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Eared Grebe Nesting Ecology and Chronology Along the Great Salt Lake, Utah

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EARED GREBE NESTING ECOLOGY AND CHRONOLOGY ALONG THE GREAT

SALT LAKE, UTAH

by

Leah M. Delahoussaye

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ABSTRACT

Eared Grebe Nesting Ecology and Chronology Along the Great Salt Lake, Utah

by

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Utah State University, 2019

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Eared Grebes (*Podiceps nigricollis*) are colonial-nesting waterbirds, which typically nest in the Prairie Pothole region of southern Canada and northern United States; however, a previously uncertain number of Eared grebes (grebes) also nest around the Great Salt Lake (GSL), Utah at the southern edge of their breeding range. My objectives for this research were to determine the status of the grebe nesting population as well as their habitat characteristics along the GSL in freshwater wetlands. I found over 4,280 grebe nests distributed amongst 35 colonies. Grebes built nests by mounding submerged aquatic vegetation (SAV) beginning the first week of June. My results indicate grebes prefer to nest in areas with an average water depth of 48 cm, high invertebrate biomass density, and abundant mats of SAV. Water depth at colony sites were shallower and mean clutch sizes were lower along the GSL than in colonies located at more northern latitudes. All colonies in this study were established on SAV as opposed to colonies found elsewhere which were built on emergent vegetation. The number of incubated nests peaked during the last week of June, which was later than reported

elsewhere. The differences in nesting could be attributed to the need to wait for SAV to form mats on the water's surface, or a need to wait for invertebrate prey to reach harvestable size.

When grebes leave their nesting grounds and move to their fall-staging area, the GSL, they are able to thrive on the brine shrimp population (*Artemia franciscana*). Brine shrimp produce live young, as well as hard-walled eggs called cysts; the latter are of great economic value and are commercially harvested from the GSL. I evaluated cyst viability, which is the percentage of cysts in a condition conducive to hatching, of cysts that had passed through the digestive tract of grebes and cysts samples obtained from the GSL. There was a significant difference in viability between cysts that had passed through grebes (30%) and those that did not (63%). Viable cysts that passed through the digestive tract could serve to repopulate ephemeral waterbodies with brine shrimp after grebes defecate there.

(93 pages)

PUBLIC ABSTRACT

Eared Grebe Nesting Ecology and Chronology Along the Great Salt Lake, Utah

Leah M. Delahoussaye

Eared Grebes (*Podiceps nigricollis*) are migratory birds that build their nests over water and in large groups called colonies. Their typical breeding range is in central southern Canada and northern United States; however, a previously uncertain number of Eared Grebes (grebes) also nest around the Great Salt Lake (GSL), Utah, at the southern edge of their breeding range. Little is known about the habitat requirements for grebe nesting colonies at such low latitudes and if they are different from colonies found elsewhere. My objectives for this research were to determine the status of the grebe nesting population as well as their habitat characteristics along the GSL in freshwater wetlands. I found over 4,280 grebe nests distributed among 35 colonies. Grebes built nests by mounding submerged aquatic vegetation (SAV) beginning the first week of June. The results from my habitat study show that grebes prefer to nest in areas with an average water depth of 48 cm, high invertebrate density, and abundant areas of floating SAV. Water depth and vegetation type at colony sites as well as timing of nesting and average number of eggs per nest of GSL colonies differed from colonies located at more northern latitudes. The differences in nesting could be attributed to the need to wait for SAV to grow and form mats on the water's surface, or a need to wait for their food source to reach harvestable size.

After grebes leave their nesting grounds, they stop at the GSL where they prepare for their final migration southward by consuming their fill of brine shrimp (*Artemia*

franciscana). Brine shrimp are tiny invertebrates that are well-adapted to salty environments; they produce hard-walled eggs called cysts which are of great economic value and are commercially harvested from the GSL. I compared cyst viability, which is the percentage of cysts in a condition conducive to hatching, for cysts that had passed through the digestive tract of grebes and cysts samples obtained from the GSL. Only 30% of the cysts that had passed through grebes were viable, whereas 63% of cysts from the GSL were viable.

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Leah M. Delahoussaye

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CHAPTER 1

INTRODUCTION

INTRODUCTION

Everything we know about Eared Grebe (*Podiceps nigricollis*) nesting habitat is from more northern latitudes in the United States and Canada, which may not be transferable to Eared Grebes (hereafter referred to as grebes) nesting around the Great Salt Lake (GSL), Utah. It is important understand the habitat selection of nesting grebes to better manage for them around the GSL. Habitat selection is broken into 4 orders by Johnson (1980). First-order habitat selection is the species' geographical range. The second order of selection is the home range of an individual. Third-order selection is the individual's usage of various habitat components within the home range. Fourth-order selection is the actual procurement of resources from a site (Johnson 1980). In this study, I examined factors contributing to the second- and third-order of habitat selection for nesting.

The first-order of habitat selection for grebes during their breeding season in North America begins west of the Mississippi River in the United States and extends northward to Canada, southward into Arizona and New Mexico, and westward into California and Oregon of the United States (Cullen et al. 1999). For the second-order of habitat, grebes choose to nest on shallow, eutrophic lakes and wetlands within their geographic range (Boe 1994). Grebes are colonial nesters and build colonies on emergent vegetation (e.g. *Scirpus* spp., *Carex* spp., *Typha* spp., *Schoenoplectus* spp., and *Chenopodium* spp.), and floating mats of submerged aquatic vegetation (SAV) such as

Potamogeton spp., *Utricularia* spp., *Spirogyra* spp., *Ulothrix* spp., and *Rhizoclonium* spp. (Boe 1993, Boe 1994, Hill et al. 1997, Cullen et al. 1999). These colonies are established far from shore when vegetation is available (Breault 1990). In Minnesota, grebe nesting colonies were 0.1–1.5 km from shore, and the average water depth at colony sites ranged from 50-120 cm (Boe 1993). Vegetation is critical when choosing colony sites, as it serves as the framework of nests and provides food and refuge for many birds (Parker 1986). The nests average 0.5–1.5 m in diameter with half of that diameter being above water (Bochenski 1961). Colony sites constitute the third-order of habitat selection while nests sites are the fourth order habitat selection. Grebe nesting begins after many other waterbird species have already completed incubation. Grebes lay clutches with 1 to 6 eggs, with the average clutch of 3 or 4 (McAllister 1958). Incubation starts when the first egg is laid and lasts 20–22 days (Cullen et al. 1999).

Food can be an important factor when it comes to selecting a nesting colony site (Burger 1985). Grebes eat primarily invertebrates and occasionally small fish and will not nest in a lake if invertebrates are scarce (Cullen et al. 1999, Littlefield 1990). Invertebrate density in the natal wetlands is critical because grebe hatchlings cannot fly and are unable to regulate their own body temperature because their down feathers are not waterproof, meaning they can neither swim, nor stay in a wet nest (McAllister 1963). Instead, one parent carries the hatchlings on its back, while the other forages for food and feeds it to the young (Cullen et al. 1999). Parents and young are confined to the wetland the nest is located in until the hatchlings area about a week old and can regulate their own body temperature and swim on their own (McAllister 1963).

After their first week, the hatchlings begin to swim on their own while being fed by both parents (McAllister 1963). Once the chicks are about 10 days old, the brood will often split with each chick being cared for by a parent. Parental care continues until the chicks are about 20 days old (Cullen et al. 1999). At this point, parents leave the breeding grounds and undertake a molt migration to the fall staging areas, and juveniles will follow once their flight feathers are fully formed. Movement from the breeding grounds to the fall staging areas occurs anytime from late July to October (Jehl and Henry 2010).

Over half the North American population of grebes chooses the GSL as their fall-staging area along with over 200 other species of birds (Aldrich and Paul 2002, Gwynn 2002). The GSL has been designated as a site in the Western Hemisphere Shorebird Reserve Network due to its importance as a staging area for many waterbirds likely because the abundant brine shrimp population in the GSL. Brine shrimp are invertebrates that have adapted to hypersaline environments and inhabit the GSL. Migrating waterbirds are not the only ones to value brine shrimp on the GSL. Brine shrimp cysts (eggs in diapuase) have been commercially harvested from the GSL since 1952 and are used as food for larval fish and other crustaceans at aquaculture facilities around the world (Belovsky et al. 2011, Stephens and Birdsey Jr. 2002). The GSL contributes approximately 90% of the world's commercial harvest of brine shrimp cysts, an estimated $50 and $100 million annually in economic value (Treece 2000, Bioeconomics 2012).

At their peak, brine shrimp abundance in the GSL has been recorded at a density of 8 individuals/L of lake water (Wurtsbaugh and Gliwicz 2001). Their population is dynamic and cyclical in nature with salinity being the most important variable associated

with their distribution and abundance. The salinity of the GSL is determined by how much freshwater enters the lake. Brine shrimp populations also fluctuate with other environmental factors, such as water temperature and algal populations (Stephens and Birdsey Jr. 2002).

The cysts that are commercially harvested are hard-walled brine shrimp eggs in diapause. In late February or March, once temperatures reach above freezing (0º C), nauplii, the first larval stage of brine shrimp, hatch from over-wintering cysts. These nauplii will grow into the first generation of adults. If conditions are favorable, adults will reproduce ovoviviparously (live birth). Each year, there are 2 or 3 generations of brine shrimp produced on the GSL. When food becomes scarce and temperatures begin dropping, brine shrimp adults will produce young oviparously, producing diapausing eggs (cysts). Brine shrimp adults will die when temperatures drop below 3º C; however, the cysts are able to survive through winter (Stephens and Birdsey Jr. 2002).

The cysts are buoyant and with the help of wind and water currents, form large concentrations, called streaks, on the surface of the lake. These high densities of cysts are commercially harvested beginning on October 1st, and the season is closed when brine shrimp cyst density falls below 2 cysts/L, which usually occurs sometime in January. The commercial harvest of cysts is heavily monitored by the GSL Ecosystem Program to ensure that there are enough cysts to produce a viable population in the following spring; but, we have little information on the effects of waterbirds' consumption of brine shrimp cysts. I investigated if grebe digestive tracts had any impact on brine shrimp cyst viability. Previous studies have shown that a seed passing through the digestive tract of waterfowl aids in the scarification, germination, and transportation of some wetland plant

species such as *Bolboschoenus maritimus, Scirpus paludosus,* and *Najas marina* (Agami and Waisel 1986, Kettenring 2016, Muellar and van der Valk 2002). The chemicals of a duck's digestive system, as well as the grinding in their gizzards, help bring the wetland seeds out of dormancy (Kettenring 2016).

It is important to learn what effect, if any, grebes have on the brine shrimp population of the GSL. If grebes are having a deleterious effect on the brine shrimp population of the GSL, commercial harvest of the cysts may have to decrease to ensure a brine shrimp population for future generations. The nesting ecology of grebes along the GSL is also important because the information we have on grebe nesting ecology is from more northern latitudes than the GSL. I learned about the nesting habitat requirements and chronology of grebes during this study. This information provides managers with more accurate information on grebes' nesting habitat to better drive management decisions.

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CHAPTER 2

NESTING STATUS AND CHRONOLOGY OF EARED GREBES ALONG THE GREAT SALT LAKE, UTAH

ABSTRACT

Eared Grebes (*Podiceps nigricollis*) are colonial-nesting waterbirds which typically nest in the Prairie Pothole region of southern Canada and northern United States. An uncertain number of grebes also nest around the Great Salt Lake (GSL), Utah, which is at the southern edge of their breeding range. During the 2018 breeding season, I studied Eared Grebe (hereafter referred to as grebes) nesting status and chronology in the freshwater wetlands around the GSL and found over 4,280 grebe nests distributed among 35 colonies. Average clutch size was 2.4 ± 1.0, lower than some colonies located in more northern latitudes. Grebes around the GSL nested on submerged aquatic vegetation and began nesting by the first week of June. The number of incubated nests peaked during the last week of June, which was later than reported in more northern colonies. The differences in nesting could be due to the need to wait for submerged aquatic vegetation to form floating mats on the water surface, or a need to wait for invertebrate prey to reach harvestable size.

INTRODUCTION

The status of Eared Grebe (*Podiceps nigricollis*) nesting colonies along the Great Salt Lake (GSL) was uncertain prior to this study. Management of freshwater wetlands along the GSL has proven difficult in an arid landscape with various stakeholder interests. In future years, limited water could reduce the area of freshwater wetlands

along the GSL and negatively impact the nesting population of Eared Grebes (hereafter referred to as grebes). What information we do have on nesting chronology of grebes is from the northern United States and Canada. Less is known about the nesting chronology of grebes on the southern edge of their range.

The grebe's regular breeding distribution in North America begins west of the Mississippi River in the United States and extends northward to Canada and southward into Arizona and New Mexico and westward into California and Oregon of the United States (Cullen et al. 1999). The birds nest in shallow, eutrophic lakes and wetlands with emergent and floating submerged aquatic vegetation upon which they build their nests (Boe 1994). Grebes are colonial nesters, sometimes associating with other colonies of breeding birds (Cullen et al. 1999). Their nests average 0.5–1.5 m in diameter with half of that diameter being above water (Bochenski 1961). Grebes lay clutches with one to six eggs, with the average clutch of three or four (McAllister 1958). Incubation starts when the first egg is laid and lasts 20–22 days (Cullen et al. 1999). Grebes nest after many other waterbird species have already completed incubation

The semi-precocial hatchlings are cared for by both parents. The hatchlings can neither swim, nor stay in the wet nest due to their inability to regulate their own body temperature (McAllister 1963). Instead, one parent carries the hatchlings on its back, while the other searches for food and feeds it to the young (Cullen et al. 1999). After a week, the hatchlings can regulate their own body temperature, and they begin to swim on their own while being fed by both parents (McAllister 1963). Once the chicks are about 10 days old, the brood will often split with each chick being cared for by a parent. Parental care continues until the chicks are about 20 days old (Cullen et al. 1999). At this

point, parents leave the breeding grounds to migrate to the fall staging areas, leaving the juveniles behind. The juvenile grebes will follow once their flight feathers are fully formed. Movement from the breeding grounds to the fall staging areas occurs anytime from late July to October (Jehl and Henry 2010).

I studied grebe nesting chronology on the wetlands along Utah's GSL to find out more about the nesting strategy of grebes at the southern edge of their breeding range. This information can be used by managers of the freshwater wetlands around the GSL to make decisions that would promote grebe nesting. I hypothesized that grebes around the GSL would begin nesting earlier than more northern colonies because temperature has been shown to impact nesting and average temperatures decrease at you increase in latitude (Drever and Clark 2007). It has been found that earlier nest initiation dates correspond to larger clutch sizes (Klomp 1970), which led me to test the hypothesis that average clutch size around the GSL would be larger than elsewhere. I hypothesize that the nesting substrate will be similar to those found elsewhere because of the wide distribution of the plants grebes choose to nest on in northern colonies.

STUDY AREA

There is a matrix of impounded and natural wetlands on the east side of the GSL, Utah that are fed by the waters of the Bear, Weber, and Jordan rivers. These freshwater wetlands are managed by state, federal, or private landowners. Freshwater wetlands are not found on the west side of the GSL because of the lack of freshwater inflow there. This study includes two state-run waterfowl management areas (WMAs): Farmington Bay and Ogden Bay, and a private duck club: Rudy Duck Club. These managed

properties are all impounded, controlled wetlands that vary in size. Also included in this study is one natural wetland (Willard Spur) that is the largest wetland in this study (Figure 2–1). For a more detailed description of the study area, please refer to Aldrich and Paul 2002.

METHODS

In 2018, I visited wildlife management areas around the GSL to locate grebe nesting colonies (Figure 2-4). I also talked to landowners and managers about locations of previous grebe nesting colonies. Using this information, I visited previously known colony sites once a week beginning on May 15, 2018. On each visit, grebe pairs were observed with binoculars for incubation behavior to determine when nesting began and where colonies were located. Grebe colonies were not counted in Willard Spur on a regular basis due to problems accessing the site. I conducted a flight over the wetlands surrounding the GSL during the peak of nesting to locate any grebe nesting colonies I may have missed. Each colony was photographed and marked with a GPS point in the middle of the colony. I defined first nesting as the first day I observed grebes incubating nests. The peak of nesting in this study is defined as the week of nesting season when the most nests were counted.

When nesting began, I selected colonies to monitor based on their size (colonies with <10 nests were not monitored) and accessibility by canoe. Colonies were initially located from land and counted using binoculars or spotting scopes depending on their distance from shore. I counted every nest (Figure 2-3) in each colony on a weekly basis unless I saw the nest being incubated by a Western Grebe (*Aechmophorus occidentalis*),

American Coot (*Fulica americana*), California Gull (*Larus californicus*), or Common Tern (*Sterna hirundo*). Grebe nests around the GSL were built from floating SAV (Chapter 3) that requires constant maintenance so that the nest can remain afloat; therefore, I do not believe I counted nests that were not being incubated. I visited colonies in the canoe, and on each visit ~20% of nests in each colony were observed to determine clutch size. A line through the colony was randomly chosen using GPS and navigated with the canoe; each nest within 2 m of the line was checked for clutch size. If one line was not sufficient to include 20% of the colony, another line was chosen, and nests were counted. On one of the visits, all eggs in a nest were floated to determine clutch initiation date using methods of Boe (1994). Results of floating eggs were divided into 6 stages based on the age of the embryo (1–5, 4–10, 10–16, 14–19, 16–21, or >19 days old). All eggs in a single nest were of similar age. Clutch sizes were counted at colony sites during the peak of nesting on at least two occasions five to six days apart. I combined the data from each visit to get a mean clutch size per colony. My time present in the colonies was kept to a minimum to avoid impacting incubating grebes.

Throughout nesting, I recorded the edges of each colony with GPS points and uploaded the points to a shapefile in ArcMap. Based on the GPS points, polygons of colonies were drawn in ArcMap to estimate colony size. The colony center point was placed in the middle of the colony polygon.

On every visit to the study sites, I counted and observed with binoculars adult and juvenile grebes in the waterbodies containing a nesting colony. I was only concerned with the adult to chick ratio; therefore, counts of adults did not include those that were incubating a nest. If there was a pair of adults, often times one would exhibit feeding

behavior, bringing its catch to the back of the other parent to feed the chick(s). If I was not able to determine if there was more than one chick on an adult's back, I assumed there was only one. The count of adults and juveniles was used to determine when each group left the colonies, presumably for the GSL for fall staging.

Data for this study were collected and organized by management units of the WMAs; however, in the body of this paper, I will refer to the management units as waterbodies. I compared waterbodies with multiple colonies in each (FBWMA Waterbody 1, FBWMA Waterbody 2, FBWMA Turpin, and OBWMA) using a one-way analysis of variance (ANOVA, Table 2–1) to determine if grebe colonies within the same waterbody differed from other waterbodies. Colonies 3 and 4 of Farmington Bay Waterbody 1 were removed from the date of maximum nests analyses because the data is believed to be incorrect. I converted date of first nest and maximum number of nests to the Julian date for statistical analysis. Waterbodies with only one colony were excluded (Rudy Duck Club) because a one-way analysis of variance uses the mean of each group in the analysis. Individual grebe colonies were the experimental unit for this analysis. Significance was defined at $\alpha \leq 0.05$ for all analyses.

I conducted a literature review to compare colonies in my study to those located in more northern latitudes. I collected data from 12 previously published studies that looked at nesting habitat and chronology of grebes that had comparable data to my study. I compared characteristics of all nesting colonies around the GSL to those found elsewhere using a one-way ANOVA to test for differing means between the groups.

RESULTS

Nesting Locations

I located 35 nesting colonies of grebes along the GSL containing over 4,280 grebe nests; all were located on the east side, where there is freshwater inflow (Figure 2–1). The colonies were distributed amongst nine impounded wetlands and one natural wetland, Willard Spur (Table 2–1). Willard Spur was not monitored throughout nesting, instead it was counted once during an aerial survey at the peak of nesting and it contained 12 colonies with approximately 2,060 nests. Farmington Bay WMA had three different impoundments containing multiple colonies each. Waterbody 1 at Farmington Bay contained the most nests (1,211 nests) of the impounded wetlands.

The number of nests in each colony ranged from 19 to 902 nests. The largest colony in this study (902 nests) was the larger than any colony reported in the literature. As expected, the number of nests and colony size were significantly correlated ($r = 0.93$, $P < 0.001$). The largest colony in size (5.5 ha) also had the greatest number of nests (902 nests), although most colonies were under 1 ha. Nest density ranged from 74 nests/ha to 636 nests/ha. Nest density was not significantly different among waterbodies (Table 2–1). The average clutch size over all of the colonies and study sites was 2.4 ± 1.0 ($\bar{x} \pm SD$) eggs. Mean clutch size was not significantly different among waterbodies (Table 2–1). Only one nest in the entire study contained a clutch of 6 eggs (Appendix 1).

Nesting Chronology

I visited 16 of the 35 grebe nesting colonies around the GSL on a weekly basis throughout nesting. Grebes started building nests during the week of May 24, 2018, but

the nests were fragile, sinking when a grebe was on top, and contained no eggs. Eggs were found in nests starting the first week of June. Peak nesting occurred during the last week of June (June 25–29). Chicks started hatching and showing up on bird counts on July 5, 2018. Nest numbers slowly declined over July, few remained in the month of August, and none remained on August 20, 2018 (Figure 2–5).

Clutch initiation date, as determined by floating eggs, varied among waterbodies. Colonies in Farmington Bay Waterbodies 1 and 2 had clutch initiation dates that occurred between June 10 and 16. This timing corresponded with my observation of the first nest being incubated on June 4. Turpin in Farmington Bay had clutch initiation dates that occurred earlier as determined by floating eggs, ranging from June 5 and June 16. The earliest nest observed in this waterbody was on June 15.

Numbers of Adults and Chicks

The number of nests was used as a proxy for breeding population size, which peaked during the last week of June. I counted about 4,300 active nests during this time. Grebe chicks were first observed on June 22; however, they were not abundant until the first week of July (Figure 2–6). Adult grebe counts peaked during the week of July 23 at 699 adults and grebe chick counts peaked a week earlier at 643 chicks. The trend across all my study sites showed that grebe chicks started outnumbering adults by the last week of July. Adults left their young behind as they moved out of the waterbodies where they raised their chicks, and the difference in numbers between the two groups grew until the end of the study period (Figure 2–7).

Literature Review

Average clutch size across my study area was significantly lower than the average clutch size of one other colony found elsewhere (Gray's Lake, Idaho, Figure 2–2). Clutch sizes compiled from the literature review were not significantly correlated with changes in latitude (r = 0.24, $P = 0.46$) The colonies in my study area differed significantly compared to other colonies found elsewhere in the date of earliest nesting (Table 2–2). The maximum number of nests in each colony did not differ significantly.

DISCUSSION

I hypothesized that grebes nesting around the GSL would initiate nesting sooner than grebes in more northern colonies, but this hypothesis was incorrect; grebes nesting on the GSL initiated later than more northern colonies (Table 2–2). When colonies elsewhere used emergent vegetation as nesting substrate such as *Typha* spp., *Scirpus* spp., *Chenopodium rubrum,* and *Shoenoplectus acutus,* initiation dates occurred in early May (Table 2–2). These emergent species were not found at GSL colony sites; instead, colonies were established on mats of floating SAV such as *Stuckenia pectinate* and *Ruppia cirrhosa*. Colonies located in more northern latitudes built on floating SAV mats began in late May (Boe 1993, McAllister 1963). Nesting colonies in my study did not form until the month of June. I hypothesize that the delay of nesting around the GSL could be due to the vegetation type upon which the nesting colony was built. Emergent vegetation is lacking except along the levees in impounded waterbodies around the GSL. The lack of emergent vegetation away from shore could explain why grebes choose SAV mats instead, and therefore nest later because the grebes must wait for the mats to form.

Warmer temperatures (>50º F) and water depths of 38–45 cm are required for SAV to thrive (Robel 1962, Yeo 1965). The GSL wetland impoundments are frozen throughout most of the winter. With warmer temperatures in the spring, the impoundments thaw and receive an influx of fresh water from snow melt, raising the water depth but keeping the water cold. Support for this hypothesis can be found in the similar nest initiation dates for colonies in the same wetland impoundments because all colonies in the same impoundment would experience the same water temperature (Table 2–1). Another possible explanation for later nest initiation dates could be the food abundance in colony wetlands. The cold water in the impoundments in the spring may slow the growth of invertebrates, delaying nesting (Jacobsen et al. 1997). Floating mats of SAV were abundant in the impoundments I studied (Chapter 2). Hence, there is no evidence that competition for suitable nest sites limits the size of the nesting colonies within wetlands.

I hypothesized the average clutch size found in this study would be larger than reported elsewhere, and this hypothesis was partially incorrect (Figure 2–2). Mean clutch size around the GSL was significantly lower than one colony located elsewhere (Gray's Lake, Idaho). While the average clutch sizes of colonies found along the GSL was lower than anything found elsewhere, the standard deviation of one overlapped with the majority of the other colonies found in more northern latitudes. Clutch sizes can vary according to the quantity and quality of food available to females (Brockelman 1975). Daily energy requirements for female birds increase during egg-laying (Tinbergen and Dietz 1994),-and multiple studies have shown a positive correlation between food abundance during egg-laying and clutch sizes (Korpimaki and Hakkarainen 1991, Bolton et al. 1993, Tinbergen and Dietz 1994, Tortosa et al. 2002). The lower clutch size on the

waterbodies around the GSL could suggest lower food abundance compared to the Gray's Lake colony site. Clutch size has been proven to be negatively correlated with nest initiation date which could also explain the lower average clutch size (Rohwer 1992).

Most of the waterbodies in my study contained more than one colony; something that was not commonly reported elsewhere. Grebes leaving nesting colonies around the GSL migrate to their fall staging ground, probably the GSL. If so, they have <11 km to reach it. The adults in my study began leaving colony sites during the last week of July, later than birds reported in Jehl and Henry (2010), which began migrating as early as June 23 towards the GSL. The later migration in my study is probably due to the late start of nesting. The juvenile grebes in my study migrated after the adults, similar to the findings of Jehl and Henry (2010).

Grebes around the GSL have a different nesting strategy compared to more northern colonies by nesting later and on a different type of vegetation. This information could propel management of waterbodies around the GSL to happen earlier in the spring to promote growth of SAV, before grebes start nesting.

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TABLES AND FIGURES

TABLE 2–1. All known data from nesting colonies around the Great Salt Lake, Utah. Colony size was the area determined by GIS polygons. Maximum number of nests was the most nests counted in each colony. Nest density was the maximum number of nests divided by the colony area. Mean clutch size with standard deviation are provided for every colony visited. Earliest known nests dates were determined by floating eggs. Peak of nesting is the date the maximum number of nests were counted for each colony. P-values are from 1-way ANOVAs that compare 4 different waterbodies that contained multiple colonies (Farmington Bay, Waterbody 1, Waterbody 2, and Turpin, and Ogden Bay. Farmington Bay, Waterbody 1, Colonies 3 and 4 were excluded from the analyses because they are believed to be incorrect. Willard Spur was only counted once from the air and had a total of 2,060 nests among the 12 colonies on July 5, 2018.

Site	Colony	Latitude	Longitude	Colony size (ha)	Max # of nests	Nest density (nest/ha)	$\bar{X}$ clutch size ± SD	Earliest known nest	Peak of nesting
Farmington Bay, Waterbody 1	1	40.93477	-111.93464	5.53	902	163	2.5 ± 0.9	6/12	7/6
Farmington Bay, Waterbody 1	2	40.93573	-111.92817	1.89	395	208	2.1 ± 0.8	6/12	6/26
Farmington Bay, Waterbody 1	3	40.94013	-111.92150		117				7/19
Farmington Bay, Waterbody 1	4	40.93224	-111.93424		267				7/19
Farmington Bay, Waterbody 2	1	40.92724	-111.93835	1.65	200	121	2.5 ± 1.1	6/4	6/26
Farmington Bay, Waterbody 2	2	40.92587	-111.93929	0.31	95	303	2.3 ± 1.1	6/4	6/15
Farmington Bay, Waterbody 2	3	40.92641	-111.93493	0.34	213	636	2.2 ± 1.1	6/4	7/17
Farmington Bay, Turpin	1	40.92628	-111.96894	1.55	114	74	2.4 ± 0.8	6/15	6/26
Farmington Bay, Turpin	2	40.92343	-111.97454	0.09	54	614	1.8 ± 1.2	6/15	6/15
Farmington Bay, Turpin	3	40.92243	-111.97569	0.27	84	307	2.4 ± 1.0	6/15	6/15
Farmington Bay, Turpin	4	40.91447	-111.98732		120			6/15	7/6
Farmington Bay, Turpin	5	40.90047	-112.00701	0.90	136	151		6/15	6/26
Farmington Bat, South Crystal	1	40.88346	-112.02100		20				
Ogden Bay	1	41.19395	-112.19009	0.18	28	152	2.4 ± 1.4	6/6	6/25
Ogden Bay	2	41.19794	-112.19185	0.11	66	623	3.0 ± 1.0	6/6	6/19
Ogden Bay	3	41.20351	-112.19239	0.37	155	416	2.5 ± 0.9	6/6	6/19
Ogden Bay	4	41.20501	-112.19280	0.04	19	528	2.7 ± 0.8	6/6	6/19
Ogden Bay	5	41.20581	-112.19209	0.11	55	524	2.0 ± 1.3	6/6	6/25
Ogden Bay	6	41.20721	-112.19098	0.12	42	339	2.9 ± 0.5	6/6	6/19
Rudy Duck Club	1	40.84390	-112.00627		380		2.6 ± 0.6	6/22	6/22
Willard Spur	1	41.40796	-112.10229						
Willard Spur	2	41.40764	-112.11301						
Willard Spur	3	41.40616	-112.12498						
Willard Spur	4	41.39434	-112.14491						
Willard Spur	5	41.39832	-112.14731						
Willard Spur	6	41.38046	-112.14931						
Willard Spur	7	41.38166	-112.14193						
Willard Spur	8	41.37774	-112.14806						
Willard Spur	9	41.38247	-112.15749						
Willard Spur	10	41.37393	-112.16082						
Willard Spur	11	41.37652	-112.17423						
Willard Spur	12	41.38025	-112.18510						
Northpoint	1	40.87789	-112.01105						
Northpoint	2	40.86356	-112.01022						
Harrison	1	40.82570	-112.02248		59				
Means ± SD				0.8 ± 1.4	168 ± 200	344 ± 200	2.4 ± 0.3	6/10	6/27
df				3, 13	3, 14	3, 11	3, 10	3, 12	3, 12
F-value				1.62	4.32	0.88	1.14	$3.016e^{31}$	0.99
P-value				0.23	0.02	0.48	<0.001	<0.001	0.43

Table 2–2. Nesting habitat and chronology in previous studies compared to the Great Salt Lake, Utah. Wetland area is provided for the wetland the colony was located in. Maximum number of nests throughout nesting, and the date the maximum number of nests were counted. P-values are from 1-way ANOVA tests comparing colonies in all other studies to colonies in my study. For the wetland area, only one colony was chosen from each waterbody for the test.

*Colonies that were built with submerged aquatic macrophytes

[1]Boe 1993, [2]Breault 1990, [3]Lyon and Everding 1996, [4]McAllister 1958, [5]Hill et al. 1997, [6]Austin and Pyle 2004, [7]Faaborg 1976.

Location	Year	Max # of nests	Earliest nest	Nesting substrate 17
*FBWMA, Waterbody 1, Colony 1	2018	902	6/12	*Stuckenia pectinata*
*FBWMA, Waterbody 1, Colony 2	2018	395	6/12	*Stuckenia pectinata*
*FBWMA, Waterbody 2, Colony 1	2018	200	6/4	*Stuckenia pectinata*
*FBWMA, Waterbody 2, Colony 2	2018	95	6/4	*Stuckenia pectinata*
*FBWMA, Waterbody 2, Colony 3	2018	213	6/4	*Stuckenia pectinata*
*FBWMA, Turpin, Colony 1	2018	114	6/15	*Stuckenia pectinata* and *Ruppia cirrhosa*
*FBWMA, Turpin, Colony 2	2018	54	6/15	*Stuckenia pectinata* and *Ruppia cirrhosa*
*FBWMA, Turpin, Colony 3	2018	84	6/15	*Stuckenia pectinata* and *Ruppia cirrhosa*
*FBWMA, Turpin, Colony 4	2018	120	6/15	*Stuckenia pectinata* and *Ruppia cirrhosa*
*FBWMA, Turpin, Colony 5	2018	136	6/15	*Stuckenia pectinata* and *Ruppia cirrhosa*
*OBWMA, Colony 1	2018	28	6/6	*Stuckenia pectinata*
*OBWMA, Colony 2	2018	66	6/6	*Stuckenia pectinata*
*OBWMA, Colony 3	2018	155	6/6	*Stuckenia pectinata*
*OBWMA, Colony 4	2018	19	6/6	*Stuckenia pectinata*
*OBWMA, Colony 5	2018	55	6/6	*Stuckenia pectinata*
*OBWMA, Colony 6	2018	42	6/6	*Stuckenia pectinata*
*Rudy Duck Club	2018	380	6/22	*Stuckenia pectinata* and *Ruppia cirrhosa*
Minnesota[1]	1987-1989	173	5/6	*Populus* spp., *Salix* spp., *Typha* spp., *Scirpus* spp., *Chenopodium rubrum*
*Minnesota[1]	1987-1989	145	5/25	*Potamogeton* spp., *Stuckenia pectinatus, Utricularia vulgaris, Ceratophyllum demersum, Chlorophyceaespp.*
British Columbia[2]	1985	40	5/27	*Scirpus* spp., *Typha* spp.
Jamieson Meadow, British Columbia[3]	1988	47	6/3	*Shoenoplectus acutus*
*Caribou Region, British Columbia[4]	1955-1956	250	5/17	*Scirpus* spp., *Ruppia* spp., *Ceratophyllum* spp., *Myrophillum* spp., *Potamogeton* spp., *Cladophora* spp., *Aphanizomenon* spp.
Malheur National Wildlife Refuge[5]	1993-1994	44	late June	*Chenopodium rubrum, Scirpus acutus*
Gray's Lake, Idaho[6]	1997-2000	26	5/11	medium to tall hydrophytes
North Dakota[7]	1972	31		*Scirpus* spp.
Means		148 ± 177	6/8	
df		27	23	
F-value		0.99	17.11	
P-values		0.33	<0.001	

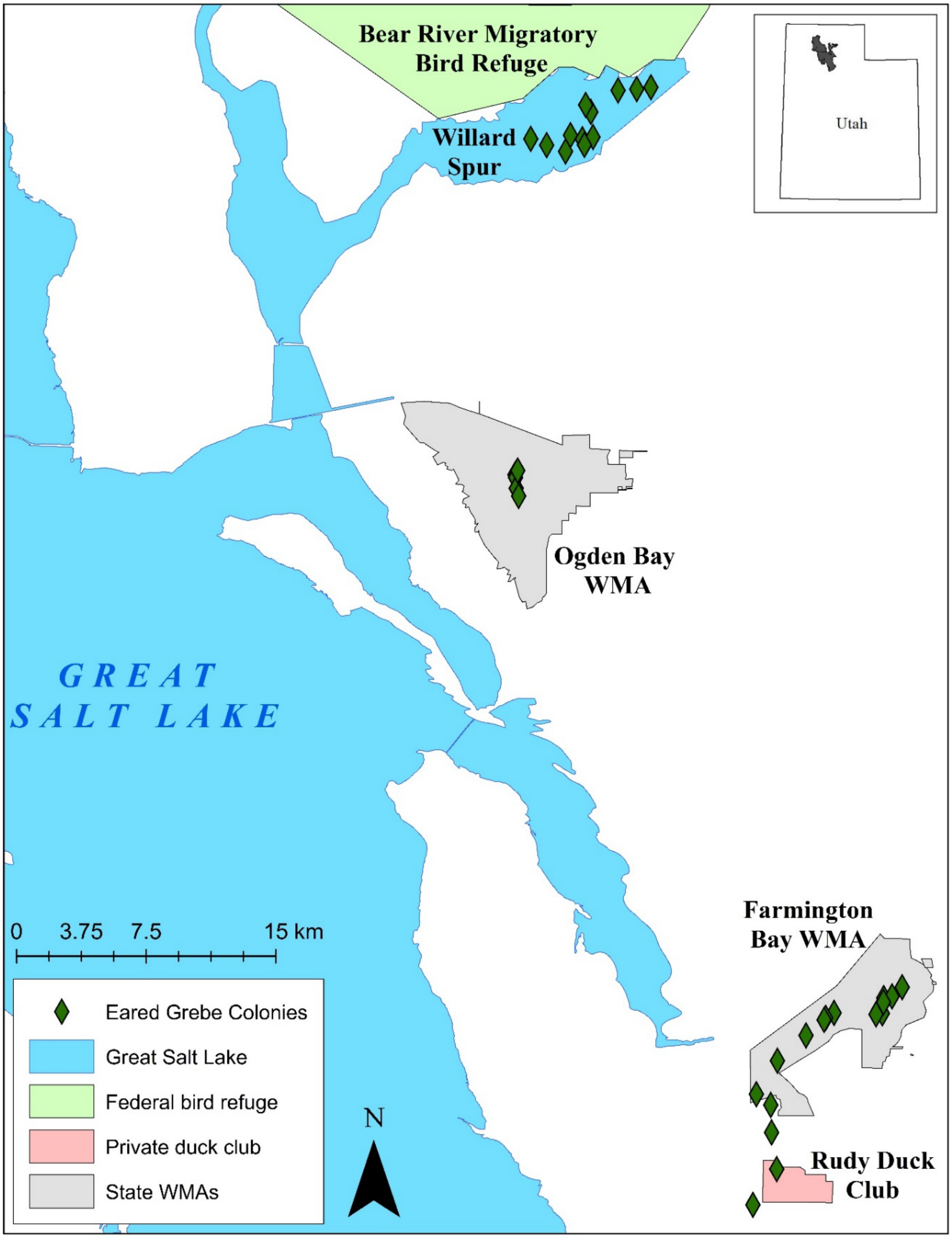

Figure 2–1. Locations of Eared Grebe colonies around the Great Salt Lake, Utah during 2018.

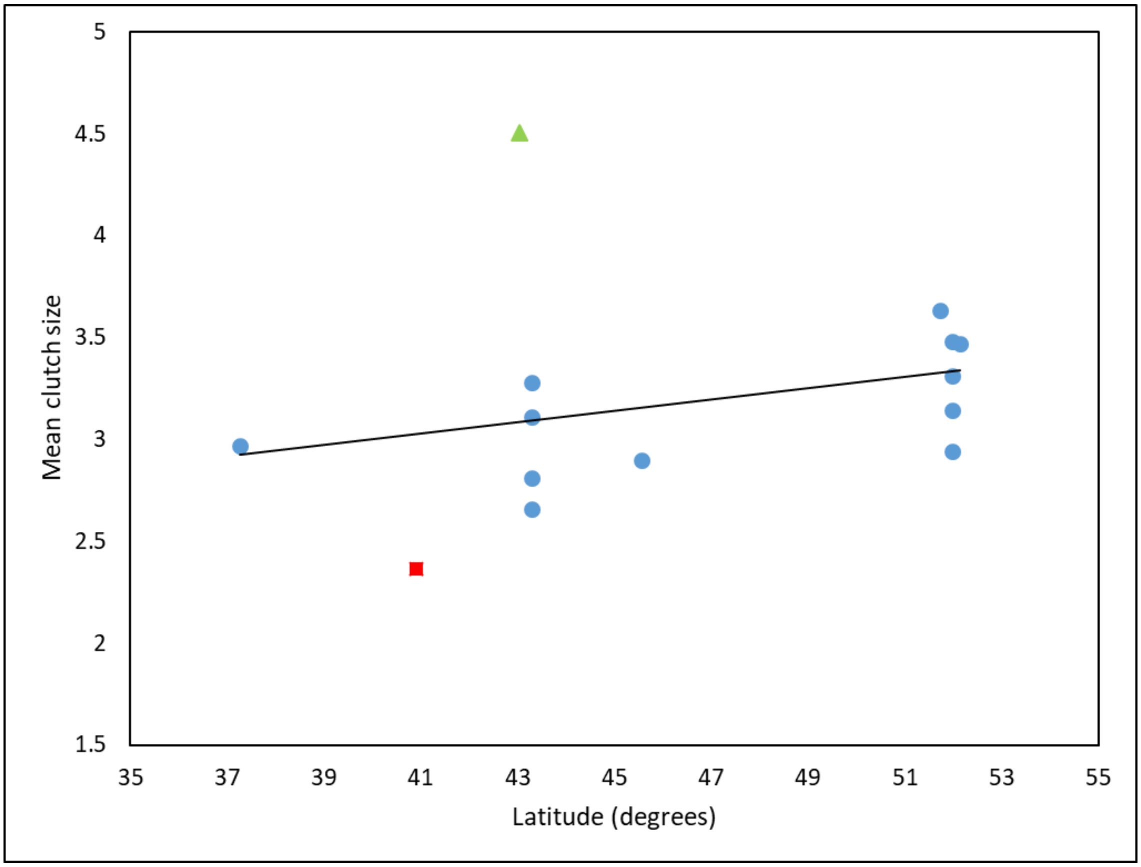

Figure 2–2. Clutch size variation in Eared Grebes across latitudes. Gray's Lake, Idaho clutch size (green triangle) significantly differed from mean clutch size of colonies in this study (red square) (P = 0.001) (Table 4–1). Clutch sizes were obtained from the following studies: Bochenski 1961, Broekhuysen and Frost 1968, Lyon and Everding 1996, McAllister 1958, Breault 1990, Campbell et al. 1990, Riske 1976, Hill et al. 1997, Ohlendorf et al. 1989, Boe 1993, Austin and Pyle 2004.

Figure 2–3. Nesting platform of Eared Grebe built from submerged aquatic vegetation in waterbody around the Great Salt Lake, Utah.

Figure 2–4. Nesting colony of Eared Grebes in waterbodies along the Great Salt Lake, Utah. The lighter dots are nests in a flooded wetland. The floating mats of submerged aquatic vegetation makes it appear to be solid land. Taken from an airplane on July 5, 2018.

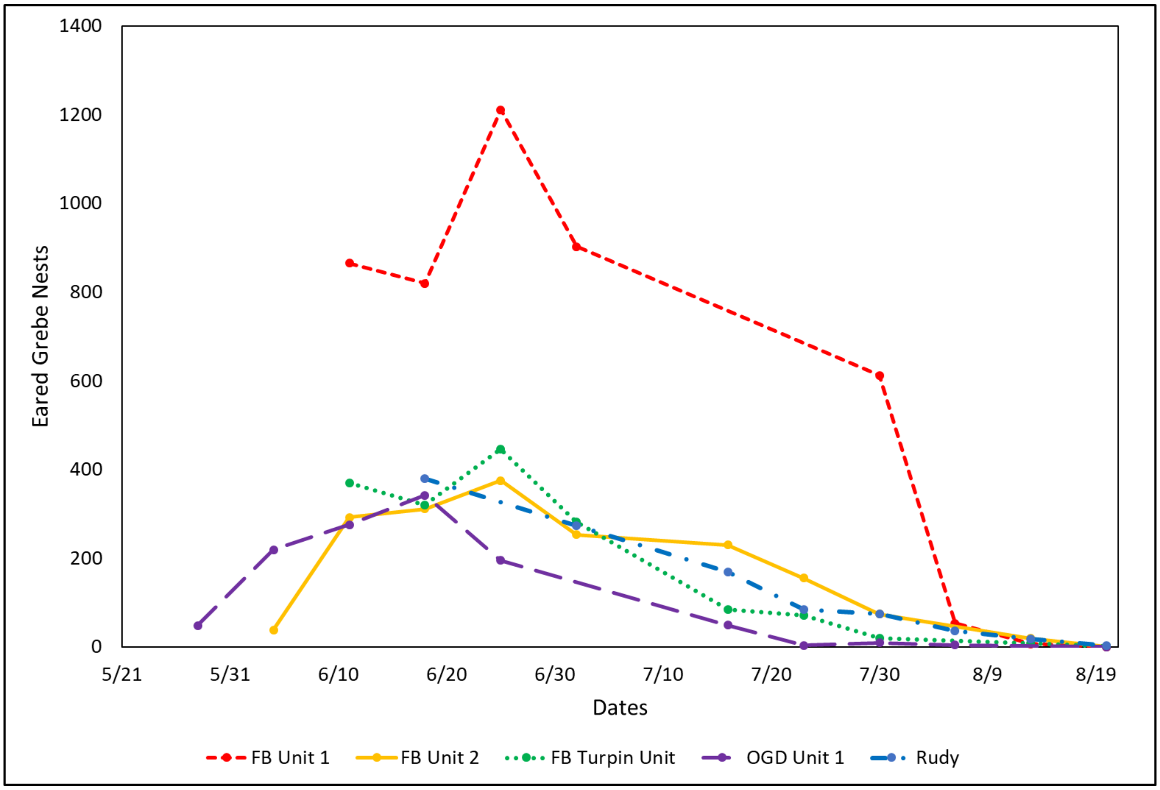

Figure 2–5. Number of incubated Eared Grebe nests over the course of the 2018 breeding season shown per wetland impoundment, Great Salt Lake, Utah.

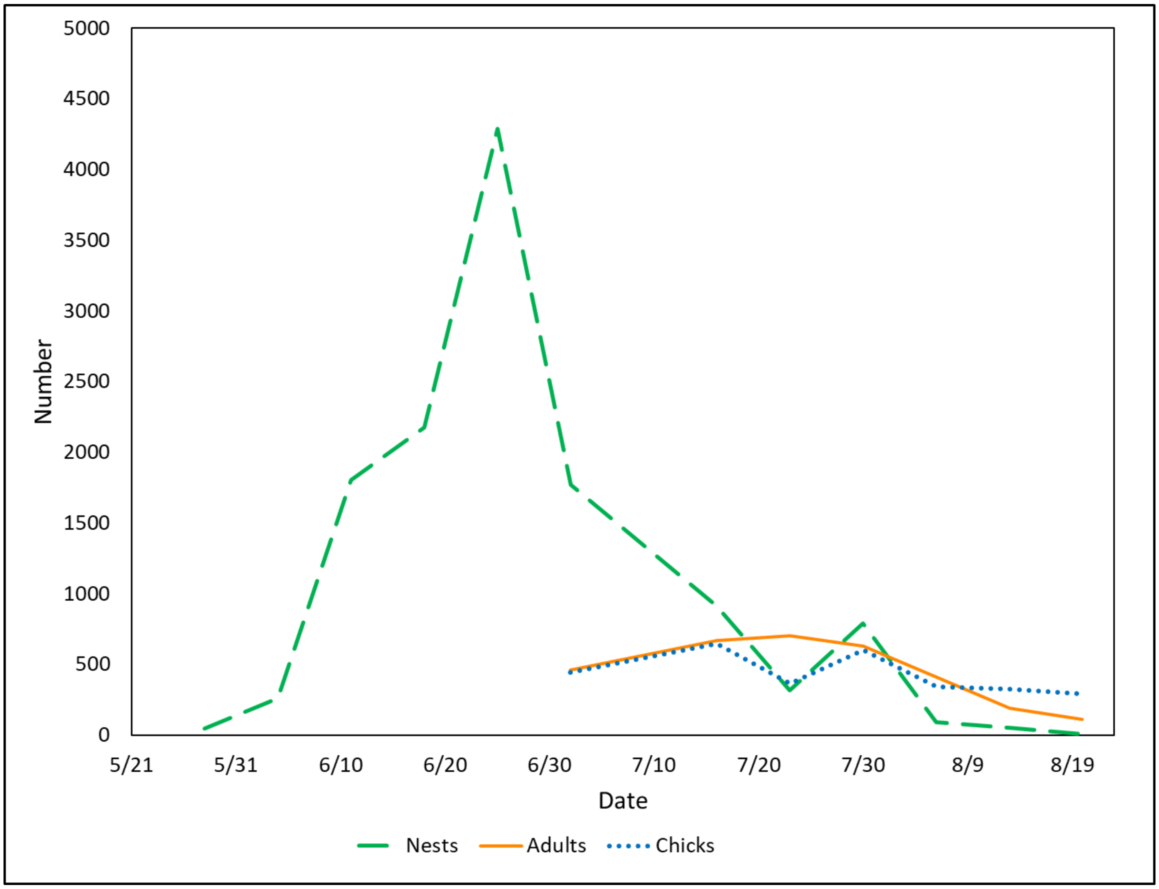

Figure 2–6. Number of Eared Grebe nests, adults, and chicks observed at all study sites throughout nesting in 2018. The decline of Eared Grebe numbers is due to their migration to their fall staging areas. The dashed green line is total number of nests. The solid orange line is adult Eared Grebes. The dotted blue line is the number of Eared Grebe chicks. Great Salt Lake, Utah.

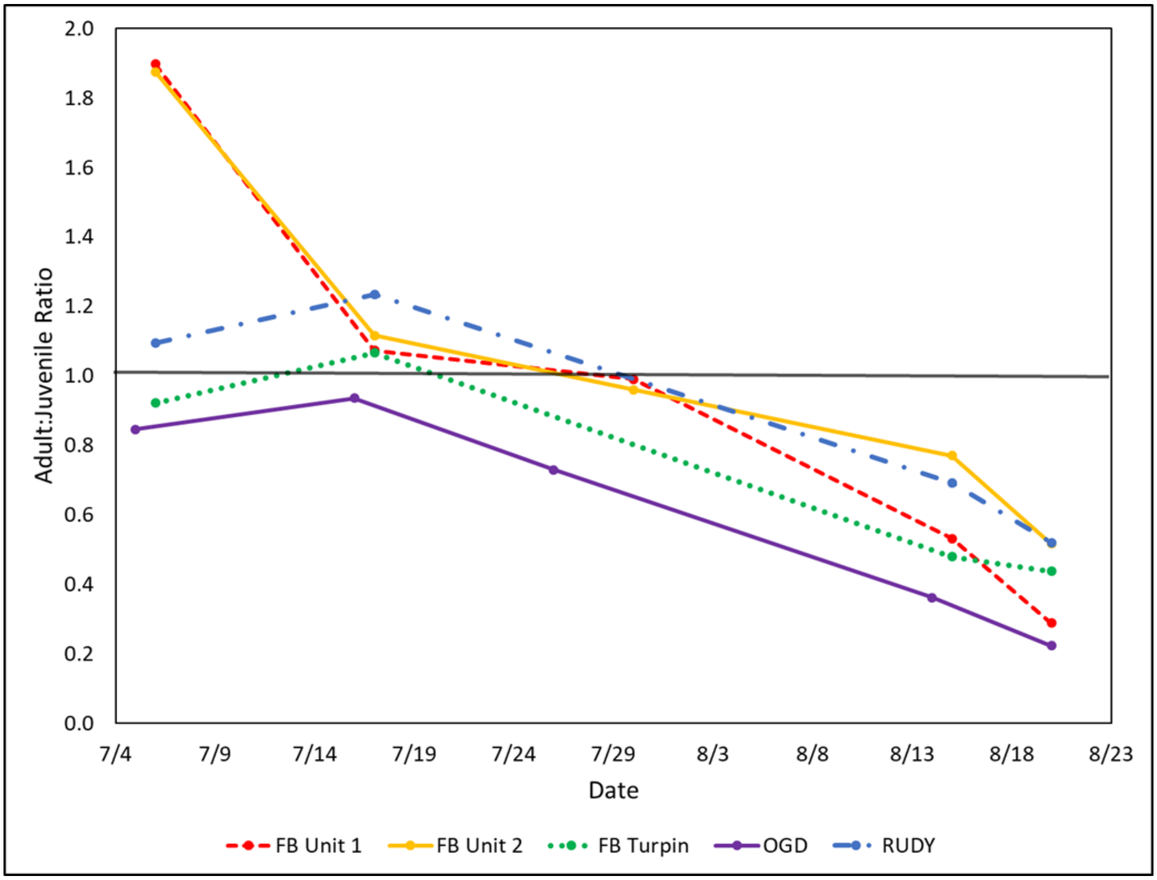

Figure 2–7. Adult to chick ratios in each wetland impoundment throughout nesting season, 2018. Gray line illustrates a 1:1 ratio of adults to chicks. Great Salt Lake, Utah.

CHAPTER 3

HABITAT SELECTION BY NESTING EARED GREBES ALONG THE GREAT SALT LAKE

ABSTRACT

Eared Grebes (*Podiceps nigricollis*) are colonial-nesting waterbirds which utilize wetlands along the Great Salt Lake (GSL), Utah for nesting. I examined what characteristics Eared Grebes (hereafter referred to as grebes) seek when selecting a colony site including water depth, invertebrate biomass density, vegetation species, vegetation cover, wetland area, distance to shore, distance to nearest emergent vegetation, and distance to the GSL. Samples and measurements were taken from inside grebe nesting colonies, outside nesting colonies, and other wetlands that did not contain nesting colonies. Using logistic regression to build models, I compared inside-colony sites to outside-colony sites, and there were no differences between them. When compared to other wetlands, inside-colony sites had deeper water depth, larger wetland area, and were closer to the GSL. Outside-colony sites had deeper water depth and higher percent cover of submerged aquatic vegetation (SAV), in comparison to other wetlands. Results from colonies around the GSL were compared to colonies found in the literature review. Water depth in colonies around the GSL were shallower than colonies located elsewhere. All of the colonies in this study were established on SAV as opposed to colonies in other studies that were built on emergent vegetation. My results indicate that grebes on the GSL prefer to nest in areas with relatively deep water, high invertebrate density, and abundant mats of SAV.

INTRODUCTION

Everything we know about Eared Grebe (*Podiceps nigricollis*) nesting habitat is from more northern latitudes of the United States and Canada, which may not be transferable to Eared Grebes (hereafter referred to as grebes) nesting around the Great Salt Lake (GSL), Utah. It is important understand the habitat selection of nesting grebes to better manage for them around the GSL. Habitat selection is broken into 4 orders by Johnson (1980). First-order habitat selection is the species' geographical range. The second order of selection is the home range of an individual. Third-order selection is the individual's usage of various habitat components within the home range. Fourth-order selection is the actual procurement of resources from a site (Johnson 1980). In this study, I examined factors contributing to the second- and third-order of habitat selection for nesting.

The first-order of habitat selection for grebes during their breeding season in North America begins west of the Mississippi River in the United States and extends northward to Canada, southward into Arizona and New Mexico, and westward into California and Oregon of the United States (Cullen et al. 1999). For the second-order of habitat, grebes choose to nest on shallow, eutrophic lakes and wetlands within their geographic range (Boe 1994). Grebes are colonial nesters and build colonies on emergent vegetation (e.g. *Scirpus* spp., *Carex* spp., *Typha* spp., *Schoenoplectus* spp., and *Chenopodium* spp.), and floating mats of submerged aquatic vegetation (SAV) such as *Potamogeton* spp., *Utricularia* spp., *Spirogyra* spp., *Ulothrix* spp., and *Rhizoclonium* spp. (Boe 1993, Boe 1994, Hill et al. 1997, Cullen et al. 1999). These colonies are established far from shore when vegetation is available (Breault 1990). In Minnesota, grebe nesting

colonies were 0.1–1.5 km from shore, and the average water depth at colony sites ranged from 50-120 cm (Boe 1993). Vegetation is critical when choosing colony sites, as it serves as the framework of nests and provides food and refuge for many birds (Parker 1986). The nests average 0.5–1.5 m in diameter with half of that diameter being above water (Bochenski 1961). Colony sites constitute the third-order of habitat selection while nests sites are the fourth order habitat selection.

Food can be an important factor when it comes to selecting a nesting colony site (Burger 1985). Grebes eat primarily invertebrates and occasionally small fish and will not nest in a lake if invertebrates are scarce (Cullen et al. 1999, Littlefield 1990). Invertebrate density in the natal wetlands is critical because grebe hatchlings cannot fly and are unable to regulate their own body temperature because their down feathers are not waterproof, meaning they can neither swim, nor stay in a wet nest (McAllister 1963). Instead, one parent carries the hatchlings on its back, while the other forages for food and feeds it to the young (Cullen et al. 1999). Parents and young are confined to the wetland the nest is located in until the hatchlings area about a week old and can regulate their own body temperature and swim on their own (McAllister 1963). Fourth-order habitat selection in grebe nesting would be the nest site, which was outside the scope of this study.

What information we have on grebe nesting ecology is from more northern latitudes than the GSL. Determining the nesting ecology of grebes on the wetlands surrounding the GSL will provide more accurate information to drive our management decisions for southern populations of grebes and help managers improve habitat of nesting grebes.

STUDY AREA

On the east side of the GSL, Utah, there is a matrix of 1,619 km^2 of impounded and natural wetlands fed by the waters of the Bear, Weber, and Jordan rivers. Some of these wetlands are in nature preserves, others are managed by state, federal, or private landowners. Fresh or brackish water wetlands are not found on the west side of the GSL because of the lack of freshwater inflow there. This study includes 5 state-run waterfowl management areas (WMAs): Farmington Bay, Ogden Bay, Harold S. Crane, Salt Creek, and Public Shooting Grounds; the federally managed Bear River Migratory Bird Refuge (BRMBR); a private property: Rudy Duck Club; and Cutler Reservoir, which is owned by a utility company (Fig. 3–1). These managed properties are all impounded, controlled wetlands that vary in size. Also included in this study is one natural wetland known was Willard Spur. It is a part of the Bear River Bay of the GSL and adjacent to BRMBR; it is the largest wetland in this study. All of these wetlands contained fresh or brackish water at the time of this study.

METHODS

I obtained information on the locations of previous grebe nesting colonies from WMA managers. During the spring and summer, I visited these colony sites once a week beginning on May 15, 2018. I also conducted a flight over the wetlands surrounding the GSL during the peak of nesting to locate grebe nesting colonies. The peak of nesting in this study is defined as the week of nesting season when the most nests were counted. Efforts were focused on locations managed by the state and local governments, such as:

Bear River MBR, Farmington Bay WMA, and Ogden Bay WMA. Each colony was photographed and marked with a GPS.

After nest numbers started to decline, I collected several habitat measurements in 3 categories: inside the nesting colony, outside of the nesting colony but in the same wetland, and in other wetlands without a nesting colony (Fig. 3–2). I sampled from 12 sites inside colonies, 6 sites outside of colonies, and 12 sites in other wetlands. The unequal amount of sites among groups is due to some wetlands having >1 colony. I selected 5 random sample sites at least 10 meters apart within each grebe colony. For comparison, 5 sites were randomly selected outside of the colony but in the same wetland at least 100 meters away from the colony, and 5 random sites in other wetlands unoccupied by grebes. An effort was made to choose unoccupied wetlands that were close (range = 1.1–4.3 km) to colony sites to avoid spatial variation (Fig. 3–1). My time spent in the colonies was kept to a minimum to avoid impacting incubating grebes.

Water depth was measured using a meter stick at each of the sample points. Invertebrate samples were collected using methods from Frank (2016). If the water depth was <30 cm, a stovepipe sampler was used to measure invertebrates in the water column. The stovepipe sampler was a 19-L plastic bucket with the bottom removed. It had an inside diameter of 29 cm at the top and 25 cm at the bottom. Once the bottom of the stovepipe sampler was secured by pushing it into the bottom substrate, a jar was used to scoop out water into a sieve with a mesh size of 500 μm. If the water depth was ≥30 cm, a vertical tow net was used to measure invertebrates. The tow net had a diameter of 50 cm and a mesh size of 153 μm (Research Nets Inc., Bothell, WA). The tow net was placed vertically into the water until it reached the bottom. Then the net was moved into a

horizontal position with the open portion facing up. It was quickly pulled up to capture any invertebrates in the water column. If SAV was brought up during the invertebrate sample, as much as possible was rinsed and removed before transferring the contents of the sieve or tow net into a jar with 95% ethanol which was kept on ice until processing. Emergent aquatic vegetation species and percent cover were documented, then cleared away to evaluate SAV species and percent cover using a 1-m^2 circular quadrat. The entire water column was evaluated for percent cover of SAV. Percent cover was broken into 8 different categories: <1, 1–5, 5–25, 25–50, 50–75, 75–95, 95–99, and 99–100%. After emergent vegetation was assessed for percent cover, it was cleared away, and SAV species and percent SAV cover were documented while keeping the 1-m^2 plot in place.

Wetland area was determined using ArcMap polygons. Throughout nesting, I marked the edges of each colony with GPS points and uploaded the points to a shapefile in ArcMap. Based on the GPS points, I drew polygons around all nests of each colony in ArcMap to estimate colony size. The colony center point was placed in the middle of the colony polygon. Using aerial imagery data, I determined the distance of colony from nearest shore, distance of colony to nearest patch of emergent vegetation, and distance to the GSL from the colony center point. Random points were generated in ArcMap using the Random Points tool for each wetland surveyed. These measurements were repeated at the random points in outside-colony sites and other wetland sites.

I compared sites inside a colony, sites outside a colony, and sites in other wetlands to each other using a separate analysis for each of the 3 pairings (Fig. 3–2). All statistical analysis was done in program R. Models were built using the package MuMIn, and I created plots using ggplot2. Models predicting grebe nesting colony presence were

built with logistic regression and compared using Akaike's Information Criterion (AIC). I included mean and standard deviation in the results when appropriate.

I compared the colonies found in my study to those found elsewhere. I collected data from colonies described in 7 previously published studies (listed in Table 3–1) that looked at nesting habitat of grebes. I compared characteristics of nesting colonies around the GSL to those found elsewhere using a 1-way analysis of variance (ANOVA). I compared vegetation composition in my study and those found elsewhere using a chi-squared analysis. I considered *P*-values $\alpha < 0.05$ to be statistically significant in all comparisons.

RESULTS

Nesting Habitat

I located 35 nesting colonies of grebes around the GSL (Fig. 3–3). The colonies were distributed among 9 impounded wetlands and one natural wetland, Willard Spur. I randomly selected colonies from as many sites as logistically feasible and collected samples from 12 colonies that were included in all the following analyses unless otherwise stated.

Water depth within nesting colonies in this study ranged from 36–63 cm (48 ± 9 cm; $\bar{x}$ ± SD), water depths outside of the colonies were similar with a range of 37–65 cm (52 ± 12 cm). Water depths in non-colony wetlands were shallower on average (29 ± 11 cm) with a range of 18–44 cm (Fig. 3–4b).

All colony sites in this study were composed of floating mats of SAV including sago pondweed (*Stuckenia pectinate*), common duckweed (*Lemna minor*), chara (*Chara*

spp.), leafy pondweed (*Potamogeton foliosus*), and spiral ditchgrass (*Ruppa cirrhosa*). None of the sites sampled for this study contained emergent aquatic vegetation. Sago pondweed and spiral ditchgrass were the 2 species upon which grebes built their nesting colonies. Vegetation species composition showed no difference between inside-colony sites and outside-colony sites. The average percent-cover of SAV in every category of habitat was between 75–95% cover. However, percent cover inside colonies and outside colonies was greater than that of other GSL wetlands (Fig. 3–4c). Water depth and percent cover of SAV were not correlated (r = 0.19, $P = 0.38$); however maximum percent cover of SAV was most abundant when the water depth was 35 to 55 cm. At water depths less or more than these values, percent cover of SAV decreased.

The analyses of invertebrate biomass density excluded 5 sites that did not have a value for biomass, as well as one major outlier in other wetland sites, leaving 23 observations for this variable. The outlier was the very first sample I took in this study, and I believe I sampled the site incorrectly. Invertebrate biomass density inside grebe colonies was higher than invertebrate biomass density in outside-colony sites and in other wetlands. Invertebrate biomass density in outside-colonies sites was very similar to invertebrate biomass density in other wetlands (Fig. 3–4a).

Habitat Measurements

Wetland area in occupied wetlands (1,191 ± 2,259 ha) was much larger than unoccupied wetlands (238 ± 152 ha), which could contribute to the difference seen in the distance measurements that follow. Distance to shore ranged from 93 to 2,153 m (907 ± 771 m) for colonies and 129 to 3,852 m (827 ± 1486 m) for outside-colony sites, and 26

to 670 m (209 ± 274 m) for other wetlands (Fig. 3–5a). Distance to nearest patch of emergent vegetation was similar to the distance to shore measurement because most of the emergent vegetation found in the impounded wetlands was on or adjacent to the shore, this was not the case for Willard Spur sites. Distance to nearest emergent vegetation ranged from 93–1,577 m (389 ± 410 m) for colony sites (Fig. 3–5b). Outside-colony sites had a range of 14–1,839 m (409 ± 706 m). Other wetlands had the smallest range of 26–670 m (208 ± 274 m). Distance to the GSL did not differ much among habitat categories (Fig. 3–5c). Distance to the GSL for nesting colonies ranged from 0–11,309 m (5091 ± 4669 m). For outside-colonies sites, distance to the GSL ranged from 0–9,982 m (7076 ± 3640 m). The 0 value at the lower end of both of these groups was because Willard Spur is part of the GSL's Bear River Bay. Other wetlands had an average distance of 5,713 ± 4,981 m from the GSL and a range of 779–12,440 m.

Models

Of the 30 sites in this study, 23 were included in the overall model. I excluded 6 sites in other wetland that did not have a value for invertebrate biomass density. I also excluded a large outlier for invertebrate biomass density in other-wetland sites because I believed the sample to be incorrect due to human error. Out of the 8 variables that I measured at each of my sites, I included six in the final model. I eliminated vegetation species because it did not differ among the habitat categories. I eliminated distance to shore because it was highly correlated with distance to nearest emergent vegetation ($r = 0.83$, $P = <0.001$). This correlation likely resulted from most of the emergent vegetation in impounded wetlands in this study being located along the shore. Distance to shore (r =

0.86, *P* = <0.001) and distance to nearest emergent vegetation (r = 0.62, *P* = 0.002) were both correlated with wetland area. I decided to keep distance to nearest emergent vegetation and area, because it was the least correlated. I ran these models with and without Willard Spur sites because Willard Spur is an unimpounded wetland that is part of the GSL, effecting the distance to the GSL wetland area variables. The results from the regression models that excluded Willard Spur did not significantly change the top three models, it only replaced distance to the GSL with distance to nearest emergent vegetation in those models. Only models with ΔAIC of <2 were considered competitive.

Inside-colony versus outside-colony. – In the model comparing inside-colony sites to outside-colony sites, I removed wetland area because it was the same for both categories. The top model was the null model containing no variables. The next competitive model included only invertebrate biomass density. The third competing model, with an ΔAIC = 2.01, only included distance to the GSL (Table 3–2).

Inside-colony versus another wetland. –The top performing model included water depth and wetland area (Table 3–3). The next competing model only included water depth. The last competing model contained just water depth and distance to the GSL; however, when Willard Spur was removed from the analysis, this model contained water depth and distance to nearest emergent vegetation. All 3 competing models performed better than the null model (ΔAIC = 8.85).

Outside-colony versus another wetland. – The top performing model for outside-colony sites and other wetlands only included water depth (Table 3–4). There were 2 competing models; the first one included water depth and percent cover of SAV and the

second included water depth and wetland area. All of these performed better than the null model (ΔAIC = 5.23).

Literature Review

Colonies found in the literature review and used for comparison were located in natural ponds and wetlands. Almost all colonies found in my study were located in impounded wetlands. Mean water depth at GSL colony sites was lower than colony sites located elsewhere (F = 43.68, df = 14, P < 0.001, Table 3–1). Wetland area did not differ significantly between my colony sites and those of other studies (F = 1.32, df = 11, P = 0.28).

Every nesting colony in my study contained *Stuckenia pectinata* which was significantly more frequent than colonies found elsewhere (X^2 = 26.88, df = 1, P = <0.001). The proportion of my colonies that contained *Ruppia cirrhosa* were similar to colonies found elsewhere (X^2 = 0.55, df = 1, P = 0.46). Colonies found elsewhere contained multiple other species of vegetation which all differed significantly from the colonies in my study (X^2 = 6.40, df = 1, P = 0.01, Table 3–1).

DISCUSSION

Water depth showed up multiple times in models differentiating between occupied and unoccupied waterbodies, indicating that it is an important factor for second order habitat selection for nesting grebes. Grebes are diving waterbirds that dive to forage and avoid predation, which could explain the importance of water depth. Deeper water may also make it harder for common nest predators, raccoons (*Procyon lotor*) and red foxes (*Vulpes vulpes*), to reach the colony because they would have to swim to it. Percent

cover of SAV showed up in a competing model for outside-colony sites and other wetlands, with outside-colony sites having 95–99% cover and other wetlands having 75–95% cover. The vegetation grebes chose to nest on around the GSL requires a water depth of 38–45 cm to become established (Robel 1962). It is possible that because the other wetlands in this study were shallow, the conditions were not conducive to adequate SAV cover. Grebes do not seem to be limited in colony sites, their third order of habitat, because the null model was the top model distinguishing between inside colonies and outside colonies. These results indicate the homogenous nature of impounded wetlands and suggest that the number of grebe colonies or the number of nesting grebes in a wetland is not limited by the availability of suitable nesting sites.

Invertebrate biomass density was included in the top performing model for inside-colony sites and other wetlands. Throughout nesting and brood rearing, grebes do not leave their colony wetland. Both sexes participate in incubation and once the eggs hatch, the chicks are unable to fly or swim, so they are confined to their parents' backs, which constrains a grebes' foraging locations to the wetland they chose to nest. This limited dispersal ability may explain why grebes prefer wetlands with higher invertebrate biomass densities. Distance to the GSL also showed up in a competing model for inside-colony sites and other wetlands. The GSL is a fall-staging ground for grebes, and grebes may make their way there after nesting. The closer the nesting colony is to the GSL, the shorter their flight or swim to their fall-staging grounds. Wetland area showed up in both models distinguishing from occupied and unoccupied sites, indicating that grebes choose larger waterbodies to build their colonies. Distance from nearest emergent vegetation showed up in models that excluded Willard Spur data.

After comparing results from the GSL to colonies found in the literature review, results showed that GSL nesting colonies were located in shallower water than those found elsewhere. Average water depth inside the colonies in this study was lower (48 cm) than other studies (50-190 cm). The lower water depth could be due to the nature of the impounded wetlands in this study. The vegetation in colonies around the GSL was similar to other colonies built on floating mats of SAV. Out of the 8 colonies that were found in the literature review, 6 of them were built on emergent vegetation, something grebes around the GSL did not utilize. Emergent vegetation is lacking in the wetland impoundments around the GSL except along the levees. The lack of emergent vegetation away from shore could explain why grebes choose SAV mats instead.

To better manage for grebe nesting colonies, I think it is important to focus on providing a water depth that is ideal for producing plenty of SAV and improving invertebrate biomass density. Ideal water depth for the most percent cover of SAV vegetation in this study was 35–55 cm.

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TABLES AND FIGURES

Table 3–1. Nesting chronology and habitat variation in previous studies compared to the Great Salt Lake, Utah. Mean clutch size is the average clutch size for the colony. Wetland area is the size of the wetland the colony is located in. Number of nests is the maximum number of nests found in that colony during the 2018 nesting season. Nesting substrate is the plants that made up the nests in that colony. The abbreviations stand for Farmington Bay Wildlife Management Area (FBWMA), Ogden Bay Wildlife Management Area (OBWMA). P-values are from 1-way ANOVA tests comparing other studies to this one. For the wetland area, only one colony was chosen from each of my wetlands for the test.

*Colonies that were built with submerged aquatic macrophytes

** maximum water depth; not included in analysis

[1]Boe 1993, [2]Breault 1990, [3]Lyon and Everding 1996, [4]McAllister 1958, [5]Hill et al. 1997, [6]Austin and Pyle 2004, [7]Faaborg 1976.

Location	Year	Mean water depth ± SD (cm)	Wetland area (ha)	# of nests	Nesting substrate
*FBWMA, Waterbody 1, Colony 1	2018		499	902	*Stuckenia pectinata*
*FBWMA, Waterbody 1, Colony 2	2018		499	395	*Stuckenia pectinata*
*FBWMA, Waterbody 1, Colony 3	2018	46 ± 7.6	499	117	*Stuckenia pectinata*
*FBWMA, Waterbody 1, Colony 4	2018	45.2 ± 1.6	499	267	*Stuckenia pectinata*
*FBWMA, Waterbody 2, Colony 1	2018		137	200	*Stuckenia pectinata*
*FBWMA, Waterbody 2, Colony 2	2018		137	95	*Stuckenia pectinata*
*FBWMA, Waterbody 2, Colony 3	2018	59.6 ± 1.9	137	213	*Stuckenia pectinata*
*FBWMA, Turpin, Colony 1	2018	54.2 ± 2.6	419	114	*Stuckenia pectinata* and *Ruppia cirrhosa*
*FBWMA, Turpin, Colony 2	2018		419	54	*Stuckenia pectinata* and *Ruppia cirrhosa*
*FBWMA, Turpin, Colony 3	2018		419	84	*Stuckenia pectinata* and *Ruppia cirrhosa*
*FBWMA, Turpin, Colony 4	2018		419	120	*Stuckenia pectinata* and *Ruppia cirrhosa*
*FBWMA, Turpin, Colony 5	2018		419	136	*Stuckenia pectinata* and *Ruppia cirrhosa*
*OBWMA, Colony 1	2018	40.2 ± 0.4	259	28	*Stuckenia pectinata*
*OBWMA, Colony 2	2018		259	66	*Stuckenia pectinata*
*OBWMA, Colony 3	2018		259	155	*Stuckenia pectinata*
*OBWMA, Colony 4	2018		259	19	*Stuckenia pectinata*
*OBWMA, Colony 5	2018		259	55	*Stuckenia pectinata*
*OBWMA, Colony 6	2018	42.8 ± 0.4	259	42	*Stuckenia pectinata*
*Rudy Duck Club	2018	60.4 ± 3.9	45	380	*Stuckenia pectinata* and *Ruppia cirrhosa*
Willard Spur, Colony 1	2018	36.2 ± 1.9	5790		*Stuckenia pectinata*
Willard Spur, Colony 2	2018	63.2 ± 0.8	5790		*Stuckenia pectinata*
Willard Spur, Colony 3	2018	52.4 ± 1.3	5790		*Stuckenia pectinata*
Willard Spur, Colony 4	2018	42.2 ± 1.1	5790		*Stuckenia pectinata*
Willard Spur, Colony 5	2018	38.0 ± 0.7	5790		*Stuckenia pectinata*
Minnesota[1]	1987-1989	83 ± 22	1300	173	*Populus* spp., *Salix* spp., *Typha* spp., *Scirpus* spp., *Chenopodium rubrum*
*Minnesota[1]	1987-1989	95 ± 25	667	145	*Potamogeton* spp., *Stuckenia pectinatus, Utricularia vulgaris, Ceratophyllum demersum, Chlorophyceaespp.*
British Columbia[2]	1985	90 ± 10	104	40	*Scirpus* spp., *Typha* spp.
Jamieson Meadow, British Columbia[3]	1988			47	*Shoenoplectus acutus*

*Caribou Region, British Columbia[4]	1955-1956	152**	130	250	*Scirpus* spp., *Ruppia* spp., *Ceratophyllum* spp., *Myrophillum* spp., *Potamogeton* spp., *Cladophora* spp., *Aphanizomenon* spp.
Malheur National Wildlife Refuge[5]	1993-1994	183**	18211	44	*Chenopodium rubrum, Scirpus acutus*
Gray's Lake, Idaho[6]	1997-2000	71.0 ± 3	15000	26	medium to tall hydrophytes
North Dakota[7]	1972	100**	48	31	*Scirpus* spp.
df		1, 14	1, 11	1, 26	
F-value		43.68	1.32	1.17	
P-values		<0.001	0.28	0.29	

Table 3–2. Top 8 logistic regression models for inside-colony sites vs. outside-colony sites. Variables included: invertebrate biomass density (Invert), distance to the GSL (DistGSL), water depth (Wdepth), percent cover of submerged aquatic vegetation (SAV), and distance to nearest patch of emergent vegetation (DistVeg). The sign in parentheses indicates if the variable in the outside colony data is lesser (-) or greater (+) than the inside colony data. K is the degrees of freedom. LogLik is the log likelihood of the model. AICc is the Akaike's Information Criterion of the model.

Model	K	logLik	AICc	ΔAICc	weight
Null	2	-12.0	28.8	0.00	0.314
(-) Invert	3	-11.0	29.6	0.83	0.208
(+) DistGSL	3	-11.6	30.8	2.01	0.115
(+) Wdepth	3	-11.8	31.3	2.46	0.092
(+) SAV	3	-11.9	31.5	2.73	0.080
(-) Invert (+) DistGSL	4	-10.3	31.7	2.88	0.075
(+) DistVeg	3	-12.0	31.7	2.91	0.073
(-) Invert (-) Wdepth	4	-10.9	32.8	3.98	0.043

Table 3–3. Top 9 logistic regression models for inside-colony sites vs. other wetland sites. Variables included: water depth (Wdepth), invertebrate biomass density (Invert), Distance to the GSL (DistGSL), wetland area (Area), distance to nearest patch of emergent vegetation (DistVeg), and percent cover of submerged aquatic vegetation (SAV). The sign in parentheses indicates if the variable in the other wetland data is lesser (-) or greater (+) than the inside colony data. K is the degrees of freedom. LogLik is the log likelihood of the model. AICc is the Akaike's Information Criterion of the model. The null model was ranked 26th with a ΔAICc = 8.85.

Model	K	logLik	AICc	ΔAICc	weight
(-) Wdepth (-) Area	4	-16.9	44.9	0.00	0.310
(-) Wdepth	3	-18.8	45.4	0.50	0.242
(-) Wdepth (+) DistGSL	4	-18.1	47.2	2.27	0.100
(-) Wdepth (-) Area (-) Invert	5	-16.4	47.7	2.81	0.076
(-) Wdepth (-) Area (+) DistVeg	5	-16.5	48.0	3.13	0.065
(-) Wdepth (-) Invert	4	-18.5	48.1	3.22	0.062
(-) Wdepth (-) Area (-) DistGSL	5	-16.7	48.4	3.53	0.053
(-) Wdepth (-) SAV	4	-18.8	48.7	3.81	0.046
(-) Wdepth (-) DistVeg	4	-18.8	48.7	3.81	0.046

Table 3–4. Top 8 logistic regression models for outside-colony sites vs. other wetland sites. Variables included: water depth (Wdepth), percent cover of submerged aquatic vegetation (SAV), invertebrate biomass density (Invert), distance to nearest patch of emergent vegetation (DistVeg), wetland area (Area), and distance to the GSL (DistGSL). The sign in parentheses indicates if the variable in the other wetland data is lesser (-) or greater (+) than the outside colony data. K is the degrees of freedom. LogLik is the log likelihood of the model. AICc is the Akaike's Information Criterion of the model.

Model	K	logLik	AICc	ΔAICc	weight
(-) Wdepth	3	-4.3	17.5	0.00	0.457
(-) Wdepth (-) SAV	4	-2.8	19.4	1.83	0.183
(-) Wdepth (-) Area	4	-3.5	20.6	3.09	0.097
(-) Wdepth (-) DistVeg	4	-3.6	20.9	3.39	0.084
(-) Wdepth (+) DistGSL	4	-3.9	21.5	4.01	0.061
(-) Wdepth (+) Invert	4	-4.1	22.0	4.46	0.049
(-) Wdepth (-) SAV (+) Invert	5	-1.3	22.7	5.15	0.035
Null	2	-8.7	22.8	5.23	0.033

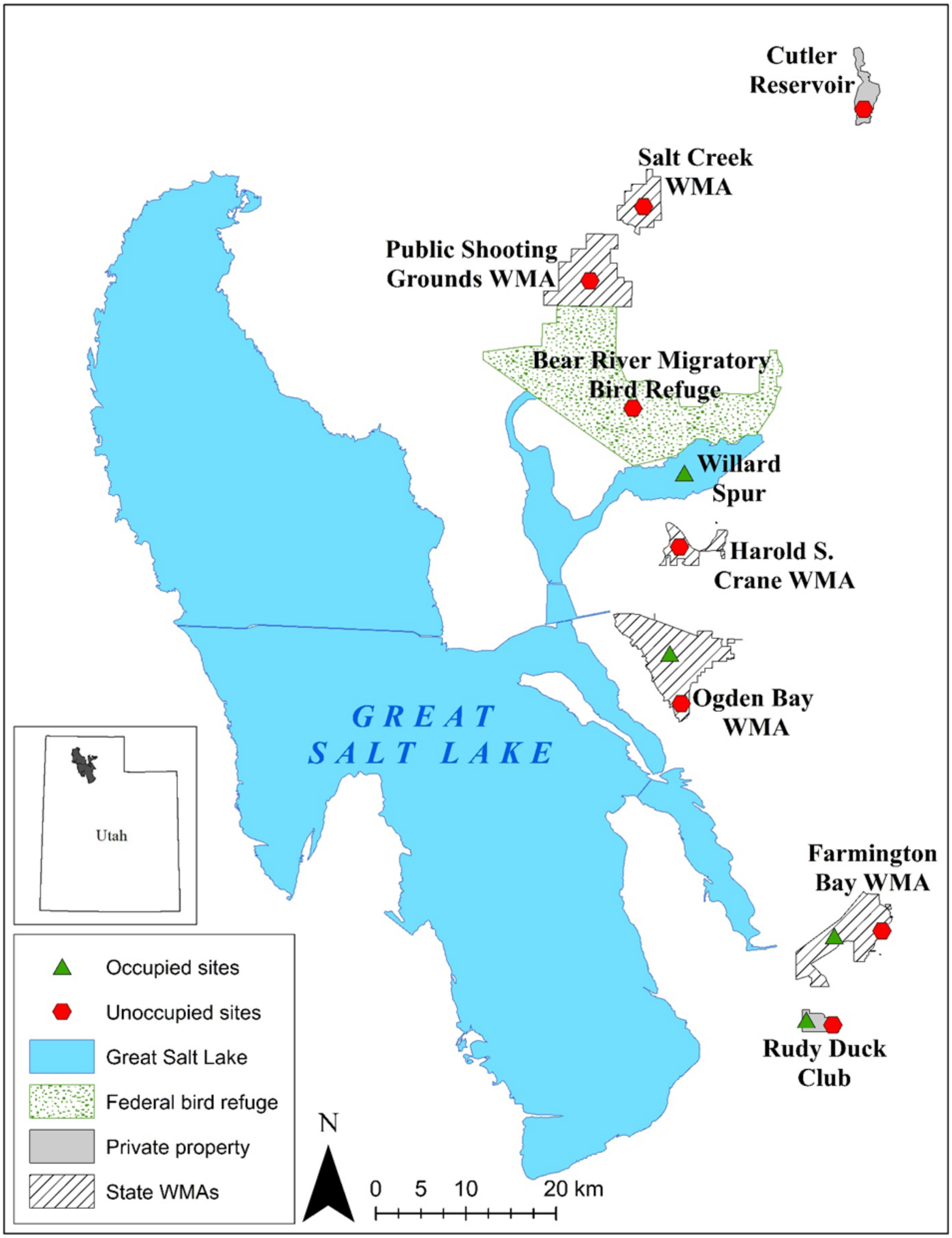

Figure 3–1. Study sites that were unoccupied or occupied by Eared Grebe nesting colonies around Great Salt Lake, Utah in 2018. Cutler Reservoir, Salt Creek WMA, and Public Shooting Grounds WMA were excluded from the logistic regression analysis.

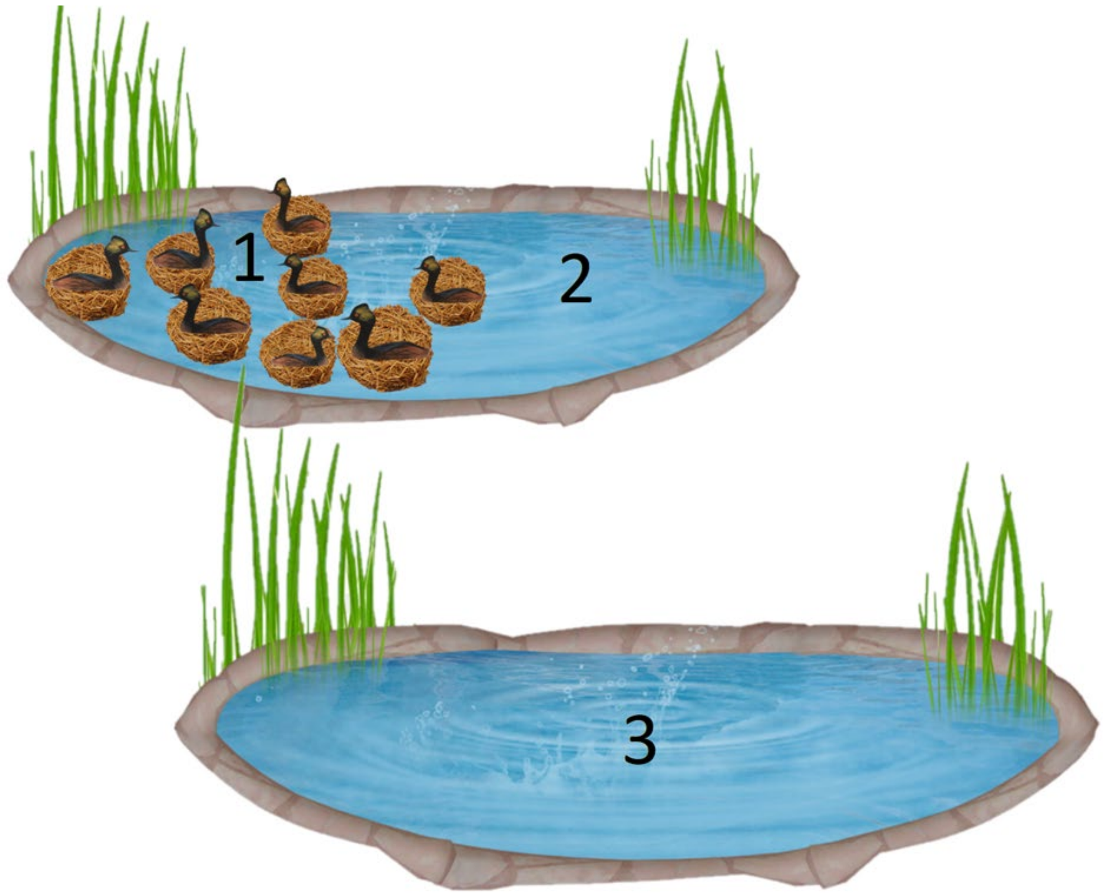

Figure 3–2. Illustration of the 3 categories of habitat in this study. One is inside a colony, 2 is outside a colony, and 3 is another wetland.

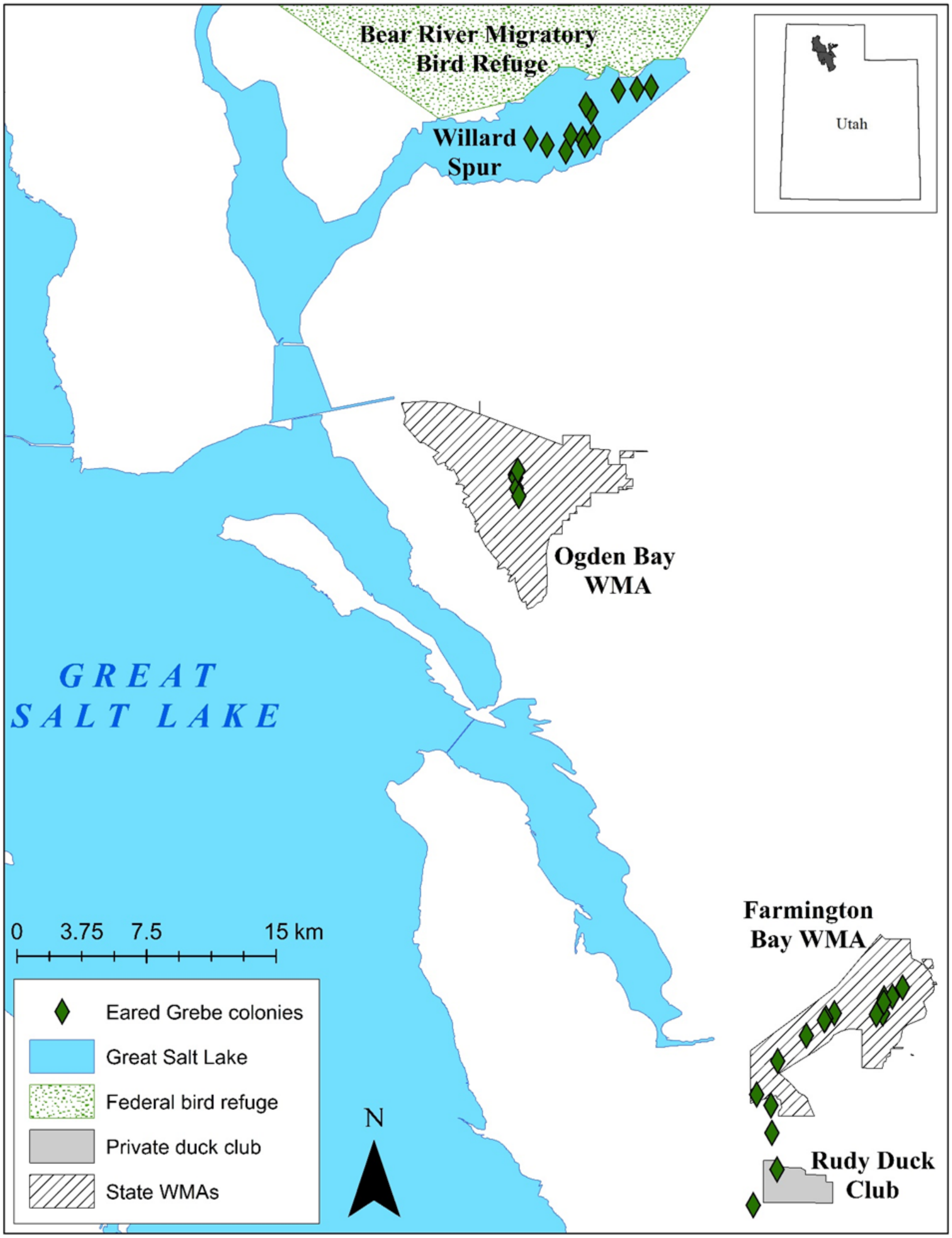

Figure 3–3. Location of Eared Grebe nesting colonies around the Great Salt Lake, Utah during 2018.

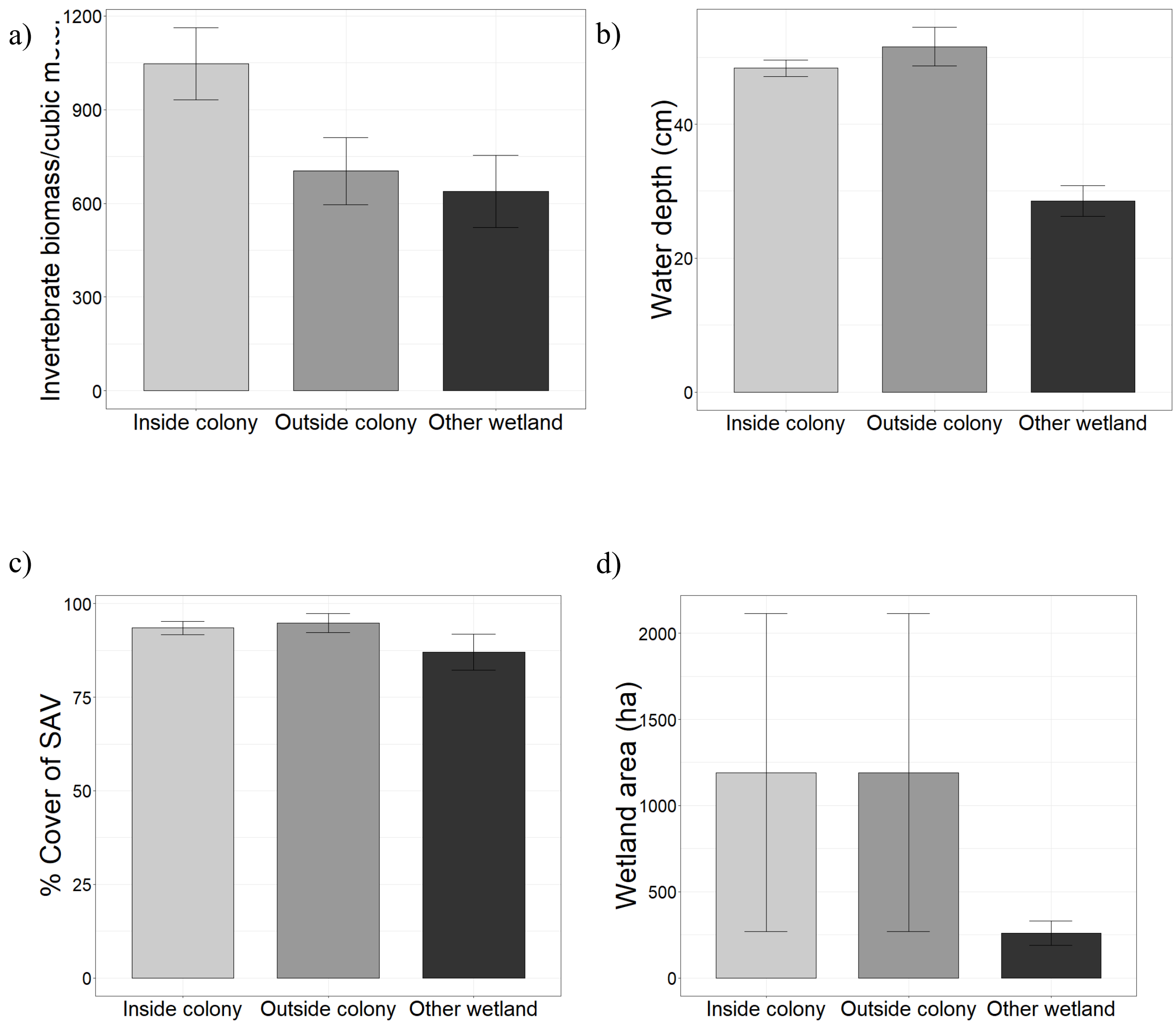

Figure 3–4. Comparisons of mean a) invertebrate biomass density, b) water depth, c) percent cover of submerged aquatic vegetation, and e) wetland area for each of the 3 different habitat locations. Error bars represent standard error. Data collected during 2018 along Utah's Great Salt Lake.

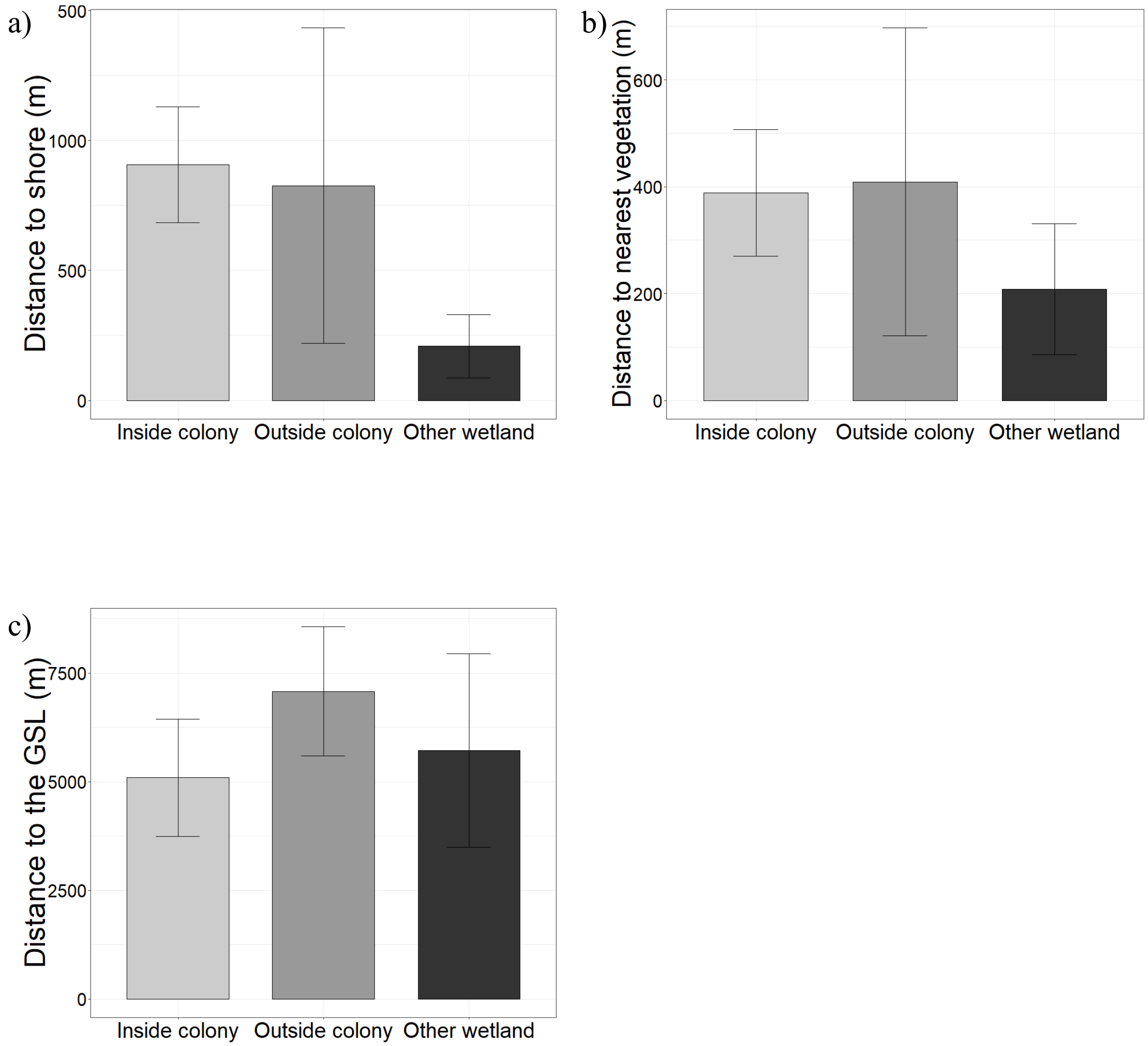

Figure 3–5. Comparison of means for a) distance to shore, b) distance to nearest emergent vegetation, and c) distance to the Great Salt Lake for each of the three different habitat locations. For habitats without Eared Grebe colonies, a random point was chosen in the wetland for measurement. Error bars represent standard error. Data collected in 2018 along Utah's Great Salt Lake.

CHAPTER 4

VIABILITY OF BRINE SHRIMP CYSTS AFTER PASSING THROUGH THE DIGESTIVE SYSTEM OF EARED GREBES

ABSTRACT

Brine shrimp (*Artemia franciscana*) are an important resource found in the Great Salt Lake (GSL), Utah, and they serve as a vital food source to migrating birds in the fall. Brine shrimp produce live young, as well as hard-walled eggs called cysts; the latter are of great economic value and are commercially harvested from the GSL and account for 90% of the world's commercial harvest of cysts (Treece 2000). While the harvest of brine shrimp cysts is heavily monitored and regulated, we are still unsure of the impact that the millions of birds that stop at the GSL have on the brine shrimp population. I evaluated cyst viability, which is the percentage of cysts that are in a condition conducive to hatching, for cysts that had passed through the digestive tract of Eared Grebes (*Podiceps nigricollis*) and cysts obtained straight from the GSL. There was a significant difference in viability between cysts that had passed through Eared Grebes (30%) and those that did not (63%). Viable cysts that passed through the digestive tract could serve to repopulate ephemeral waterbodies with brine shrimp after grebes defecate there, but they would provide no nutritional benefit for the Eared Grebes that consumed them.

INTRODUCTION

Brine shrimp (*Artemia franciscana*) are invertebrates that have adapted to hypersaline environments and inhabit the Great Salt Lake (GSL), Utah. At their peak,

brine shrimp abundance in the GSL has been recorded at a density of 8 individuals/L of lake water (Wurtsbaugh and Gliwicz 2001). Their population is dynamic and cyclical in nature with salinity being the most important variable associated with their distribution and abundance. Brine shrimp populations also fluctuate with other environmental factors, such as water temperature and algal populations (Stephens and Birdsey Jr. 2002).

Nauplii, the first larval stage of brine shrimp, hatch from over-wintering cysts (hard-walled brine shrimp eggs in diapause), which usually occurs in late February or March when temperatures are above freezing (0º C). These nauplii will grow into the first generation of adults. If conditions are favorable, adults will reproduce ovoviviparously (live birth). Each year, there are 2 or 3 generations of brine shrimp produced on the GSL. When food becomes scarce and temperatures begin dropping, brine shrimp adults will produce young oviparously, producing diapausing eggs (cysts). Brine shrimp adults will die when temperatures drop below 3º C; however, the cysts are able to survive through winter (Stephens and Birdsey Jr. 2002).

Brine shrimp cysts have been commercially harvested from the GSL since 1952 (Stephens and Birdsey Jr. 2002). The cysts are buoyant and with the help of wind and water currents, form large concentrations on the surface of the lake called streaks. It is the high density of cysts in a streak that are commercially harvested. The economic value of this industry is between $50 and $100 million annually (Bioeconomics 2012). The brine shrimp population is monitored by the state's GSL Ecosystem Program throughout the harvest season, which is open October 1st until the brine shrimp cyst density falls below 2 cysts/L (usually sometime in January). The cysts harvested from the GSL are used as food for larval fish and other crustaceans at fish and shrimp farms around the world

(Belovsky *et al.* 2011). The GSL contributes approximately 90% of the world's commercial harvest of brine shrimp (Treece 2000).

The value of the GSL is not just found in the commercial harvest of brine shrimp cysts but also in the migrating waterbirds the lake supports. Over 200 avian species migrate southward and make a stop at the GSL during the fall (Gwynn 2002). The abundant brine shrimp population provides forage for millions of birds annually. Eared Grebes (*Podiceps nigricollis*) are the most abundant species of waterbird to visit the GSL, with over half the North American population stopping at the GSL during the fall (Aldrich and Paul 2002). While on the GSL, Eared Grebes (hereafter referred to as grebes) undergo a definitive prebasic molt that renders them flightless, but they still manage to nearly double their body mass to prepare for migration (Cullen *et al.* 1999). Their diet consists of brine shrimp cysts, brine shrimp, brine flies, and brine fly larvae; however, their primary food is adult brine shrimp (Roberts and Conover 2013). As the adult brine shrimp population decreases with temperature, grebes consume more brine shrimp cysts. The commercial harvest of cysts is heavily monitored to ensure that there are enough cysts to produce a viable population in the following spring but, we have little information on the effects of waterbird consumption of brine shrimp cysts.

One way that the GSL Ecosystem Program monitors the brine shrimp cysts population is with measures of cyst hatchability and viability (K. Stone, Utah Division of Wildlife Resources, personal communication). Hatchability is the percentage of brine shrimp cysts that hatch into nauplii. Viability is the percentage of the brine shrimp cysts are in a condition conducive to hatching if the right environmental variables were present.

Previous studies have shown that a seed passing through the digestive tract of waterfowl aids in the scarification and germination of some wetland plant species such as *Bolboschoenus maritimus, Scirpus paludosus*, and *Najas marina* (Agami and Waisel 1986; Kettenring 2016; Muellar and van der Valk 2002). The chemicals of a duck's digestive system, as well as the grinding in their gizzards, help bring the wetland seeds out of dormancy (Kettenring 2016; Marty and Kettenring 2017). I hypothesize that a bird's digestive tract, due to chemical and physical abrasion, would be harmful for brine shrimp cysts. The hard-walls of brine shrimp cysts are there to protect the embryo, and if that wall were to degrade, or crack, I hypothesize it would be harmful to the embryo (Proctor 1964).

STUDY AREA

Utah's GSL is located in the Great Basin and is the fourth largest terminal lake in the world (Stephens 1990). The area of the lake varies with the balance of water inflow and evaporation paired with a gradually sloping shoreline. The highest recorded elevation of the lake was 1283.8 m above sea level, with an area of 5,950 km^2 in 1986 (Stephens and Birdsey Jr. 2002). At its current elevation of 1,278 m, the GSL occupies 3086 km^2 of water. The GSL is divided in half by the Southern Pacific Railroad Causeway: a dike that restricts water flow between the north and south arms, creating two very different sets of conditions on each side. The north arm of the lake (Gunnison Bay) is dominated by halophytic bacteria that gives it a pink hue, and it is too saline for brine shrimp or brine flies to survive (Aldrich and Paul 2002). The south arm of the lake (Gilbert Bay, Carrington Bay, Ogden Bay, and Farmington Bay) is where most of the freshwater flows

into the lake, creating a salinity that is half that of the north arm. This lower salinity allows brine shrimp and brine flies to thrive in a relatively simple food chain (Aldrich and Paul 2002). Nutrient inputs from the watershed are brought to the GSL by the Bear, Weber, or Jordan rivers or by runoff from the surrounding land. These nutrients are used by cyanobacteria, chlorophytes, and chryophytes. These organisms are consumed by brine shrimp in the lake. The brine shrimp are eaten by waterbirds, and the brine shrimp cysts are commercially harvested from the lake (Belovsky *et al.* 2011).

METHODS

Eared Grebes were captured on the south arm of the GSL during the fall of 2017 using a boat and a 91- x 3-m gill net using techniques similar to Caudell and Conover (2007). The gill net was made out of 4-kg-test monofilament and had a mesh size of 5- x 5-cm. Each end of the gill net was attached to a buoy. The net was packed into a plastic container so that one end of the net was at the bottom of the container and the other end of the net was at the top. The container with the net was placed in the back of the boat near the motor. Once a large group of grebes was spotted, I threw the buoy attached to one end of the net over the side of the boat, away from the motor. The driver of the boat would then quickly encircle the group of grebes, continuing until the net was fully deployed to create a semi-circle. The driver of the boat would then bring the boat towards the center of the net, encouraging the grebes to dive into the submerged gill net. Once we reached the net, it was quickly pulled into the boat. After the net was completely in the boat, any captured grebes were removed from the net. The grebe was placed in a plastic container with a small amount of freshwater until all grebes were out of the net. Each

grebe was banded, measured, and weighed. Sixteen of the grebes were kept in holding containers for transportation to a veterinarian who implanted a VHF transmitter into the body cavity of each grebe for a concurrent study. Grebes fitted with VHF transmitters were kept for 24 hours for observation and were returned to their capture site. During that 24 hours, the grebes defecated in their holding containers, providing us with a sample of cysts that had passed through their digestive tracks. The contents of each grebe's holding containers was placed in glass jars with 95% ethanol and kept on ice until processing.

For comparison, I took cyst samples from the GSL at grebe capture sites. I collected 10 samples from each capture site, one site on the south end of the GSL and one west of Antelope Island (Fig. 4–1). A vertical town net with a diameter of 50 cm and a mesh size of 153 µm was used to obtain cysts. The tow net was repeatedly submerged in the water and pulled up until a sufficient number of cysts were obtained. Each sample was labeled and put in a separate glass jar with ethanol and kept on ice for transport.

The contents of each sample were put through 500-µm and 150-µm sieves to filter out large debris, and then they were placed on filter paper. The cysts, along with the filter paper, were kept in whirl-pack bags to await processing. For each cyst sample, I tested 3 subsamples for hatchability and 3 subsamples for viability. A small amount of cysts was taken out of each whirl-pack and placed in a dish with tap water for approximately 30 minutes for hydration to occur. At the same time, petri dishes with liners and gridded Metricel membranes were also hydrated for 30 minutes. Each of the subsamples were given a unique number and recorded on the petri dish lid and data sheet. After 30 minutes, excess water was removed from the petri dishes. Approximately 200–300 cysts

were transferred from each sample to each petri dish using a pipette. An effort was made to distribute the cysts evenly over the gridded membrane.

To test for viability (hereafter viability test #1), 3 subsamples were counted after initial hydration. Each subsample was then covered with bleach to decapsulate the cysts. The bleach would destroy the embryo of any cyst with a broken shell. The subsamples were rinsed and drained and placed on another hydrated gridded Metricel membrane, and all intact cysts with embryos were counted through the microscope.

To determine hatchability, hydrated cysts were counted in each subsample under a microscope and recorded on the data sheet. The 3 subsamples had just enough water added to them to hydrate the membrane, but not to suspend the cysts. The subsamples were then placed in an incubator set at 21º C for 24 hours. After 24 hours, cysts that hatched into nauplii were counted in each of the subsamples and recorded on the data sheet. Then each cyst subsample was also tested for viability following the methods mentioned above. The cysts were collected in September and October, prior to a freezing event on the lake. Thus, a measure of hatchability was not indicative of the condition of the cysts after they passed through the grebes; instead, the second half of the hatchability test served as another test for viability (hereafter viability test #2).

I conducted an unpaired t-test to compare the viability of cysts samples that had passed through grebes to those that were obtained straight from the GSL in both viability test #1 and test #2. I also compared cyst viability from my two collection sites to determine if viability differed between GSL locations. *P*-values of $\alpha < 0.05$ were considered significant.

RESULTS

There were a total of 16 grebe cyst samples and 20 GSL cyst samples for a total of 36 samples. After eliminating the samples that did not contain enough cysts to run the tests, 33 samples remained. There was no significant difference between viability test #1 and test #2 ($t = 1.34$, $df = 52$, $P = 0.19$), so the results were combined and will hereafter be referred to as viability.

There was no significant difference in the GSL samples between the 2 sample site locations ($t = 0.13$, $df = 18$, $P = 0.90$). There was also no significant different in the cysts from grebes between the 2 capture site locations ($t = 0.89$, $df = 9$, $P = 0.41$). Hence samples from both locations were combined for further analysis. The analysis for viability had 13 samples from birds and 20 samples from the lake. Viability was significantly different ($t = 5.72$, $df = 31$, $P < 0.001$) between samples from grebes (30%) and samples from the GSL (63%). Viability of cysts in this study decreased by 52% if it passed through the digestive tract of a grebe.

DISCUSSION

I hypothesized that viability would decrease after passing through the digestive tract of a grebe, and this hypothesis was correct. There was a 52% decrease in the viability of cysts after they passed through a grebe's digestive tract. Roberts and Conover (2013) estimated grebes consumed between 832,200 and 978,100 kg of brine shrimp cysts throughout the months of October through December for the years 2010 and 2011. Assuming that the 30% of cysts that are viable after passing through a grebe's digestive

tract are returned to the lake via defecation, the other 70% of cysts (582,500–684,670 kg) are removed from the GSL by grebes every year. The cysts removed by grebes are only 5–7% of the cysts that are commercially harvested from the lake (Luft 2010, Luft 2011), indicating that grebes are likely not having a significant impact on the brine shrimp population of the GSL.

Although grebes decrease the viability of brine shrimp cysts, 30% of them were still viable and would have been able to hatch and reach maturity if defecated into a suitable waterbody. Other birds, such as mallards (*Anas platyrhynchos*) have been shown to transport spiny water nymph seeds (*Najas marina*) to other wetlands (Agami and Waisel 1986). The same could be possible with grebes and brine shrimp. Grebes could serve as transportation for brine shrimp, ingesting them on the GSL and defecating them into other bodies of water, which would be especially important as a mechanism to repopulate ephemeral waterbodies with brine shrimp. Brine shrimp native to the GSL have been discovered outside of their native range where they have outcompeted native invertebrate species (Green *et al.* 2005).

Unlike some plant seeds, brine shrimp cysts need their outer shell to protect the embryo inside until conditions are suitable for hatching. Hence, any cysts that are broken by the digestive system of a grebe are killed. There has been considerable debate if grebes gain any nutritional advantage from consuming cysts. I found that 70% of the consumed cysts were destroyed or broken by the digestive process, so the birds could digest the embryo within and gain nutrition from it, but would need to consume a copious amount of cysts to do so.

Brine shrimp numbers are heavily monitored by the GSL Ecosystem Program (GLSEP) as well as the viability of brine shrimp cysts. Once brine shrimp cysts fall below a threshold set by GSLEP, the harvest season is closed. It does not matter if it is grebes that are removing cysts or the commercial harvesters, both compete for cysts. However, the GSLEP should always consider the number of cysts consumed by birds in deciding when to close the season. If it were not for a program like GSLEP to monitor the brine shrimp population and commercial harvest, the GSL brine shrimp population would be less abundant.

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FIGURES

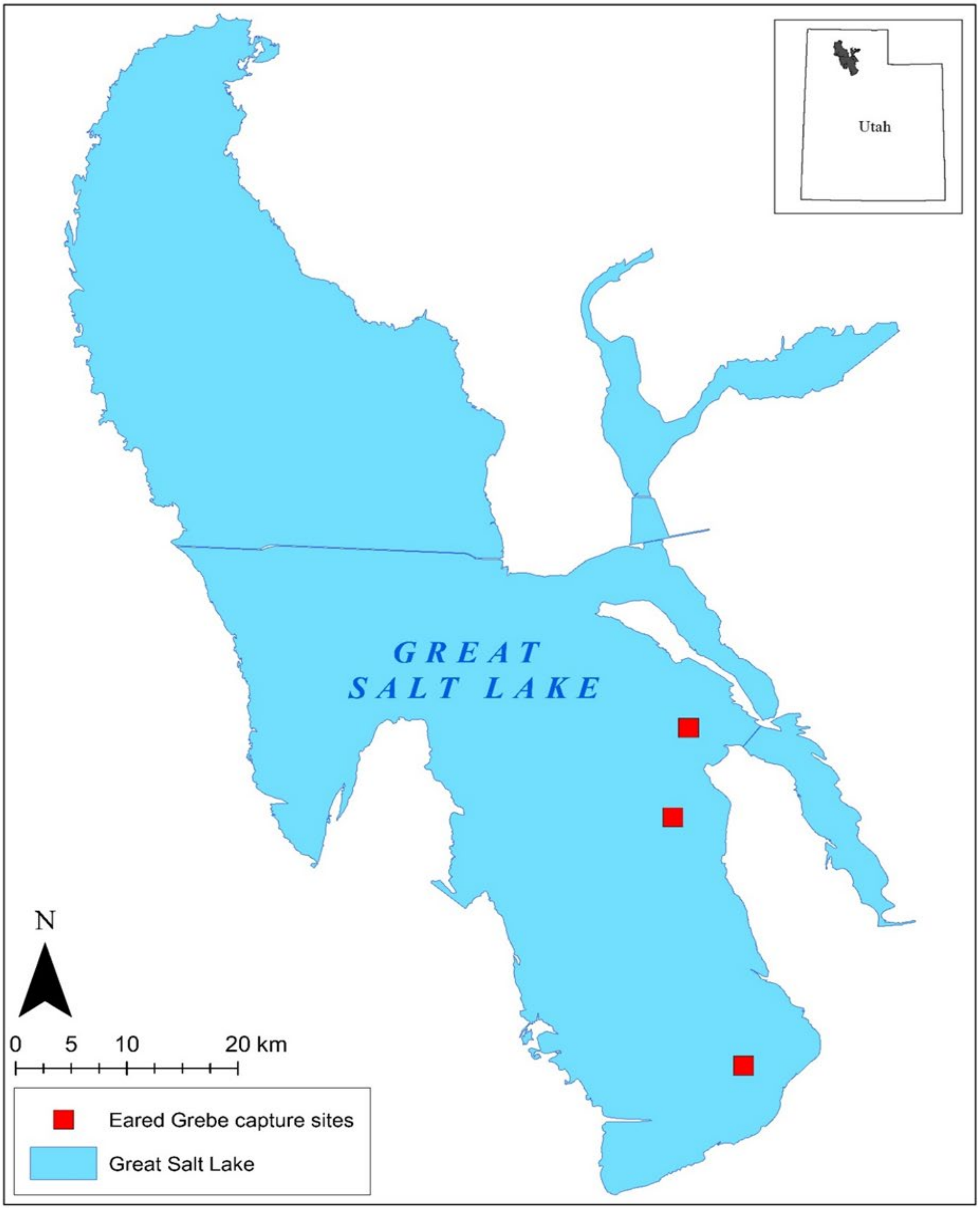

Figure 4–1. Capture sites for eared grebes during the fall of 2018 on the Great Salt Lake, Utah. Two grebes were captured from site 1, 9 grebes were captured from site 2, and 5 grebes were captured from site 3.

CHAPTER 5

DISCUSSION

DISCUSSION

It is important to manage for Eared Grebe (*Podiceps nigricollis*) nesting habitat around the Great Salt Lake (GSL). There are key differences between the colonies found in the literature at more northern latitudes compared to those around the GSL. I found that Eared Grebes (grebes) nesting around the GSL initiated nesting later than grebes in more northern colonies. When colonies were built on emergent vegetation such as *Typha* spp., *Scirpus* spp., *Chenopodium rubrum,* and *Shoenoplectus acutus,* initiation dates occurred in early May. These emergent species were not found at GSL colony sites; instead, colonies were established on mats of floating submerged aquatic vegetation (SAV) such as *Stuckenia pectinate* and *Ruppia cirrhosa*. Colonies elsewhere built on floating SAV mats began in late May. Nesting colonies in my study did not form until the month of June. The delay of nesting around the GSL could be due to the vegetation type upon which the nesting colony was built. Emergent vegetation is lacking in the waterbodies around the GSL except along the levees. The lack of emergent vegetation away from shore could explain why grebes choose SAV mats instead, and therefore nest later because grebes must wait for the floating mats to form. Warmer temperatures (>10º C) and water depths of 38–45 cm are required for SAV to thrive (Robel 1962, Yeo 1965). The GSL wetland impoundments are frozen throughout most of the winter. With warmer temperatures in the spring, the impoundments thaw and receive an influx of fresh water from snow melt, raising the water depth but keeping the water cold. Another possible

explanation for later nest initiation dates could be food abundance in colony wetlands. The cold water in the impoundments in the spring may slow the growth of invertebrates, delaying nesting. Floating mats of SAV were abundant in the impoundments I studied; therefore, there is no evidence that competition for suitable nest sites limits the size of the nesting population.

Mean clutch size around the GSL was significantly lower than one colony located elsewhere (Gray's Lake, Idaho). While the average clutch sizes of colonies found along the GSL was lower than anything found elsewhere, the standard deviation of 1 overlapped with the majority of the other colonies found in more northern latitudes. Clutch sizes can vary according to the quantity and quality of food available to females (Brockelman 1975). Daily energy requirements for female birds increase during egg-laying and multiple studies have shown a positive correlation between food abundance during egg-laying and clutch sizes (Korpimaki and Hakkarainen 1991, Bolton *et al*. 1993, Tinbergen and Dietz 1994, Tortosa *et al.* 2002). The lower clutch size on waterbodies around the GSL could suggest lower food abundance compared to the Gray's Lake colony site. Clutch size has been proven to be negatively correlated with nest initiation date which could also explain the lower average clutch size (Rohwer 1992).

I located 35 nesting colonies of grebes along the GSL containing over 4,280 grebe nests during the summer of 2018. The number of nests in each colony in my study was significantly greater than colonies in other studies. I also found the largest known grebe nesting colony (902 nests). Most of the waterbodies in my study contained >1 colony; something that was not commonly reported elsewhere. Grebes leaving nesting colonies around the GSL migrate to their fall staging ground, probably the GSL. If so, they have

<11 km to reach it. The adults in my study began leaving colony sites during the last week of July, later than birds reported in Jehl and Henry (2010), which began migrating as early as June 23. The later migration in my study is probably due to the late start of nesting. The juvenile grebes in my study migrated after the adults, similar to the findings of Jehl and Henry (2010).

Water depth showed up multiple times in models differentiating between occupied and unoccupied waterbodies, indicating that it is an important factor for second order habitat selection for nesting grebes. Grebes are diving waterbirds that dive to forage and avoid predation, which could explain the importance of water depth. Deeper water may also make it harder for common nest predators, raccoons (*Procyon lotor*) and red foxes (*Vulpes vulpes*), to reach the colony because they would have to swim to it. Percent cover of SAV showed up in a competing model for outside-colony sites and other wetlands, with outside-colony sites having 95–99% cover and other wetlands having 75–95% cover. The vegetation grebes chose to nest on around the GSL requires a water depth of 38–45 cm to become established (Robel 1962). It is possible that because the other wetlands in this study were shallow, the conditions were not conducive to adequate SAV cover. Grebes do not seem to be limited in colony sites, their third order of habitat, because the null model was the top model distinguishing between inside colonies and outside colonies. These results indicate the homogenous nature of impounded wetlands and suggest that the number of grebe colonies or the number of nesting grebes in a wetland is not limited by the availability of suitable nesting sites.

Promoting high invertebrate biomass density could also be important when managing for more grebe nesting habitat. Invertebrate biomass density was included in

the top performing model for inside-colony sites and other wetlands. Throughout nesting and brood rearing, grebes do not leave their colony wetland. Both sexes participate in incubation and once the eggs hatch, the chicks are unable to fly or swim, so they are confined to their parents' backs, which constrains a grebes' foraging locations to the wetland they chose to nest. This limited dispersal ability may explain why grebes prefer wetlands with higher invertebrate biomass densities. Distance to the GSL also showed up in the top performing model for inside-colony sites and other wetlands. The GSL is a fall-staging ground for grebes, and grebes may make their way there after nesting. The closer the nesting colony is to the GSL, the shorter their flight or swim to their fall-staging grounds. Wetland area showed up in both models distinguishing from occupied and unoccupied sites, indicating that grebes choose larger waterbodies to build their colonies

Distance from nearest emergent vegetation did not show up in any of the top performing models until I removed Willard Spur sites. Willard spur was the only natural wetland and was very large comparatively, impacting the distance measurements included in this study. To better manage for grebe nesting colonies, I think it is important to focus on providing a water depth that is ideal for producing plenty of SAV and improving invertebrate biomass density.

After comparing results from the GSL colonies to colonies found in the literature review, results showed that GSL nesting colonies were located in shallower lakes than those found elsewhere. Average water depth inside the colonies in this study was lower (48 cm) than other studies (50–190 cm). The lower water depth could be due to the nature of the impounded wetlands in this study. The vegetation in colonies around the GSL was similar to other colonies built on floating mats of SAV. Out of the 8 colonies that were

found in the literature review, 6 of them were built on emergent vegetation, something grebes around the GSL did not utilize. Emergent vegetation is lacking in the impounded wetlands around the GSL except along the levees. The lack of emergent vegetation away from shore could explain why grebes choose SAV mats instead.

When grebes leave their nesting grounds and move to the GSL, they are able to thrive on the brine shrimp population in the GSL before they continue on southward. Although grebes decrease the viability of brine shrimp cysts, 30% of them were still viable and would have been able to hatch and reach maturity if defecated into a suitable waterbody. Mallards have been shown to transport *Najas marina* seeds to other wetlands (Agami and Waisel 1986). Grebes could serve as transportation for brine shrimp, ingesting them on the GSL and defecating them into other bodies of water, which would be especially important as a mechanism to repopulate ephemeral waterbodies with brine shrimp. Brine shrimp native to the GSL have been discovered outside of their native range where they have outcompeted native species (Green et al. 2005).

Unlike some plant seeds, brine shrimp cysts need their outer shell to protect the embryo inside until conditions are suitable for hatching. Hence, any cysts that are broken by the digestive system of a grebe are killed. If grebes consume enough cysts, they could have an effect on the over-wintering cyst density in the GSL, which could also have an impact on the commercial harvest of brine shrimp cysts; however, grebes are only consuming 5-7% of cysts that are commercially harvested from the GSl.

Brine shrimp numbers are heavily monitored by the GSL Ecosystem Program (GLSEP) as well as the viability of brine shrimp cysts. Once brine shrimp cysts fall below a threshold set by GSLEP, the harvest season is closed. If it were not for a program

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APPENDIX

Table A–1: Clutch size variation in Eared Grebe nesting colonies around the Great Salt Lake, Utah during 2018.

Site	Colony	Clutch size						
		0	1	2	3	4	5	6
Farmington Bay, Waterbody 1	1	13	36	108	212	19	0	0
Farmington Bay, Waterbody 1	2	18	47	216	101	12	0	1
Farmington Bay, Waterbody 2	1	9	17	20	66	14	1	0
Farmington Bay, Waterbody 2	2	8	6	9	37	3	0	0
Farmington Bay, Waterbody 2	3	9	14	23	39	3	0	0
Farmington Bay, Turpin	1	3	3	27	35	2	0	0
Farmington Bay, Turpin	2	6	8	8	12	1	0	0
Farmington Bay, Turpin	3	3	4	13	22	4	0	0
Farmington Bay, Turpin	5	3	3	11	24	6	0	0
Ogden Bay	1	3	4	2	9	4	1	0
Ogden Bay	2	2	1	3	21	10	0	0
Ogden Bay	3	4	9	20	66	3	0	0
Ogden Bay	4	0	3	8	15	4	0	0
Ogden Bay	5	15	10	8	32	4	0	0
Ogden Bay	6	0	0	5	20	3	0	0
Rudy Duck Club	1	0	3	30	46	1	0	0
All GSL Colonies		96	168	511	757	93	2	1