantly less than the nesting success rate (46%) in 1973 (χ^2= 211.85, p< 0.001, df = 1, n = 445). Nesting success was 6.5% lower in 2010 compared with 1973.

Table 7. Nesting success of initial nests within major Western Grebe colonies during 1973, 1974 (Nuechterlein 1975), 2009, and 2010, at Delta Marsh, Manitoba.

Year	Water level	Initial nests	Successful nests	Percent success
1973	Low	195	90	45.9
1974	High	181	152	84.0
2009	High	211	104	49.3
2010	Low	445	190	42.7

The greatest source of nesting losses of initial nests in both 2009 and 2010 was wave destruction (Table 8). Destruction of initial nests by spawning carp was the second-greatest cause of nest failure (Table 8), but this occurred solely in 2009 and in only one colony. No initial nests in 2009 failed from mammalian depredation, but one nesting adult Western Grebe was killed in 2010 (Table 8). Causes and rates of nesting losses sustained by initial nests in the 1970s were not reported by Nuechterlein (1975).

Table 8. Nesting outcomes of initial nests within major Western Grebe colonies during 2009 and 2010, at Delta Marsh, Manitoba.

Year	Water level	Initial nests	Wave action		Carp destruction		Mammalian depredation		Abandonned		Conspecific parasitism	
			n	%	*n*	%	*n*	%	*n*	%	*n*	%
2009	High	211	60	28.4	41	19.4	0	-	16	7.6	3	1.4
2010	Low	445	231	51.9	0	-	1	0.2	3	0.7	19	4.3

Abandoned initial nests influenced nesting success rates of initial nests in both years. Of the 16 abandoned nests in 2009 (Table 8), 14 nests located near the center of the nesting island were abandoned after becoming inaccessible due to a slight decrease in water level and cattail litter that had piled up from wave action. Of the remaining two abandoned nests, one contained malformed eggs, and the other nest failed due to researcher disturbance. Of the three initial nests abandoned in 2010, one nest was abandoned because it became inaccessible, while the other two were attributed to researcher disturbance.

In the sample of initial nests, there were fewer nests parasitized by conspecifics (nests containing >6 cold eggs) in 2009 than there were in 2010 (Table 8). Some of these nests may have been parasitized while the nest was active and left unattended, while others may have been parasitized after the nest was abandoned (Storer & Nuechterlein 1992).

Similar to the 1970s, the ratio of chicks-to-adults of 0.39 in the low water year of 2010 was less than the chick-to-adult ratio of 0.60 in the high water year of 2009 (Table 9). In the low water year of 2010, the chick-to-adult ratio was 20% less than in the high water year of 2009 (Table 9, Figure 14). In comparing years with similar water levels (1973 & 2010, 1974 & 2009; Figure 3), the 2009 chick-to-adult ratio was 38.6% less than 1974, and between 1973 and 2010 there was a decrease of 24.5% (Table 9, Figure 14).

The count of 495 adult Western Grebes detected in the vicinity of Delta Marsh in early August of 2009 remained similar to the count of 483-488 during the 1970s (Table 9). Numbers of Western Grebes detected increased by ~30% from the 1970s to 2010.

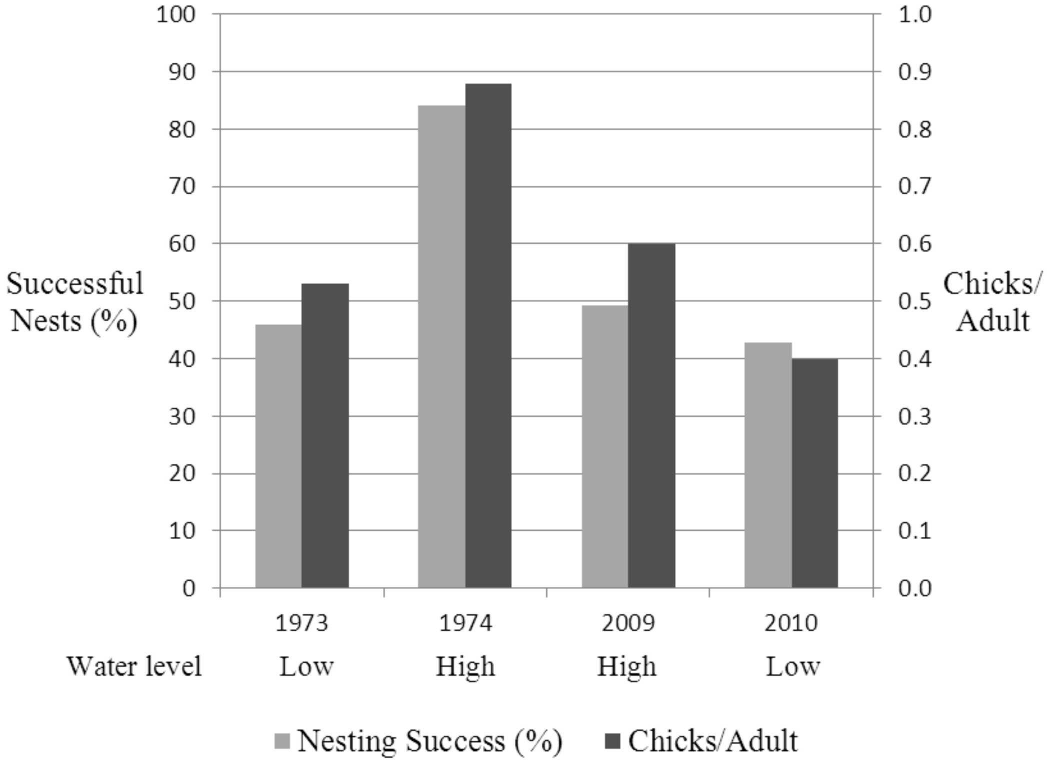

Figure 14. Nesting success of initial nests and chick-to-adult ratios of Western Grebes at Delta Marsh during 1973, 1974, 2009, and 2010.

Table 9. Population estimates and Western Grebe chicks-to-adult ratios from August brood surveys at Delta Marsh during 1973, 1974, 2009, and 2010.

Date	Water level	Location	# Adults	# Chicks	Chicks / Adults
Aug 1 & 3, 1973	Low	Delta Marsh	483	267	0.53
August 5, 1974	High	Delta Marsh	488	429	0.88
August 5, 2009	High	Delta Marsh	298	163	0.55
August 6, 2009		Lake Manitoba	197	133	0.68
		Total	495	296	0.60
August 6, 2010	Low	Delta Marsh	632	251	0.39
August 6, 2010		Lake Manitoba	0	0	NA

4.10 Causes of Nest Failure

The rate of depredation and storm-related nesting losses in a sample of 142 (Table 10) Western Grebe nests during the 1970s was significantly lower than the rate of Western Grebe nesting losses of 2009-2010 ($\chi^2 = 4571.3$, $p<0.001$, df = 1, $n = 830$).

4.10.1 *Wave destruction*

The highest proportion of nesting losses for both study periods was caused by wave action during storms (Figure 15). The proportion of nest failures caused by wave destruction in the 1970s compared with the 2000s increased by 123.3% (Figure 15).

All 37 nests in the 22 Bay East colony were destroyed by strong winds on June 4, 2009. High winds occur unpredictably on the Delta Marsh. However, average maximum daily wind speeds from May 18 to July 31 were lower in 2009/2010, and there were fewer high wind events than during both 1973 and 1974 (Table 11). Average maximum daily wind speeds from May 18 to July 31 between 1973 and 1974, 1973 and 2010, 1974 and 2010, were not significantly different (p=0.01; Table 11). Average maximum wind speeds were significantly less between 2009 and 1973 (t=3.065, df=118, p=0.0027), 2009 and 1974 (t=2.873, df=140, p=0.0047), and between 2009 and 2010 (t=3.528, df=133, p=0.0006; Table 11). Additionally, counts of high wind events in the >30 km/h and >50 km/h categories of high wind speeds (Table 11), between 1973 and 1974, 1973 and 2010, and between 1974 and 2010, were not significantly different (p=0.01). Counts of high wind speed events in the >30 km/h and >50 km/h categories were significantly less in 2009 than 1973 ($\chi^2 = 8.71$, $p<0.01$, df = 1, $n = 51$), 1974 ($\chi^2 = 11.92$, $p<0.01$, df = 1, $n = 51$), and 2010 ($\chi^2 = 9.28$, $p<0.001$, df = 1, $n = 51$).

Table 10. Probable causes of nest failures within four major Western Grebe colonies at Delta Marsh during the 1970s, and within Gibby's and Blackfox North Islands during 2009, and 2010.

		Nesting Losses					
		1973-74		2009		2010	
Probable Cause	Evidence	Total Number of Losses	% of Nests	Total Number of Losses	% of Nests	Total Number of Losses	% of Nests
Accidentally Broken Eggs	Cracked or smashed egg shells	4	0.8	0	NA	1	0.1
Abnormal Eggs	Malformed eggs	0	NA	2	0.3	0	NA
Predation							
Mammalian	Portions of carcass on or near nest	7	1.4	2	0.3	4	0.4
Avian	Pecked eggs	24	4.7	2	0.3	0	NA
Carp Destruction	Direct observation	0	NA	41	7.1	0	NA
Abandonment							
Human Disturbance	Eggs cold, marked eggs not rotated	17	3.3	7	1.2	6	0.5
Water Level	Absence of water around nest	0	NA	15	2.6	1	0.1
Wave Destruction	Nest and eggs missing or washed out	111	21.5	284	49.1	538	47.4
Total losses of checked nests*		163	31.6	353	61.1	550	48.4

**n*=516 (1970s), *n*=578 (2009), *n*=1136 (2010)

Table 11. Frequency and intensity of high wind events at Delta Marsh during 1973, 1974, 2009, and 2010.

May 18- July 31	1973	1974	2009	2010
# Days >30 km/h	51	53	45	56
# Days >50 km/h	18	21	6	17
# Days >70 km/h	6	2	0	3
Average daily wind speed (km/h)	39.63	37.29	30.13	39.63

Synchrony of Western Grebe clutch initiations within colonies may break down when nesting losses and renesting rates are high. The temporal distribution of clutch initiations during 2009 and 2010 differed from the single peak in clutch initiations recorded for 1974, and the bi-modality in clutch initiations during the low water year of 1973 (Nuechterlein 1975). Clutch initiations during 2009 and 2010 were markedly multi-modal with many peaks in clutch initiations. The multi-modality of clutch initiations in 2009 and 2010 is symptomatic of increases in rates of nest failures caused by wave destruction after powerful storms (Nuechterlein 1975), and the subsequent renesting efforts.

4.10.2 *Common Carp*

Upon entering the Gibby’s Island colony on June 11, 2009, violently thrashing carp were observed to have flushed all of the adults off nests in a shallow area of the nesting island, and were upsetting the stability of unoccupied nests. In order to prevent any additive disturbance due to my presence, I withdrew to a nearby shore and observed the event through binoculars from a distance of 150 m. Upon returning the following day, 41 nests (Table 10) were found to have been both completely destroyed and missing, or partially destroyed and abandoned. These nests had very shallow water (<30 cm) below them and were located nearer the center of the colony than to the open-water edge. Nests in deeper waters closer to the open-water edge were not affected. No high wind event occurred that could otherwise explain this event. The probable cause of these nesting losses is that carp destroyed the nests by violently bumping and uprooting the cattails to which nests were anchored. This behavior was observed in several other island and shoreline locations that were not selected for nesting by Western Grebes.

4.10.3 *Depredation*

Similar to 1973/1974, few events of depredation of nesting Western Grebes occurred within Delta Marsh during 2009 and 2010. Compared to 1973/1974, rates of depredation within the largest colonies decreased in 2009/2010 (Table 10, Figure 15). Within all of the colonies, I documented seven depredation events of nesting adults in 2009, and 21 in 2010, while Nuechterlein (1975) documented 12 in 1973/1974. During 2009/2010, the number of depredated nesting adult Western Grebes increased from 12 individuals throughout 1973/1974, to 28 individuals throughout 2009/2010.

Possible predators of nesting Western Grebes include Mink, River Otter, and Great Horned Owl. These depredations all occurred within island colonies that were inaccessible to terrestrial predators. Several carcasses in 2009 and 2010 were decapitated, which is characteristic of Mink and Great Horned Owl depredation (Burkholder 1955, Olmsted 1950). Mink scat and tracks were found at nearby shorelines, indicating that Mink were present within the marsh during 2009. No mink scat or tracks were found during 2010. Several sightings of River Otters occurred within and around the marsh during 2010 but not in 2009. At a River Otter latrine at the 22 Bay boat launch in 2010, River Otter scat was found containing Western Grebe body feathers.

Scatological evidence was first detected in late June and continued up to early August and coincided with nearby depredations.

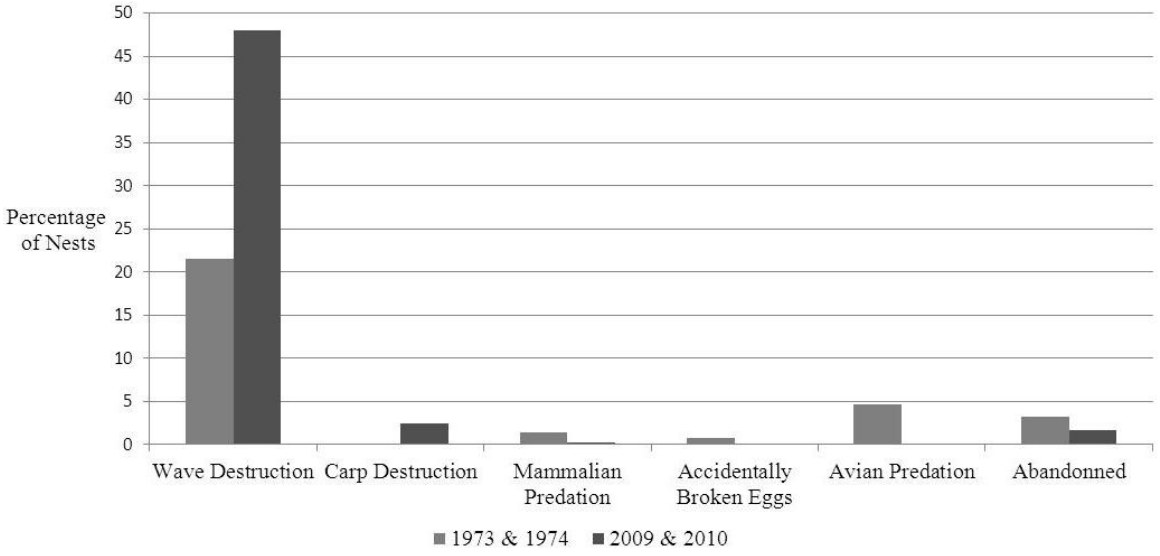

Figure 15. Nesting losses (%) in major Western Grebe colonies at Delta Marsh during 1973/1974, and 2009/2010.

In addition, in mid-July, four nesting adult Western Grebes at the eighteen-nest Goldeye Pond colony, were depredated within a week. Several flight feathers of a Great Horned Owl were found accompanying the few remains of Western Grebe carcasses at one of these four nests. Great Horned Owls had been sighted nearby several times during 2010. The remaining 14 nests in the colony were abandoned in the same week, possibly following repeated visits by a Great Horned Owl. Because all my evidence of depredation was circumstantial, the predators responsible for killing nesting adult Western Grebes cannot be specifically identified.

The primary avian predator of Western Grebe eggs within the largest colonies was probably Forster's Terns (*Sterna forsteri*), which commonly nested within the colonies. Avian predators were of minor importance to Western Grebes eggs within Delta Marsh during both the

1970s and 2009/2010, and were likely only depredated during colony disturbance by the researcher (Nuechterlein 1975). In comparison with the 1970s, avian depredation of eggs in the largest colonies decreased in 2009, and was nonexistent in the largest colony of 2010 (Table 10).

4.10.4 *Human Disturbances*

Although poor accessibility minimizes human disturbance to most Western Grebe colonies in Delta Marsh, in more accessible areas, human disturbance can be of major importance as demonstrated by the 22 Bay Islands East colony. This 2009 colony of 162 nests was established in a small bay near the north shore at the center of the marsh (Figure 2.). This bay provides one of the few access points to the marsh from the northern beach-ridge access road and was used frequently by other researchers to regularly launch a powered water-craft, causing wake and noise disturbances. In addition, an autonomous hydro-lab was deployed within 50 m of the colony during June 2009. During a major storm, the large orange buoy that marked the hydro-lab's position came loose and was found bobbing several meters inside the cattail island colony two days later, likely causing the abandonment of nearby nests.

Human disturbance also includes wakes from powered water-craft. Nests at the Moses Creek colony were located on both sides of a 40 m wide channel, and were situated in cattail stands less than two meters from the open-water edge. On June 14, 2010, researchers traveling by airboat passed through this channel. Even though the airboat speed was slow, the wake from the craft washed out and effectively destroyed all 34 nests. No Western Grebes attempted to renest in this site following this event, and likely relocated their nesting efforts to the nearby colonies of Gibby's Island and Division Bay North.

4.10.5 Nest abandonment

Rates of nest abandonment were significantly lower ($\chi^2 = 7.88$, $p<0.01$, df = 1, $n = 1714$) between the 1970s and 2009/2010. Some nests, which were positioned in central areas of the colonies, were abandoned because they became inaccessible due to dropping water levels, and piles of accumulated dead vegetation that severely restricted access to nests. The remaining nests were likely abandoned due to researcher disturbance at colony checks (evidenced by marked eggs not being turned since last checked).

Combined researcher-disturbance caused abandonment rates in major colonies for 2009 and 2010 was 0.8% (Table 10). Compared to the 1970s, the effect of researcher-disturbance caused abandonment decreased by 75.8%.

4.10.6 Abnormal eggs

Only two eggs during 2009 were found that were malformed and consequently abandoned. No nesting losses due to egg thinning were observed during 2009, though one such event did occur during 2010, not unlike the rate of 1% of nests observed during the 1970s (Table 10). Thin or abnormal eggs were uncommon, and continue to be of minor importance at Delta Marsh.

4.1 Flightlessness

The proposed carp barriers will limit movements of Western Grebes to the marsh; they will not be able to access Lake Manitoba without regaining their ability to fly. Because Nuechterlein’s (1988) sample size of Western Grebe monthly flight mass data is small, there is uncertainty regarding the timing of changes in flight muscle mass. Of a sample of 27 adult

Western Grebe carcasses collected from Delta Marsh in 2009, and 37 collected in 2010 (Figure 16), average percentage of total body mass for flight muscles of both male and female Western Grebes (Table 12) was well below the average percentage of total body mass of 11% necessary for sustained flight for eared-grebes (Jehl 1997). This was true for both males and females throughout June, July, and August.

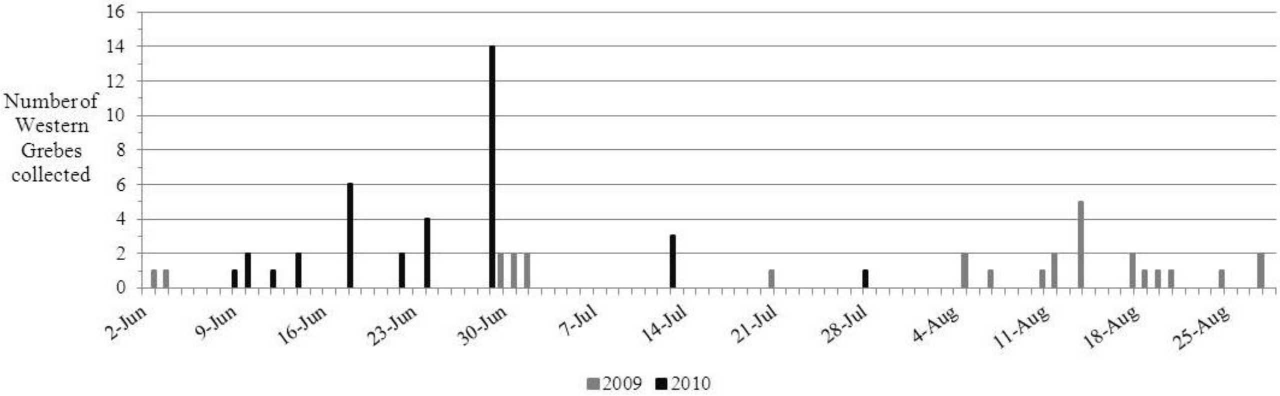

Figure 16. Temporal distribution and counts of Western Grebes drowned in gill-nets during 2009 and 2010 within Delta Marsh, Manitoba.

The differences between average monthly percentage of total body mass for flight muscles of male and female Western Grebes between the 1970s (Nuechterlein 1975) and the combined 2009 and 2010 data were not significantly different (p<0.01), but are biologically meaningful. In contrast with Western Grebes collected by Nuechterlein (1988) in August, that exhibited a return to post-migratory muscle mass, average percentage of total body for flight muscle mass of males and females continued to decline in August of 2009/2010 (Figure 17).

Table 12. Monthly variation in the fresh body mass (g) and fresh breast mass (g) of Western Grebes collected during the breeding season at Delta Marsh during 2009 and 2010, and average monthly percentage of total body for flight muscles of mass of male and female Western Grebes during the 1970s (Nuechterlein 1988), 2009 and 20100, at Delta Marsh, Manitoba.

	Males				Females			
	Body mass	Breast mass	% body mass	% body mass (1970s)*	Body mass	Breast mass	% body mass	% body mass (1970s)*
May				8.6				8.2
June	1373.9 (SE=38.4, *n*=19)	80.8 (SE=4.4)	5.8	5.5	1183.3 (SE=32.5, *n*=17)	59.1 (SE=3.6)	5.0	5.7
July	1341.8 (SE=111.0, *n*=4)	77.0 (SE=10.8)	5.7	6.1	1312.6 (SE=55.6, *n*=5)	73.4 (SE=7.3)	5.6	6.1
August	1236.7 (SE=55.6, *n*=14)	68.1 (SE=6.4)	5.4	8.3	1090.2 (SE=43.9, *n*=5)	53.4 (SE=11.5)	4.8	9.6

*Values from Nuechterlein 1988.

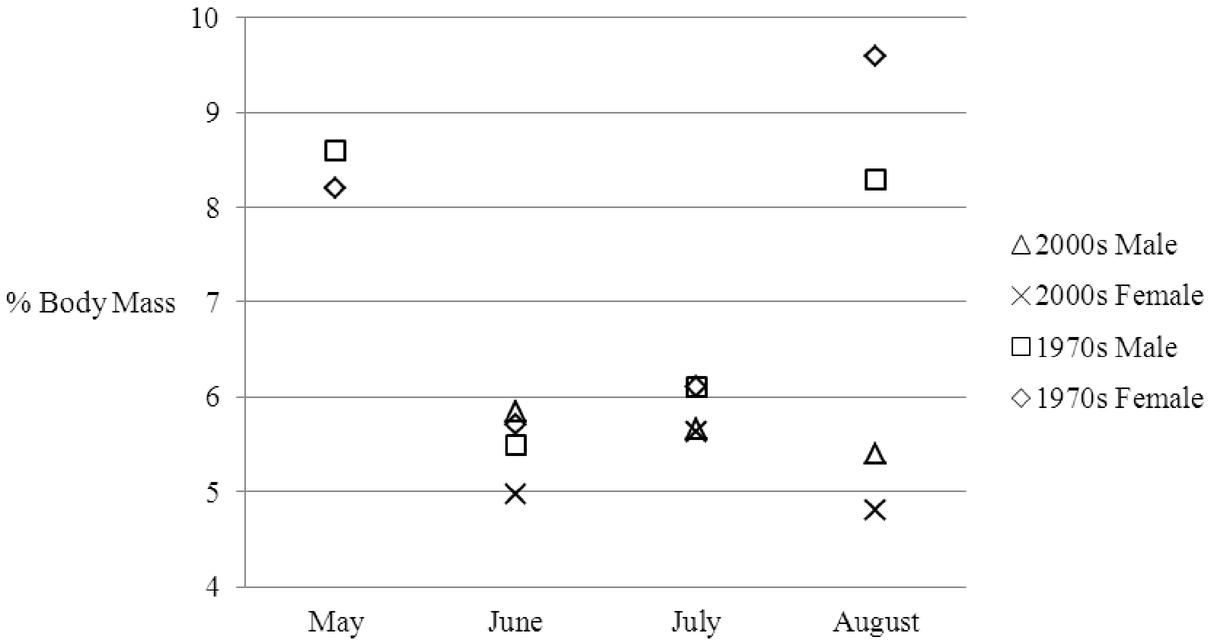

Figure 17. Average monthly percentage of total body mass of male and female flight muscles during the breeding seasons of the 1970s (Nuechterlein 1988), 2009, and 2010 at Delta Marsh, Manitoba.

4.12 Migration from Delta Marsh to Lake Manitoba

Counts of Western Grebe adults and chicks on Delta Marsh and on Lake Manitoba during August brood surveys (Table 8), and observations at channels between the East Unit of the marsh and the lake (Table 13), demonstrate that Western Grebes travel through two of the channels where the proposed carp screens may be located. It is unlikely that the Western Grebe population surveyed on southern Lake Manitoba had inputs from other areas. Therefore, Western Grebe broods counted on Lake Manitoba originated from colonies located within Delta Marsh.

Observations at the channels where carp screens are to be installed (Figure 2) provide evidence that Western Grebes move between Waterhen Bay and Small Bluebill Bay to Clandeboye Bay, and out to the lake (Table 13). The largest channel, Waterhen Creek, was the most used channel, while Crooked Creek was somewhat used and Fish Creek was not used at all. Western Grebes are unlikely to swim through a 5 m long, 3 m diameter culvert on Fish Creek. At Delta Channel, which is covered by a culvert and is often completely submerged, Western Grebes were often present on the marsh side of the channel but were never observed on the lake side, suggesting that Western Grebes do not swim underwater through this culvert.

The timing of brood movements between the two bodies of water was different in both years. In 2009, nearly half of the Western Grebe population had moved to the lake before Aug 5, but no Western Grebes were present on the lake by the same date in 2010. Casual observation of Western Grebes on the lake suggested that movements to the lake increased sharply after August 5 in 2010.

Table 13. Counts of Western Grebes traveling through channels connecting Delta Marsh and Lake Manitoba (Figure 1) during 2009.

		Adults		Chicks	
Date	Location	In	Out	In	Out
13-Jul-09	Waterhen Creek	32	21	6	10
16-Jul-09	Waterhen Creek	7	3	7	3
21-Jul-09	Waterhen Creek	38	18	3	3
07-Aug-09	Waterhen Creek	9	16	4	4
07-Aug-09	Crooked Creek	0	0	0	0
21-Aug-09	Crooked Creek	13	34	0	6
07-Aug-09	Fish Creek	0	0	0	0
21-Aug-09	Fish Creek	0	0	0	0
		99	92	20	26

4.13 Effects of habitat structure on nesting success

A total of 197 nests (118 successful nests) from 2009, and 102 nests (48 successful nests) from 2010, were included in the model for a total sample of 299 nests. Of these nests 55.2% were successful. Failed nests destroyed by wave action on the periphery of islands leave little to no evidence of their earlier presence, thus these nests were underrepresented in the sample of nests used in the model.

The effect of year between the two breeding seasons of this study was significant (*p*=0.0721; Table 14). The odds of a nest being successful were significantly influenced by Julian initiation date (*p*=0.0020; Table 14). The odds of nest survival increased from being 40% less likely to succeed on May 25th, and peaked at being 18% less likely to succeed than succeed on June 15th (Figure 18). The odds of nest survival after June 15th decreased to being 63% less likely to succeed on July 24th (Figure 18). As I had only two nests initiated after July 24th, my confidence in the shape of the relationship after this date is low.

The distance of a nest to the open-water edge of the nesting island had a strong effect on the odds of nesting success. For every increase of 1 m from the open-water edge of the island, there was a 12.47% increase in the odds of nesting success (Table 14). For every increase of 100 m in fetch of open water, the odds of nesting success decreased by 0.06% (Table 14). However, the effect of a nest being on the leeside or wayside of a nesting island did not affect the odds of nesting success (Table 14).

Table 14. Modeled parameter estimate, and odds ratios with 95% confidence intervals, for factors affecting odds of nesting success for Western Grebes at Delta Marsh, Manitoba, during 2009 and 2010.

Parameter	β	Odds ratio (95% CI)	Pr>t
Intercept	3.7350	41.8880 (24.5841, 71.3464)	<0.0001
Year	-0.4751	0.6218 (0.4027, 0.96012)	0.0721
Day (adjusted)	0.0040	1.0040 (0.9909, 1.0173)	0.6162
Day (adjusted)2	-0.0124	0.9877 (0.998112, 0.9994)	0.0020
Distance to edge (m)	0.1175	1.1247 (1.0681, 1.1844)	0.0002
Fetch (100 m)	-0.0006	0.9994 (0.9991, 0.9998)	0.0053
Leeside or Wayside	-0.1491	0.8615 (0.6176, 1.2018)	0.4609

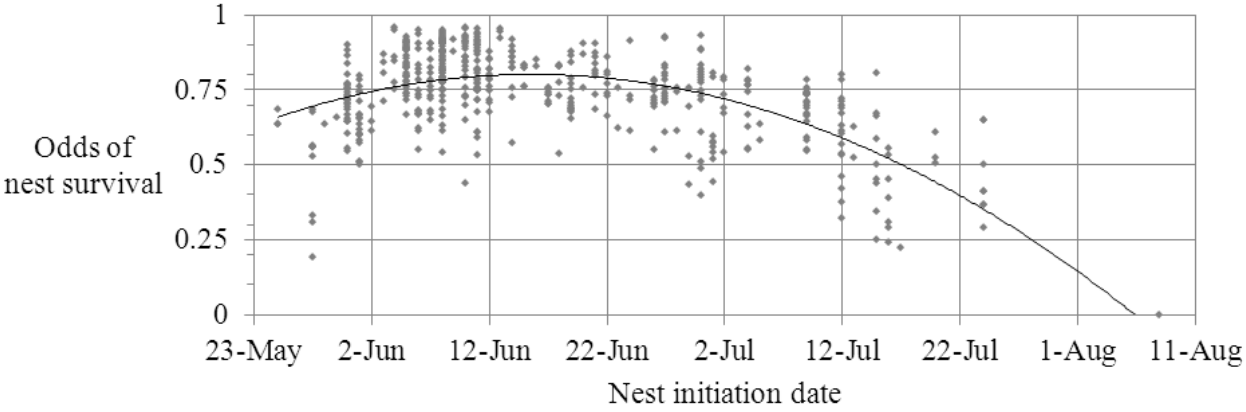

Figure 18. Odds of Western Grebe daily nest survival relative to nesting season during 2009 and 2010 at Delta Marsh, Manitoba.

5.0 DISCUSSION

Forty years after Nuechterlein's (1975) study, artificially stabilized water levels (Jones 1978, Batt 2000, Goldsborough & Wrubleski 2001), hybrid cattail encroachment (Goldsborough & Wrubleski 2001), and increased presence of carp (Goldsborough & Wrubleski 2001) have not changed the size of the Western Grebe population at Delta Marsh. However, elements of their nesting ecology, such as reductions in breeding success, and increases in rates of nest failure from wave action, have changed.

5.1 Population Estimates

Delta Marsh continues to be a major breeding site for Western Grebes in Manitoba. Population estimates of adult birds counted during systematic August brood surveys of open water areas suggest that the population at Delta Marsh is relatively stable, or has slightly increased, in comparison to the 1970s. Due to their cryptic nature (tendency to dive; Storer & Nuechterlein 1992), population estimates from systematic open-water surveys can only be relied upon as a minimum population size estimate (Hanus et al. 2002b). In addition, count data may be only weakly correlated with actual population size for waterbirds (Kushlan 1992); therefore, my calculation of a 30% increase in the number of adults in 2010 may be inaccurate. This increase may reflect the increase seen in the prairie pothole region's Western Grebe population from 1966 to 2009 (Sauer et al. 2011). However, habitat conditions in other breeding sites may also affect local population numbers (van Horne 1983). Threats of habitat loss and degradation (O'Donnel & Fjeldsa, 1997) elsewhere in the breeding range may be causing population shifts from other areas.

The total number of Western Grebe nests initiated during 2009/2010 increased by over 100% per year from the number of nests in 1973 and 1974, but this does not indicate that the local population has increased. The higher number of nests in 2009 and 2010 may have resulted from increased rates of nest failure and subsequent renesting efforts, rather than as a result of an increased population size. The apparent lack of a relationship between the total number of nests relative to population estimates from brood surveys demonstrates that counts of nests can dramatically overestimate Western Grebe populations (Hanus et al. 2002b). Western Grebes will persistently renest when their nests are disturbed or damaged and the total number of nests should not be interpreted as an indication of the absolute number of breeding pairs (Hanus et al. 2002b).

5.2 Changes in Western Grebe nesting ecology

The most important aspects of Western Grebe nesting ecology that have changed from 1973/1974 to 2009/2010 are: an overall decrease in breeding success when years with similar water levels are compared, an increase in the rate of wave-caused nesting losses, and the destruction of nests by spawning carp.

The destruction of nests by wave action was the single most important source of nesting failure in the 1973/1974 (Nuechterlein 1975) and 2009/2010. Wave action has been implicated as a significant source of nest failure for many waterbirds including Forster’s Terns (Cuthbert 1993), Black Terns (Bergman et al. 1970), and Ring-billed Gulls (Brown & Morris, 1996). Destruction of nests by wave action is also a major source of nest failure for Horned Grebes (Fjeldsa 1973, Summers et al. 2009), Red-necked Grebes (DeSmet 1987, Nuechterlein 2003)

Eared-Grebes (Broekhuysen & Frost, 1968, Boe 1994), Great Crested Grebes (Prestt & Jefferies, 1969), Pied-billed Grebes (Glover 1953, Chabreck 1963), and Silver Grebes (Burger 1974).

The 123% increase in the percentage of nest failures due to wave action was not caused by more frequent or more intense storms, but may have been caused by changes in the habitat of Delta Marsh. Western Grebes may have more successful nests when winds are less frequent and intense (Allen et al. 2008a). However, average wind speeds and the frequency of high wind events in the vicinity of Delta Marsh during the spring and summer of 2009 were markedly less than winds during the summers of 1973 and 1974, while 2010 was not significantly different from 1973, 1974 and 2010, and thus wind speed and frequency cannot explain the decrease in breeding success. The increase in nesting losses caused by wave action in the largest colonies of 2009 and 2010 may be explained by changes in composition and structure of the vegetation community, a decrease in abundance of emergent and submerged macrophytes (Goldsborough & Wrubleski 2001), and by nests being closer to the open-water edge than they were in 1973/1974.

However, distances of nests to the open-water edge are a function of the size and shape of the nesting islands. In 2009, nests in the largest colonies were closer to the open-water edge than nests in the largest colony during 1974, probably because the nesting islands in 2009 were much smaller than the nesting island sampled by Nuechterlein (1975) in 1974. Although the shorter distances to open-water edge for nests in the largest colony in 2010 were also a function of the size and shape of the nesting island, nests in 2010 were closer to the open-water edge, probably due to impenetrable stands of dense hybrid cattail.

The effect of hybrid cattail growing in dense mono-dominant stands (Boers 2006) contributed to shorter distances of nests to the open-water edge. As the 2009 season advanced, the hybrid cattail islands selected for nesting became very dense and impenetrable to nesting pairs seeking sheltered nest sites, resulting in distances to open-water edge decreasing as the season advanced. In 2010, low water levels that exposed cattail litter, and increasingly dense stands of cattails (Boers 2006), limited the distance in which nesting pairs could penetrate the island to <6 m from the open-water edge.

The energy carried by waves to the edges of nesting islands may have increased since the 1970s due to a decrease in submerged vegetation. Goldsborough and Wrubleski (2001) reported a 54% decline in total-area of submerged plant cover in the open bays of Delta Marsh from 1974 to 1997, with a near-complete absence of submerged vegetation in the large open bays during 2009 and 2010 (pers. obs.). The flexible structure of submerged vegetation allows them to bend with wave action, thus absorbing energy and increasing the frictional forces to attenuate waves (Denny 1998, Hall et al. 1998). A decrease of submerged vegetation at Delta Marsh may have lessened the frictional forces acting on waves in open water areas, therefore subjecting nests to more destructive waves.

Furthermore, because beds of bulrush (*Schoenoplectus* spp.) have greater amounts of underwater surface area, and thus greater frictional forces to attenuate wave energy than hybrid cattail (Denny 1988, Hall et al. 1998), cattail and bulrush have different capacities for wave attenuation (Hall et al. 1998). The extensive root system of cattails causes them to grow at relatively large distances from each other; in comparison, bulrush grows more closely together. The shift from predominately nesting in bulrush in 1973/1974 to exclusively nesting in hybrid cattail in 2009/2010 probably influenced the amount of energy nests were subjected to and contributed to the increase in wave caused nesting losses in 2009/2010. Hall et al. (1998) found that the presence of hybrid cattail or bulrush diminishes wave transmission; however, the effect of cattail density on wave attenuation was not significant, while bulrush density was. Research by Allen et al. (2008a) also demonstrated that high-density stands of bulrush better attenuated wave energy than low-density stands, and that areas protected by bulrush had smaller waves than exposed areas. In addition, the density of bulrush stems surrounding nests was less important than the amount of distance between the nest and the open-water edge (Allen et al. 2008b). With distance from nest to open water being equal, waves washing against nests with only cattail between the nest and open water in 2009/2010 were probably subjected to greater waves than nests in colonies protected by a buffer of bulrush in 1973/1974 (Nuechterlein 1975).

My results were consistent with those of Allen et al (2008a), who found that the greater the distance a nest was from the open-water edge, the more likely it was to succeed. In years with high water levels, such as 1974 and 2009, nesting birds are able to penetrate the inner areas of vegetated islands and benefit from the protection a vegetated buffer provides to the nest platform (Nuechterlein 1975, Allen et al. 2008a). During years with low water levels, such as 1973 and 2010, Western Grebes tend to suffer increased rates of wave caused nesting losses and reduced nesting success (Nuechterlein 1975, Storer & Nuechterlein 1992). When water levels are lower and nesting activities are restricted to the peripheral areas of the island, the odds of nesting success decreases. Because nesting season water levels at Delta Marsh partly determine the extent that nesting pairs are able to penetrate into stands of emergent cattails, and therefore the distance nests can potentially be from the open-water edge, hydrology is critical in influencing nesting outcomes. However, vegetation composition is also influential. If the nesting islands examined in 2009 and 2010 had a buffer of bulrush encircling them, distances from nests to the open-water edge and wave attenuation might have increased, in turn increasing breeding success.

Exposure, measured by the fetch of open water, also influences Western Grebe nest success, though the effect size was so low that the influence of fetch of open water on nesting success in the largest colonies is negligible. The kinetic energy of waves is determined by water depth, wind speed, direction, duration, and fetch of open water (Denny 1988). Waves generated across a large distance can potentially transmit a more destructive force against nests than waves generated across short fetch distances. During 2009/2010, Western Grebes at Delta Marsh continued to nest in areas protected from the prevailing westerly and northwesterly winds, but were slightly less exposed than the colonies of 1973/1974 (Nuechterlein 1975). During 1973/1974 (Nuechterlein 1975), 25.6% (41) of fetch measurements for colonies were greater than 0.5 km, but decreased to 19.1% (26) in 2009/2010. Therefore, changes in the degree to which colonies were exposed did not contribute to the reduced breeding success between 1973/1974 and 2009/2010.

In contrast to many species of birds, for which breeding success is commonly higher in early nesters (Ainley & Schlater, 1972, McNeil & Leger, 1987, Nolan 1978, Perrins 1970), initial nests in my model had lower odds of succeeding than nests initiated after June 14th. From late May to early June at Delta Marsh, beds of cattail had only begun to emerge from below the water surface and provided little protection to nests during storms. As cattail stands at the edge of the island grew, their ability to provide protection from waves increased (Hall et al. 1998), thus increasing the odds of successful nesting outcomes after the initial nesting period. However, as the cattails grew denser (Hall et al. 1998) and central areas of the island became inaccessible to nesting pairs, nests were initiated closer to the open-water edge thus increased their vulnerability to wave action (Allen et al. 2008a).

When spawning carp are present within Western Grebe colonies, their thrashing behavior may threaten the structural stability of nests. This is a novel, rarely reported, cause of nest failure. Other than one Forster’s Tern egg being broken by the tail of a spawning Common Carp at Delta Marsh, and another 13 eggs that fell into the marsh after nests were damaged by spawning carp (McNicholl 1982), nest failure caused by spawning carp have not, to my knowledge, been documented in any other areas where carp are present. My brief presence in the area of the colony where carp were abundant may however have increased the observed effect of carp damaging nests. If I had not approached the area where carp were disturbing the stability of nests, the carp may not have thrashed as violently, which may have resulted in fewer nesting losses caused by spawning carp.

The direct effect of spawning carp destroying Western Grebe nests may increase if the carp population increases. This behaviour was observed elsewhere within the marsh, and thus it was not a unique or isolated event; fortunately, Western Grebes did not nest in these areas. Common Carp commonly spawn in shallow waters (20-50 cm; Crivelli 1983) within stands of macrophytes (Balon 1995, Chow-Fraser 1999). Because the nests destroyed by carp were in very shallow water, and other nearby nests in deeper water were not affected, nests in shallow water may be more vulnerable than nests in deeper water. Over-water nesting birds such as Canvasbacks (*Aythya valisineria*; Mowbray 2002) Redheads (*Aythya Americana*; Woodin & Michot, 2002), terns (McNicholl 1982), and other grebe species, that nest in similar water depths, should be considered similarly vulnerable to nest destruction in areas with high densities of spawning carp. Since Western Grebe colonies occupy a relatively small area of the potential carp spawning habitat within Delta Marsh, the current risk of destruction of Western Grebe nests at Delta Marsh is probably low. However, the risks posed by carp, which are increasingly invading freshwater habitats across North America (Zambrano et al. 2006), and Manitoba (Badiou & Goldsborough 2010), may become severe if the carp population at Delta Marsh increases.

The exclusion of carp from Delta Marsh by carp screens should benefit the local Western Grebe population. This should reduce the likelihood of carp destroying nests, and should also reduce water turbidity caused by the activities of carp (Anderson et al. 1978, Keen & Cagliardi 1981, King et al. 1997, Hamilton & Mitchell 1997), which should lead to the reestablishment of submerged and emergent macrophytes (Hnatiuk 2006, Miller & Crowl, 2006). When carp increase turbidity in the water column, inadequate quantities of sunlight decrease the establishment of macrophytes (Hootsman et al. 2006) If turbidity decreases and emergent stands of macrophytes (i.e. bulrush) once again become abundant within the marsh, nests should be better protected from wave action. Greater cover of submerged plants in the open water bays and the reestablishment of bulrush should diminish the amount of energy that waves could potentially transmit to nests (Denny 1988, Hall et al. 1998), and should result in an increase in nesting success (Allen et al. 2008a, Allen et al. 2008b). In addition, increased diversity in the plant community should also result in increased amounts of available nesting habitat, more choices for nest sites, and improved availability of high quality nest sites leading to improved nest success.

Western Grebes at Delta Marsh continue to establish their colonies in areas where human disturbance is minimal. During 2009/2010, no colonies were located in the most Western bay of the East Unit of the marsh (Cadham Bay), while during 1973/1974, there were two colonies in this area. In 1973 a colony of eight nests was established at The Gap, and in 1974 there was a colony of 42 nests in the Delta Channel (Figure 2, Nuechterlein 1975). As a species that is highly sensitive to human disturbance (Nuechterlein 1975, Lindvall & Low 1982, Berger 1997), it is likely that as this area underwent increased development following the 1970s, Western Grebes shifted their colony sites farther from disturbances, and out of Cadham Bay.

5.3 Flightlessness & carp barriers

Flightlessness in Western Grebes during the breeding season may have significant consequences for the conservation of this species at Delta Marsh, and elsewhere in their breeding range. While flightless (Nuechterlein 1988), Western Grebes may have difficulties following concentrations of prey if barriers are in place that allow the passage of fish but not Western Grebes. In such cases, if prey abundance within Delta Marsh declines to unexploitable levels, Western Grebes might depart from the breeding grounds prior to autumn migration (Allen et al. 2007). For Western Grebes that approach the carp screens too closely, these carp barriers may pose a drowning risk. During the flightless period, when they have limited means of dispersal, they may also be vulnerable to predators and environmental disasters.

Data on the mass of Western Grebe flight muscles during the breeding seasons of 2009 and 2010 are similar to Nuechterlein's (1988) data, and reflect comparable changes in flight muscle mass reported for Great Crested Grebes (Piersma 1988), Pied-billed Grebes (Storer 1960), and Eared Grebes (Jehl 1997, Gaunt et al. 1990). Although monthly sample sizes from the 1970s (Nuechterlein 1988) and 2009/2010 are small, together they strongly suggest that the flight muscles of Western Grebes are severely atrophied during June and July, and may continue losing mass well into August.

Atrophication of Western Grebe flight muscles probably persists until prey abundance declines to unexploitable levels. Similar to Eared Grebes (Gaunt et al. 1990), Western Grebes may regain flight muscle mass (Nuechterlein 1988) in advance of fall migration when densities of food decline to unexploitable levels. For example, when densities of food decreased to unexploitable levels, Western Grebes at Lake Christina, Minnesota, regained the ability to fly and departed from the lake (Allen et al. 2007). In contrast, Western Grebes may recuperate flight muscle mass even if prey is abundant. For example, when prey was abundant within Delta Marsh (Nuechterlein pers. comm.), banded breeding birds from southern Lake Manitoba were recaptured later that breeding season over 200 km to the north on Lake Winnipegosis (Storer & Nuechterlein 1992), while most of the birds remained within Delta Marsh until fall migration in October (Nuechterlein pers. comm.).

Although speculative, the reason that the vast majority of Western Grebes at Delta Marsh in the 1970s remained within the marsh until fall migration (Nuechterlein pers. comm.) may be due to poor maintenance of the carp barriers. During Nuechterlein's study (1975), the carp barriers were in place year-round, and were in poor condition with much accumulated debris clogging the barrier (Nuechterlein pers. comm.). Although prey abundances were not recorded, it is possible that the passage of fish from Delta Marsh to Lake Manitoba (Wrubleski 1998) was restricted by clogged carp barriers, thus maintaining high densities of prey within Delta Marsh. The few individuals that departed for Lake Winnipegosis (Storer & Nuechterlein 1992), or were preparing for departure (Nuechterlein 1988), may have been foraging in areas of Delta Marsh with low densities of prey, thus stimulating migration out of Delta Marsh. Nuechterlein (pers. comm.) further speculated that the few birds that departed (Storer & Nuechterlein 1992), or were preparing for departure (Nuechterlein 1988) from Delta Marsh, may have been birds whose brood had failed or were the parents of chicks that had become fully independent.

The timing of movements of flightless Western Grebes from the marsh to the lake appears elastic. Observations in 2009 and 2010 indicated that movements of Western Grebes to the lake may begin shortly after the peak in hatching in mid-July, or later in early August. Major movements of juvenile and adult fish typically begin in late summer and fall (Wrubleski 1998), and coincide with Western Grebe pairs transporting young to Lake Manitoba following hatching

(Storer & Nuechterlein 1992), suggesting that they are pursuing concentrations of prey out to the lake. If the carp barriers are removed soon after the peak in hatching in mid-July, as proposed by DUC (2009), Western Grebes and their broods will have access to the lake, and may not fly out of the marsh (Allen et al. 2007, Nuechterlein 1988, Storer & Nuechterlein 1992) when and if prey becomes less abundant late in the summer (Wrubleski 1998).

Conversely, strong winds on Lake Manitoba can be perilous to young Western Grebes. Following violent windstorms on Lake Manitoba, hundreds of young Western Grebes washed up on the southern beach shore (Storer & Nuechterlein 1992). While the carp barriers are in place, such events would be avoided. However, since such events have only been documented once (Storer & Nuechterlein 1992), mass mortalities of young on Lake Manitoba after major storms are probably uncommon events.

Flightlessness may pose some additional challenges to Western Grebes in predator and environmental disaster avoidance. Otters are known to take moulting ducks (Oring 1963, Reid et al. 1994), so Western Grebes with atrophied flight muscles (Nuechterlein 1988) should be considered similarly vulnerable. As has been shown for other flightless waterbirds (Valle 1986), flightlessness can be a perilous trait when an environmental catastrophe, such as an oil or chemical spill, occurs where populations and spills are confined within limited areas. If such an event should occur when Western Grebes with atrophied flight muscles are impounded within Delta Marsh by the proposed carp barriers, the result could be devastating to the local population.

This study was comprised of many observations and comparisons to historical data (Nuechterlein 1975), with the goal of better understanding the effects of changes in the Delta Marsh habitat since 1973 and 1974, and to provide information to managers about potential effects of the Delta Marsh Rehabilitation Project (DUC 2009) on Western Grebes. My studies have shown that changes in the plant community have altered the nesting ecology of the Western Grebe at Delta Marsh by greatly increasing the negative effects of wave action on nesting outcomes, thus reducing breeding success in comparison to the 1970s (Nuechterlein 1975). Additionally, investigations into adult Western Grebe flight muscle mass provided further support for Nuchterlein's (1988) data indicating a condition of flightlessness during the nesting period.

6.0 Management Implications

Since Nuechterlein's (1975) study, the breeding success of Western Grebes at Delta Marsh has been impacted by increased rates of nesting losses from wave action and from spawning carp. Success rates of initial nests and chick-to-adult ratios decreased between high water years and between low water years, with nesting success and chick-to-adult ratios both decreasing by approximately 50% between the high water years of 1974 and 2009. Increases in rates of nesting losses from wave action were caused by nests being closer to the open-water edge. Furthermore, the energy carried by waves to nests may have been greater in 2009/2010 than during 1973/1974 because of the decrease in submergent vegetation in the open-water bays, and the lack of emergent vegetation around the perimeters of nesting islands. Because similar coastal wetlands on Lake Manitoba are affected by the same negative stressors as Delta marsh (i.e. stabilized hydrology, increased presence of carp, and dominance of hybrid cattail), these results may also have implications for conservation of Western Grebes across the region.

In nesting habitats where stands of bulrush are absent, and where Western Grebes nest exclusively in cattails, managers may expect nesting success to be low in both high and low water years. A lack of bulrush around the perimeters of nesting islands seemed to contribute to high rates of nest failure due to waves upsetting the structural stability of Western Grebe's over-water nests. Management strategies that seek to increase richness and heterogeneity in the plant community within Delta Marsh should reduce rates of wave destruction of nests.

Although a low water year would be detrimental to nesting Western Grebes at Delta Marsh for a single season (Nuechterlein 1975), controlled draw-downs of the marsh water level to expose the marsh bottom and permit the germination of the dormant seed bank (Squires & van der Valk, 1992) would be beneficial. Periodic draw-downs should benefit the Western Grebes at Delta Marsh in the long term by reinvigorating bulrush growth (Squires & van der Valk, 1992), thus reducing the energy carried by waves to nest sites, and increasing the availability of preferential nest sites (Nuechterlein 1975).

Reducing the abundance of carp within Delta Marsh through the implementation of carp screens should be beneficial for the Western Grebes at Delta Marsh. Decreasing the abundance of carp should assist in the reestablishment of submerged and emergent macrophytes (Hnatiuk 2006, Miller & Crowl 2006) within the marsh, which should increase the frictional forces acting upon waves (Denny 1988, Hall et al. 1998), thus decreasing rates of wave caused nest destruction. Although spawning carp destroying birds nests is probably a rare event (McNichol 1982), a reduction in the carp population should reduce the likelihood of such occurrences.

Strong currents in the channels where the carp screens are proposed may pin Western Grebes against these underwater structures. Many of the Western Grebes Nuechterlein (1988) salvaged were drowned in a carp-trap, suggesting that drowning mortalities of Western Grebes at the proposed carp screen locations is probable. Carp screens should be removed following the peak in hatching in mid-July. This would allow for the continuation of the movement of Western Grebes and their broods to Lake Manitoba from Delta Marsh, and limit the period of time that carp screens threaten Western Grebes seeking safe travel to the lake. If the carp screens are kept in place throughout the breeding season, I expect many Western Grebes will drown. The risk of drowning mortalities should be diminished by removing the carp screens in mid-summer. However, when Western Grebes are impounded within the marsh, rare events of heavy chick mortality on the lake following severe storms (Storer & Nuechterlein 1992) may be avoided.

Western Grebes can be acutely sensitive to human activities near their colonies (Nuechterlein 1975, Lindvall & Low 1982, Storer & Nuechterlein 1992, Burger 1997). Boat wakes are particularly destructive to nests (Burger 1997, Allen et al. 2008b). Although powered water-crafts are not allowed within the marsh (Manitoba Conservation 2011), there are frequently some permitted vessels, mostly associated with ongoing research activities, operating within the marsh. Researchers operating powered water-crafts within Delta Marsh must be extra cautious when traveling through the marsh, especially near sensitive nesting areas in the northern bays and channels, to ensure that boat wakes do not disturb nesting Western Grebes.

A setback distance, or buffer, is a minimum distance at which wildlife is unlikely to respond negatively to human presence (Theobald et al. 1997). Most setback distances established for waterbird colonies are designed to prevent flushing of adults off nests and do not seek to prevent nest destruction by boat wakes (Blumstein et al. 2003, Rogers & Smith, 2002). Setback distances for powered water-craft have not been established to minimized disturbance to nesting Western Grebes. As Allen et al. (2008b) pointed out water-craft operators need to consider their speed, as well as the distance and density of emergent vegetation between a colony and the source of the wake, to minimize the destructive effects of waves on nests. If proper precautions are taken, events like the destruction of all 34 nests in the Moses Creek colony by an airboat on June 11, 2010 can be easily avoided.

The threat of boat wakes may be less of a threat to Western Grebe nests if extensive beds of emergent vegetation are reestablished with the marsh. Several researchers have found that if beds of emergent vegetation between nests and open water are sufficiently large, nesting structures may be subjected to little or no wave disturbance (Liddle & Scorgie 1980, Asplund & Cook 1999).

Because sizeable populations of Western Grebes remain present at Delta Marsh, and they are highly conspicuous in the large bays, this charismatic species should be a flagship species candidate for Delta Marsh as well as other coastal wetlands on Lake Manitoba. Eco-tourism activities providing opportunities for the public to observe the Western Grebe courtship ritual are feasible. However, such tours would require a means of transport from the Delta Channel to colony locations. As powered water-crafts are prohibited within the marsh (Manitoba Conservation 2011), canoes or kayaks are the only transportation option available to the public. While these craft would not generate a significant wake, their presence may cause a disturbance to colonies if approached too closely (Blumstein et al. 2003, Gill 2007). Set-back distances for Western Grebes in one area may not be applicable elsewhere. For example, Western Grebes at Lake Christine in Minnesota are so habituated to human disturbance that, for some individuals, researchers examining nest contents had to lift the incubating adult off the eggs (J. Allen pers. comm.). In contrast, at Delta Marsh in 2009/2010, the Western Grebes were very sensitive to the presence of a researcher in a kayak. Based on observation while approaching colonies, I suggest a minimum viewing distance of 200 m. Viewings from land are problematic for the public as much of the surrounding land is privately owned. An existing observation tower, managed by the Delta Waterfowl Foundation, is the only elevated vantage point accessible to the public, but is unfortunately located on Cadham Bay, a bay where colony formation did not occur in 2009 or 2010.

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