12-2013

Winter Waterbird Ecology on the Great Salt Lake, Utah, and Interactions with Commercial Harvest of Brine Shrimp Cysts

Anthony J. Roberts
Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/etd

Part of the Animal Sciences Commons

Recommended Citation
https://digitalcommons.usu.edu/etd/2042

This Dissertation is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Theses and Dissertations by an authorized administrator of DigitalCommons@USU. For more information, please contact dylan.burns@usu.edu.
ABSTRACT

Winter Waterbird Ecology on the Great Salt Lake, Utah, and Interactions with Commercial Harvest of Brine Shrimp Cysts

by

Anthony J. Roberts, Doctor of Philosophy
Utah State University, 2013

Major Professor: Dr. Michael R. Conover
Department: Wildland Resources

My research examined wintering ecology of waterbirds on the Great Salt Lake (GSL), Utah, with special reference to interactions with the harvest of brine shrimp (Artemia franciscana) eggs (i.e. cysts). The GSL is an important body of water for many avian species due to its location in the arid Great Basin of the western U.S. In chapters 2 and 4, I examine variables that influence waterfowl and eared grebe (Podiceps nigricollis) populations, respectively. Northern shoveler (Anas clypeata) abundance was correlated with temperature while common goldeneye (Bucephala clangula) abundance was correlated with food availability. The presence of commercial harvest boats was not a factor in avian abundance or distribution.

In chapters 3 and 5, I examine diet of waterfowl and eared grebes, respectively, and calculate the removal of brine shrimp cysts by birds. Northern shovelers and green-winged teal (Anas crecca) varied their diet based on the time of year. Both consumed
wetland plant seeds in fall and spring, and salt-tolerant invertebrates throughout winter. Eared grebes consumed brine shrimp until December, when they increased consumption of cysts. Measurements of bird consumption rates indicated avian species removed less than 15% of the annual cysts removed by birds and the commercial harvest industry combined.

In Chapter 6, I examined downed eared grebes and those that still occupied the GSL. Eared grebes collected pre-downing were heavier (523 g) than deceased birds (433 g). Mercury (4.4-25.8 ppm) and selenium (1.8-7.2 ppm) concentrations in both downed birds and those collected at the GSL were above levels observed to impact bird species. Though heavy metal concentrations may have impacted survival of downed birds, bad weather likely caused the mass downing.

In Chapter 7 I used 2 data sources to describe the migratory connectivity of northern shovelers wintering on the GSL. Shovelers recovered at the GSL (n = 22) had been banded during the summer in southern Canada and northern Montana. Stable-isotope data placed the largest number of shovelers collected on the GSL as breeding in the western U.S. and southern Canada. Northern shovelers wintering on the GSL had shorter migration distances than conspecifics wintering elsewhere.
PUBLIC ABSTRACT

Winter Waterbird Ecology on the Great Salt Lake, Utah, and Interactions with Commercial Harvest of Brine Shrimp Cysts

by

Anthony J. Roberts, Doctor of Philosophy
Utah State University, 2013

Interactions among commercial fisheries and birds have been studied in open ocean ecosystems and at aquaculture facilities. On the Great Salt Lake (GSL), Utah, USA, a commercial harvest of brine shrimp (Artemia franciscana) eggs (i.e. cysts) occurs annually during fall and winter. Coinciding with commercial harvest is the use of the GSL by millions of waterbirds which has the potential to result in conflict among industry and birds. The objectives of my research were to examine fall and winter ecology of birds using the GSL and interactions with the brine shrimp cyst harvest. I examined the influence of temperature and food availability on the number and distribution of waterfowl and eared grebes (Podiceps nigricollis). I also assessed the diets of the same species to see how much cyst biomass is being consumed by birds compared to removal by commercial harvest. A mass die-off (i.e. downing) of migrating eared grebes occurred during my research, so I assessed differences among birds that died and those that did not to better explain this phenomenon. Finally, I assessed the breeding
origin of northern shovelers (*Anas clypeata*) wintering on the GSL using stable isotope and banding data.

I found that commercial harvest boats did not influence duck population numbers or distribution; rather temperature and food availability most influenced abundance and distribution, though this influence varied by species. Compared to commercial harvest, northern shovelers, green-winged teal (*Anas crecca*), and eared grebes removed a small fraction of the total amount of cysts that were removed from the GSL. Waterfowl diets were mainly wetland plant seeds during fall and spring, but when freshwater marshes were frozen in winter, ducks ate mostly brine shrimp cysts and brine fly (*Ephydra* spp.) larvae. Eared grebes are highly associated with saltwater habitats and they consumed adult brine shrimp most of the fall. Eared grebes that perished during the downing had mercury and selenium concentrations above levels seen in pre- and post-downing birds and higher than observed concentration that impact bird species, providing a potential ultimate cause of death during snowstorms that accompany most downings. Stable isotope analysis indicated northern shovelers that winter on the GSL had breeding origins throughout the specie’s range, but most came from local or southern Prairie Pothole Region breeding populations.
ACKNOWLEDGMENTS

I first want to thank all the guys at the Great Salt Lake Ecosystem Program for their tremendous assistance and patience, particularly when birds weren’t flying or things weren’t going to plan. My sincere gratitude to John Luft, John Neill, Kyle Stone, Phil Brown, and Jim Van Leeuwen. I wouldn’t be at this point if not for Dr. Mike Conover, my advisor and mentor. In addition, my graduate committee was of tremendous support throughout study formulation and dissertation writing. Thanks to Drs. John Bissonette, Dave Koons, Frank Howe, and Wayne Wurtsbaugh.

Josh Vest was a great help getting this project up and running and he was gracious enough to share his data to improve this work. Flights over the lake were all great thanks to Craig Hunt and Clair Shaffer. They always made the long air-time enjoyable and steady so airsickness was at a minimum. Numerous other state employees made my job easier by helping with collections, providing data, or allowing access. Particular thanks go to Tom Aldrich, Jodi Gardberg, and Rich Hansen. My lab technicians also decreased my work load and did a great job cutting up thousands of birds. I had the privilege to supervise Josh Easter, Konrad Hafen, Darren Johnson, Caleb Kauffman, Jordan Linnell, Kim Palmer, and Tara Nagaich.

The help and support in the graduate student community at USU is immense and there are too many people to thank individually. The statistical, methodological, academic, and writing support has helped this borderline PhD student make it through the program. Despite the lack of a “real” college town feel we have always found a way to
enjoy ourselves when we get some down time. With graduate student community support
and the great outdoors available at our doorstep, my time here feels short.

My family has supported me wherever I go and in whatever I do. Time back in
Nebraska would not be the same without Cody, Kory, Dylan, and Westen. A special
family thanks to my parents for everything they have done for me and their eagerness to
visit Utah when I can’t make it back, despite my often full schedule. I love you all.

Finally, a great big thanks and hug to Suzanne Gifford. She has been by my side,
literally or figuratively, through most of my time in Utah, and I’m glad she was. Her
caring and support have been indispensable.

Anthony Roberts
CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>PUBLIC ABSTRACT</td>
<td>iv</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xiv</td>
</tr>
<tr>
<td>CHAPTER</td>
<td></td>
</tr>
<tr>
<td>1. INTRODUCTION AND LITERATURE REVIEW</td>
<td>1</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>GREAT SALT LAKE</td>
<td>3</td>
</tr>
<tr>
<td>LITERATURE REVIEW</td>
<td>6</td>
</tr>
<tr>
<td>RESEARCH OBJECTIVES</td>
<td>14</td>
</tr>
<tr>
<td>LITERATURE CITED</td>
<td>14</td>
</tr>
<tr>
<td>2. ENVIRONMENTAL INFLUENCES ON WINTERING DUCK ABUNDANCE AND DISTRIBUTION AT A HYPERSALINE LAKE</td>
<td>22</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>22</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>23</td>
</tr>
<tr>
<td>STUDY AREA</td>
<td>25</td>
</tr>
<tr>
<td>METHODS</td>
<td>26</td>
</tr>
<tr>
<td>RESULTS</td>
<td>31</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>33</td>
</tr>
<tr>
<td>MANAGEMENT IMPLICATIONS</td>
<td>39</td>
</tr>
<tr>
<td>LITERATURE CITED</td>
<td>40</td>
</tr>
<tr>
<td>3. DIET AND BODY CONDITION OF DUCKS IN ASSOCIATION WITH COMMERCIAL HARVEST OF BRINE SHRIMP CYSTS</td>
<td>56</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>56</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>57</td>
</tr>
<tr>
<td>STUDY AREA</td>
<td>58</td>
</tr>
<tr>
<td>METHODS</td>
<td>60</td>
</tr>
<tr>
<td>RESULTS</td>
<td>63</td>
</tr>
</tbody>
</table>
### 4. POPULATION FLUCTUATIONS AND DISTRIBUTION OF STAGING EARED GREBES (*Podiceps nigricollis*) IN NORTH AMERICA

- **ABSTRACT:**
- **INTRODUCTION:**
- **MATERIALS AND METHODS:**
- **RESULTS:**
- **DISCUSSION:**
- **REFERENCES:**

---

### 5. EARED GREBE DIET ON GREAT SALT LAKE, UTAH, AND COMPETITION WITH THE COMMERCIAL HARVEST OF BRINE SHRIMP CYSTS

- **ABSTRACT:**
- **INTRODUCTION:**
- **STUDY AREA:**
- **METHODS:**
- **RESULTS:**
- **DISCUSSION:**
- **MANAGEMENT IMPLICATIONS:**
- **LITERATURE CITED:**

---

### 6. CAUSES OF EARED GREBE (*Podiceps nigricollis*) MORTALITY DURING A MASS DOWNING

- **ABSTRACT:**
- **INTRODUCTION:**
- **METHODS:**
- **RESULTS:**
- **DISCUSSION:**
- **LITERATURE CITED:**

---

### 7. MIGRATION PATTERNS AND NATAL ORIGINS OF NORTHERN SHOVELERS DERIVED FROM BANDING RECORDS AND STABLE ISOTOPES

- **ABSTRACT:**
- **INTRODUCTION:**
- **METHODS:**
- **RESULTS:**
- **DISCUSSION:**
- **LITERATURE CITED:**
LIST OF TABLES

Table | Page
--- | ---
2-1. Models of total duck, northern shoveler, and goldeneye abundance on the Great Salt Lake, Utah, used to determine relative variable importance. $K$ is the number of parameters estimated in the model and AICc is the second order Akaike’s Information Criterion used to rank models. AICc weights were used to determine which variables had the most influence on duck abundance on the Great Salt Lake over 5 winters from 2005 through 2012. Variables are lake-wide mean density of brine shrimp adults (bsadults), brine shrimp cysts (cysts), and brine fly larvae (bflarvae) during the week preceding each survey, and salinity (salinity) and average daytime (0900–1800) temperature ($^\circ$C; prevtemp) during the month preceding each survey, and the sum of temperature and wind severity measures during the month preceding each survey (severity). Adjusted $r^2$ values for each model show the percentage of the variance in the change in duck density accounted for by the predictive variables. ................................................................. 46

2-3. Relative variable importance and their associated parameter estimates for variables influencing density of total ducks, northern shovelers, and goldeneye species wintering on the Great Salt Lake, Utah. Abiotic variables are average temperature during the preceding month (TEMP), average temperature (rescaled to a minimum of 0) multiplied by average wind speed during the preceding month (SEVERITY), and average salinity during the preceding month (SALINTY). Biotic variables are current water column density of adult brine shrimp (BRINESHRIMP), brine shrimp cysts (BSCYSTS), and brine fly larvae (BFLARVAE). .................................................... 49

3-1. Wet weight of food consumed, % occurrence in esophagus, and aggregate wet weight % biomass in the diets of northern shovelers and green-winged teal collected from the Great Salt Lake, Utah, during the nonbreeding season (October through April) of three winters; 2009-2010, 2010-2011, and 2011-2012. Season dates are: fall (1 Oct-18 Nov), early winter (19 Nov-28 Dec), late winter (29 Dec-28 Feb), and spring (1 March-15 April). .............................................................................................. 77

3-2. Amount of cysts (kg) removed by two species of ducks and the commercial harvest industry during three winters and the percent of total kg removed by each species and the harvest industry. Seasons are fall (1 Oct-18 Nov), early winter (19 Nov-28 Dec), late winter (29 Dec-28 Feb), and spring (1 March-15 April). Commercial harvest season occurred from 1 October to 31 January each year and no harvest occurred during the spring season. Duck removal was calculated with the formula: (((food mass in the esophagus + food mass in the gizzard) x (proportion of food in the esophagus that was cysts) x (hours of daylight + 1 hour twilight + 4 hours required for food to pass through the digestive system) / (4 hours for food to pass through digestive
system x number of days per season)) x peak duck population during that period...

4-1. Estimated population size of fall staging Eared Grebes based on photo counts corrected for submerged birds from Great Salt Lake, Utah, and Mono Lake, California, during October, 1997-2012, and the % difference from the previous year within each staging area when possible. ................................................................. 107

4-2. Estimated Eared Grebe population (± SE; in thousands) on the Great Salt Lake, Utah, as derived from monthly stratified aerial survey counts, October–January, 2009–2012.................................................................................................................. 108

4-3. Densities of Eared Grebes (#/km²; EAGR), commercial brine shrimp cyst harvest boats (#/km²; Boats) and adult brine shrimp (#/L; Brine shrimp) in aerial survey strata within the Great Salt Lake, Utah during the commercial brine shrimp cyst harvest season, 2009–2011. Commercial harvest is not allowed in the Ogden stratum, so no boat densities were calculated................................................................. 109

4-4. Competitive (delta AIC < 2) models of change in abundance of Eared Grebes on the Great Salt Lake, Utah, October–December, 2009–2011. Eared Grebe abundance was modeled with density of all brine shrimp life stages (allstages), adult brine shrimp (bsadults), and cysts (cysts), and average salinity over the previous month (salinity), average low temperature during the previous month (prevtemp), and the density of commercial brine shrimp cyst harvest boats (boats).................................................. 110

5-1. Diet of eared grebes (percent occurrence and aggregate percent wet weight) collected from the Great Salt Lake, Utah, October–December 2010-2011....................... 131

5-2. Permutational multivariate analysis of variance model results for temporal and spatial factors influencing eared grebe diets on the Great Salt Lake, Utah, October-December 2010-2011. Regions are Antelope Island, Carrington Bay, Fremont Island, and Gilbert Bay. .................................................................................................................. 132

5-3. Aggregate percent wet weight biomass of the 3 most common food items found in the esophagus of eared grebes collected on the Great Salt Lake, Utah, October through December, 2010 and 2011.................................................................................. 133

5-4. Average biomass (g/bird) of food items removed from the esophagi and stomachs of eared grebes collected from the Great Salt Lake, Utah, 2010 and 2011...................... 134

5-5. Estimated amount of brine shrimp cysts (kg) consumed by eared grebes and reported harvested by the commercial harvest industry during 2 winters on the Great Salt Lake, Utah.................................................................................................................. 135

6-1. Mean (SD) of total and organ group weights (grams wet weight) from Eared Grebes
collected before, during, and after a downing event in Cedar City, Utah. Different letters within each row signify statistical differences (p < 0.05).

6-2. Mean (SD) of wet weight mercury (Hg; ppm) and selenium (Se; ppm), and the molar ratio (Se:Hg), measured in Eared Grebe livers collected before, during, and after a downing event in Cedar City, Utah (n = 15 for all groups).

7-1. Straight–line distance (km) between initial banding and final recovery sites for all recovered Northern Shovelers banded 15 May through 31 July and recovered 1 Dec through 28 February, 1926–2012, in the Central and Pacific flyways of the US and Mexico.
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1. Map of the Great Salt Lake, Utah, including principle bays and islands.</td>
<td>21</td>
</tr>
<tr>
<td>2-1. Map of the Great Salt Lake, Utah, and the strata used in aerial surveys of wintering duck populations. Gunnison Bay was not surveyed or used in analysis as it is hypersaline and does not support populations of birds or salt-tolerant invertebrates. Green circles are the 17 sampling sites used by Utah Division of Wildlife Resources to sample limnological measurements at a weekly basis. Red triangles were used to supplement UDWR data and determine salinity measurements of the Bear River and Farmington aerial survey strata.</td>
<td>50</td>
</tr>
<tr>
<td>2-2. Average temperature during the 30 days preceding an aerial survey had a positive influence on the change in density of total waterfowl on the Great Salt Lake, Utah. Data were collected during 5 winters from 2004-05 to 2011-12. Change in density is the difference from the previous month within each of 7 strata.</td>
<td>51</td>
</tr>
<tr>
<td>2-3. Proportion of birds that occurred in 3 categories of access to freshwater for (a) total ducks and (b) northern shovelers on the Great Salt Lake, Utah. Proportion of total ha of the Great Salt Lake within each category were 0.20 (brackish), 0.23 (adjacent), and 0.57 (non-adjacent). Access to freshwater categories were assigned brackish (adjacent to freshwater inflow and average salinity &lt;5%), adjacent (adjacent to freshwater inflow and average salinity &gt;5%), and non-adjacent (not adjacent to freshwater inflow sources). Bold lines are the means of all months surveyed (n = 19, December–March, 2004-2012), box boundaries are 25% and 75% of total observations, and whisker extents are lowest and highest observed proportions.</td>
<td>53</td>
</tr>
<tr>
<td>2-4. Distribution of harvest boats and total ducks on the Great Salt Lake during December of 2011 that illustrates the average distribution of both. Gray scale is the density of harvest boats (#/km(^2)) measured by the Utah Division of Wildlife Resources during aerial surveys. Lines are random transects used during December 2011 aerial surveys and darker colors represent more total ducks observed during aerial surveys.</td>
<td>54</td>
</tr>
<tr>
<td>2-5. Influence of 3 levels of salinity on wintering distribution of goldeneye species on the Great Salt Lake, Utah. Salinity categories were long-term salinity measurements within strata that were high (≥8%), medium (3-8% salinity), or low (≤3%). Proportion of total ha within the Great Salt Lake of each category were 0.68 (high), 0.24 (medium), and 0.08 (low). Data were collected during 5 winters from 2004-05 to 2011-12. Bold lines are the means of all months surveyed (n = 19, December–March, 2004-2012), box boundaries are 25% and 75% of total observations, and</td>
<td></td>
</tr>
</tbody>
</table>
whisker extents are lowest and highest observed proportions.

3-1. Map of the Great Salt Lake, Utah and principle bays mentioned in the text.

3-2. Aggregate % wet weight of diet items removed from northern shovelers and green-winged teal collected on the Great Salt Lake, Utah. Ducks were collected 1 October through 15 April in 2009-2010, 2010-2011, and 2011-2012. Seasons are fall (1 Oct–18 Nov), early winter (19 Nov–28 Dec), late winter (29 Dec–28 Feb), and spring (1 March–15 April).

3-3. Body condition (body weight standardized to body and wing length) of northern shovelers (a) and green-winged teal (b) collected on the Great Salt Lake, Utah throughout the nonbreeding season in 2009-2010, 2010-2011, and 2011-2012. No green-winged teal were measured during early and late winter 2010-2011. Seasons are fall (1 Oct–18 Nov), early winter (19 Nov–28 Dec), late winter (29 Dec–28 Feb), and spring (1 March–15 April). Error bars represent 95% confidence intervals.

4-1. Map of Great Salt Lake, Utah and aerial survey strata used to enumerate Eared Grebe population abundance and distribution.

4-2. Plot of estimated Eared Grebe populations on Great Salt Lake, Utah and Mono Lake, California. Estimates were calculated from annual October aerial photography surveys conducted since 1997.

5-1. Map of Great Salt Lake, Utah and principle bays and islands mentioned in the text.

5-2. Mean brine shrimp densities (A) within the Great Salt Lake, Utah and mass of eared grebes collected (B) during the fall, 1 October through 28 December, 2010 and 2011. Short dashed lines are 2010, and long dashed lines are 2011.

5-3. Mean weight of stomach, one side of breast muscle, and large and small intestines of eared grebes collected from the Great Salt Lake, Utah, October through December 2011.

7-1. Distribution of likelihood-based assignment of stable hydrogen isotope flight feather ratios from Northern Shovelers collected from the Great Salt Lake, Utah, USA. Stable hydrogen isotope ratios (²H to ¹H) measurements were taken from one flight feather of Northern Shovelers collected from December–February, 2009–2011 (n = 113). Banding locations (circles; n = 22) of Northern Shovelers recovered on the Great Salt Lake during winter show the pattern of natal origin of Northern Shovelers wintering on the Great Salt Lake.

7-2. Banding location of Northern Shovelers recovered in California’s Central Valley
(green triangles; \( n = 474 \)), and the Texas Gulf Coast (red diamonds; \( n = 88 \)) during winter in relation to the Great Salt Lake, Utah. The distribution of banding locations shows natal origin of Northern Shovelers wintering across the Pacific and Central flyways and indicates birds originated from across their range rather than a specific geographic area.

7-3. Histogram of stable carbon isotope ratios in flight feathers from Northern Shovelers wintering on the Great Salt Lake, Utah, December–February, 2010–2011. Stable carbon isotope ratios were used to assign molting area where feathers were grown as either a freshwater \((<-20\%o)\) or saline \((>-20\%o)\) habitat \((n = 25)\).
INTRODUCTION

The Great Salt Lake (GSL), Utah is a large, dynamic, ecosystem set in an expanse of arid landscape. It is a large lake in a landscape mostly devoid of permanent water sources and offers food and resting areas for millions of birds throughout the year. The GSL is internationally recognized as a Site of Hemispheric Importance in the Western Hemisphere Shorebird Reserve, one of only six in the US. It is also an important economic resource for the State of Utah and the region providing mineral extraction, recreation, and lake–effect snow for the adjacent mountains. In addition, a commercial fishery occurs on open waters of the GSL during fall and winter that is regulated to maintain the health of the lake and provide resources for both wildlife and human consumers.

Interactions among avian populations and commercial fisheries are most often associated with ocean fisheries and seabird populations (Tasker et al. 2000) or aquaculture facilities and piscivorous birds (Price and Nickum 1995). Both commercial harvesters and avian consumers of fisheries resources may adversely impact each other’s use of that resource. Commercial fisheries may reduce food abundance available to birds or aquatic birds may impact the fishery industry when they forage on the resource, and reduce harvestable biomass. On the GSL, a commercial harvest of brine shrimp (*Artemia franciscana*) eggs (i.e. cysts) is conducted annually from October through January. Brine shrimp are a salt-tolerant invertebrate that thrives in the GSL’s highly saline water and
produce large numbers of cysts. Many cysts float to the surface and are concentrated by water currents and winds into masses, called streaks. An average of 9.5 million kg of wet weight cysts and other biomass is removed annually from the GSL (Great Salt Lake Ecosystem Program 2012), resulting in an annual economic effect to the Salt Lake City area of >$56 million (Bioeconomics 2012). Harvested cysts are used around the world in aquaculture facilities where they are hatched and fed to larval shrimp and fish. Though cysts are harvested in many places, the GSL consistently produces the largest biomass and the most consistent nutritional quality of cysts, and may provide up to 90% of the world’s supply of brine shrimp cysts (Kuehn 2002). Because cysts form large, concentrated, masses on the GSL, both human and avian consumers can easily access large quantities.

The GSL supports a diverse avian community throughout the year (Aldrich and Paul 2002). Migratory populations of waterfowl, shorebirds, and waterbirds rely on the GSL as a highly productive ecosystem that provides a unique place to rest and build fat reserves for continued migration. The extensive wetlands and drainages associated with the GSL provide stopover, migratory, and wintering sites for hundreds of thousands of birds each year. During the winter months, large numbers of green-winged teal (Anas crecca), northern shovelers (Anas clypeata), and common goldeneye (Bucephala clangula) utilize the open waters of the lake. When other food sources are limited once freshwater areas around the GSL freeze, these birds may be foraging on brine shrimp cysts or the larvae of brine flies (Ephydra spp.), another salt-tolerant invertebrate found in the GSL. Adult brine shrimp and their cysts may be one of the primary food resources
for birds foraging on the GSL during the non-breeding season but detailed descriptions of avian use of this resource are limited.

Information regarding avian use of GSL and its resources is needed by managers to assist with continued management and conservation actions regarding GSL brine shrimp. The GSL is under increased stress from a variety of anthropogenic activities such as water diversion, increased nutrient loads, high concentrations of selenium and mercury, and climate change. The primary objectives of this research were to determine if commercial cyst harvest has an effect on fall migrating and wintering avian populations and examine whether cyst harvest, with its resulting impacts on the spatial distribution and density of cysts, influences foraging dynamics and population distribution of birds on the GSL.

**GREAT SALT LAKE**

The GSL is a large, saline lake in the Great Basin of the western U.S. (Fig. 1-1). The entire GSL ecosystem covers nearly 780,000 ha and consists of saline open water, brackish water wetlands, and upland areas (Aldrich and Paul 2002). Brackish and freshwater marshes border the GSL, especially on the east shore on deltas of the Bear, Weber, Ogden, and Jordan rivers. Salinity across the GSL is variable due to concentrated areas of freshwater inflow and anthropogenic alterations of water exchange, most notably the Southern Pacific Railroad Causeway and the Antelope Island Causeway (Rich 2002). Salinity within Gunnison Bay is near saturation (27%), and aerial surveys have not found much use of Gunnison Bay by avian species (Vest 2009). Within the southern arm of the GSL, typical salinities are highest in Gilbert Bay, followed by Ogden, Farmington, and
Bear River bays. The GSL can experience large swings in surface elevation due to climatic conditions, particularly snowpack. These fluctuations in water level alter the surface area that can be used by birds, change the distribution of invertebrate prey, and change the salinities, and hence osmoregulatory demands, within the GSL ecosystem.

The high salinities in the pelagic areas of Gilbert Bay support populations of only two macroinvertebrates, brine shrimp and brine flies. Brine shrimp hatch from overwintered cysts in the spring as water temperature increases, then progress through three stages of increasing size: naupuli, juveniles, and adults. Juveniles and adults graze on phytoplankton and reach peak numbers in early summer, before decreasing as they reduce their food supply (Stephens and Birdsey 2002). There is a second, smaller, peak in adult brine shrimp abundance in late summer after a rebound of phytoplankton in GSL waters. Throughout summer most reproduction is ovoviparious where eggs hatch in the ovisac and young are released into the water. In fall, when food levels drop to levels too low for juvenile or adult survival, oviparity, or the production of diapausing cysts, is the primary reproductive mechanism. Most cysts in the GSL float and form large streaks that may remain over winter on the water’s surface, or may be deposited on beaches, and hatch the following spring. Densities of brine shrimp and their cysts vary across the GSL; their numbers are lowest in the hypersaline Gunnison Bay and bays with the lowest salinity, such as Farmington and Bear River bays (Stephens and Birdsey 2002).

Adult brine flies emerge from the waters of the GSL throughout summer but adults live on average less than one week. Females deposit single eggs on the water’s surface which then attach to any substrate that is contacted. Larvae hatch 5 to 6 days
later, go through 3 life stages of increasing size, then pupate until conditions are right for emergence (Collins 1980). Brine fly larvae are found primarily along the substrates of the GSL that are above an anoxic deep brine water layer; larvae densities are ten times greater on carbonate reefs (bioherms) and mud substrates than on sand substrates (Collins 1980). In fresh and brackish water marshes that border the GSL, a variety of aquatic macroinvertebrates are present (Cavitt 2006). During wet years, and in freshwater influenced areas such as Farmington and Ogden Bays, common invertebrate families available to foraging birds include Corixidae and Chironomidae.

Each year millions of waterbirds arrive at the GSL to forage on the salt-tolerant invertebrates within the open water and abundant freshwater invertebrates in the surrounding marshes. The low gradient bottom of the GSL and highly variable water levels results in expansive mudflats that create highly productive habitats where many avian species forage on a variety of aquatic invertebrates and wetland plant seeds. Notable breeding birds that use the GSL include the American white pelican (Pelecanus erythrorhynchos), California gull (Larus californicus), American avocet (Recurvirostra americana), black-necked stilt (Himantopus mexicanus), and white-faced ibis (Plegadis chili; Aldrich and Paul 2002). Monthly avian counts during migration on the GSL go as high as 700,000 waterfowl and 500,000 shorebirds, including more American avocets and black-necked stilts than any other wetland in the Pacific Flyway (Aldrich and Paul 2002). The GSL is also an important staging area for Wilson’s phalaropes (Phalaropus tricolor), red-necked phalaropes (P. lobatus), and marbled godwits (Limosa fedoa; Aldrich and Paul 2002). Wilson’s phalarope population densities were the primary factor in the
designation of the GSL as a site within the Western Hemisphere’s Shorebird Reserve Network. The GSL also hosts over half of the North American population of eared grebes (*Podiceps nigricollis*) during fall and early winter. During the winter months, large numbers of green-winged teal, northern shovelers, and common goldeneye utilize the open waters of the GSL.

**LITERATURE REVIEW**

It is clear from previous research that avian species feed extensively on the primary invertebrates within the GSL ecosystem (Roberts 2013), but data are insufficient to assess the temporal and spatial use of brine shrimp cysts by birds and the potential overlap among avian and human brine shrimp consumers. Knowledge of avian diets and population abundance is fundamental to continued management of avian populations on the GSL. High estimates of bird abundance during December and January indicate the GSL is a notable wintering site in addition to its significance to migrating birds, and winter is also the season when commercial cyst harvest occurs. Overlapping temporal use of brine shrimp cysts may create conflict among commercial harvesters and avian consumers.

Eared grebes are associated with saline lakes more than any other avian species in North America. The largest concentrations of eared grebes on the GSL occur during fall migration when 1.5 million individuals, or over half of the North American population, stage at the GSL (Aldrich and Paul 2002). While staging, eared grebe’s flight muscles atrophy and digestive organs increase in size resulting in flightlessness (Jehl 1988). Fall staging is also the period when adult birds molt. Prior to leaving the GSL in early winter,
eared grebes build up fat reserves and organ trends reverse (Jehl 1988). All food habit studies of eared grebes on the GSL have been conducted during migration and staging and have reported that adult brine shrimp were the principle item in eared grebe diets. During the early fall, eared grebes consumed both brine shrimp and brine fly adults (Paul 1996, Cullen et al. 1999, Conover and Vest 2009a); by late November, collected eared grebes were eating exclusively brine shrimp (Conover and Vest 2009a). This coincides with the die-off of adult brine flies and the last peak of adult brine shrimp before conditions become unsuitable for adult brine shrimp survival. Eared grebes living at another western U.S. saline lake, Mono Lake, have been shown to adjust diets based on food availability. Four years of data (1981-1984) from Mono Lake showed that eared grebes fed primarily on the most abundant prey items. Brine fly larvae and pupae dominated diets from mid-winter through May; when adult brine shrimp became abundant in June eared grebes relied on this resource (Jehl 1988). Throughout the summer and fall, when adult brine flies emerged in large numbers, they were the preferred food source (Jehl 1988).

Estimates of brine shrimp abundance needed for continued support of eared grebe populations have been calculated previously. Conover and Caudell (2008) estimated eared grebes needed a minimum adult brine shrimp density of 0.38 shrimp/L to maintain body mass. A decrease in densities of brine shrimp below these densities would have large consequences on individual survival of eared grebes. Belovsky et al. (2011) hypothesized a higher density of adult brine shrimp (5.80 adult brine shrimp/L) was needed to maintain and increase eared grebe body mass for migration from the GSL.
Within the GSL, Gilbert Bay currently supports brine shrimp abundances above both estimates, but Gunnison Bay does not, which may be why eared grebes are not seen there. The decline of adult brine shrimp numbers in late fall is likely an indicator for eared grebes to start decreasing organ weight and increasing flight muscle size. The timing of body condition changes have been linked to changing abundance of adult brine shrimp in the GSL (Caudell and Conover 2006, Jehl 2007).

Waterfowl are most abundant on the GSL during the fall and spring migrations. During these times, many of the Pacific Flyway waterfowl use the lake as a staging area. It has been estimated that 3–5 million ducks pass through the GSL each year (Bellrose 1976), and surveys of state and federal management areas along the GSL show that nearly 700,000 are present on these areas in September alone (Aldrich and Paul 2002). Fall is the time when food production in management areas and less saline waters in Bear River and Farmington bays peaks. Wetland plants such as alkali bulrush (Scirpus maritimus) and sago pondweed (Stuckenia pectinata), and invertebrate availability is high during the fall, and waterfowl are able to consume large numbers of seeds. Waterfowl also breed extensively in the freshwater marshes around the lake, and the GSL is recognized as a key breeding area for cinnamon teal (Anas cyanoptera), redhead (Aythya americana), and gadwall (Anas strepera, Aldrich and Paul 2002). Up to 20,000 ducks spend the winter in pelagic areas of the GSL (Vest 2009), utilizing the predator-free open waters of the lake. These birds feed on the abundant brine shrimp cysts that are easily accessible in large streaks, or on abundant brine fly larvae on benthic substrates (Vest and Conover 2011).
Waterfowl diet studies on pelagic areas of the GSL are restricted to one recent investigation. Vest and Conover (2011) examined diets of northern shoveler, green-winged teal, and common goldeneye over two consecutive winters from 2004-2006. Common goldeneye utilized brine fly larvae for up to 77% of their diet throughout the winter, with brine shrimp cysts, freshwater invertebrates, and wetland plant seeds providing the remainder of the diet (Vest and Conover 2011). Wetland plant seeds, particularly widgeon grass (*Ruppia maritima*) and alkali bulrush, were consumed more during the month of March, as ice cover retreated and birds moved into brackish marshes where seeds could be found. Female common goldeneye consumed more freshwater invertebrates than males during both years of the study (Vest and Conover 2011), likely because females need more nutrients for egg production than males.

Northern shovelers and green-winged teal relied on brine shrimp cysts during the coldest months, December–February (Vest and Conover 2011). Brine shrimp cysts comprised 80% of the aggregate percent biomass of green-winged teal diets, and nearly 52% of northern shoveler diets from October through March. During fall migration, when birds were mostly using freshwater areas, birds relied on wetland plant seeds, such as alkali bulrush and widgeon grass, and freshwater invertebrates for their nutritional needs (Vest and Conover 2011). Wintering northern shovelers and green-winged teal need daily access to freshwater, restricting their range within the GSL system to areas close to freshwater inflows. Freshwater inflow sites likely have higher populations of freshwater invertebrates, increasing the overall percent of freshwater invertebrates and plant seeds in
the diet of northern shovelers and green-winged teal, up to 100% in late fall and early winter (Vest and Conover 2011).

The few food types available to ducks on open waters of the GSL are higher in energy than foods typically utilized by wintering waterfowl. Brine flies and brine shrimp offer about 22 kJ/g of dry weight in gross energy (Caudell and Conover 2006) compared to 10 kJ/g in saltwater amphipods (Ballard et al. 2004), 17 kJ/g in marine gastropods (Jorde and Owen 1988), and 5 kJ/g in the seeds of lamb’s quarter (Chenopodium album) and alkali bulrush (Dugger et al. 2007). Though brine shrimp cysts have high protein content (64% of organic content), the shell of cysts is resilient to digestive enzymes (Horne 1966) so that ducks are unable to break the shell and utilize the energy of half the ingested cysts (MacDonald 1980). Despite this, cysts are still a valuable food resource to wintering ducks as it is the only available food source on open waters of the GSL in winter (Vest and Conover 2011).

Tietje and Teer (1988) observed that northern shoveler body weight and fat levels were higher in freshwater habitats compared to saltwater habitats along the Texas coast. The one exception to that finding was during the coldest observed periods of their study when northern shovelers in saltwater habitats were in better condition than shovelers in freshwater habitats. This was thought to be a result of ducks consuming more high-energy animal matter available in saltwater habitats during cold periods compared to the lower-energy plant matter available to ducks in freshwater habitats (Tietje and Teer 1988). In contrast, mallards (Anas platyrhynchos) and northern pintails (Anas acuta) wintering in California had consistently higher body weights in brackish habitats
compared to freshwater marshes, even though birds in both areas were eating wetland plant seeds (Miller et al. 2009). On the GSL, shovlers consume high-energy animal matter throughout the winter which may result in higher body condition than conspecifics in other wintering areas.

Many avian species have shown an increase in mercury concentrations after arrival on the GSL. Mercury concentrations in northern shovelers (Vest et al. 2009), common goldeneye (Vest et al. 2009), and eared grebes (Conover and Vest 2009a) increased from the bird’s arrival through late winter or migration. These data suggest these contaminants are ingested while on the GSL, and bioaccumulation of mercury has been demonstrated within the ecosystem (Naftz et al. 2008). Some individual birds have shown high levels of mercury early in the fall, soon after populations start arriving to the GSL (Vest et al. 2009), indicating some birds quickly accumulate mercury after arrival, or the birds are obtaining these contaminants elsewhere. In 2005, Utah was one of the first states to issue a waterfowl consumption advisory due to mercury levels in waterfowl breast muscle that exceeded safe levels for human consumption (Utah Division of Wildlife Resources 2005, Vest et al. 2009). Species covered under the consumption advisory were northern shoveler, common goldeneye, and cinnamon teal. High concentrations of trace elements such as mercury or selenium may result in decreased muscle coordination (Eisler 1987, 2000) or cause behavioral changes (Frederick et al. 2004, Hoffman et al. 2011). In birds, mercury levels can cause harmful effects at concentrations starting at 0.2-0.5 ppm (Eisler 1987, Yeardley et al. 1998), well below concentrations observed in eared grebes (Conover and Vest 2009a, Darnall and Miles
2009, Burger et al. 2013), waterfowl (Vest et al. 2009), and California gulls (Conover and Vest 2009b) on the GSL.

Selenium is an essential trace element but at toxic levels can cause deformities, lower hatching rates, and increased infertile eggs in birds (Eisler 2000). Selenium and mercury interactions may synergistically reduce the bioavailability or toxicity of the other (Belzile et al. 2005, Ralston et al. 2008), so increased concentrations do not necessarily result in harmful effects. Previous research suggests that during the staging period from September through December, as Eared Grebes undergo physiological changes, the selenium to mercury ratio increases and toxicity impact of selenium and mercury declines (Burger et al. 2013). Lower toxicity is critical as Eared Grebes approach the time for migration flights to wintering grounds as neurological links to muscles and muscle coordination are vital to a successful flight. Despite the low selenium to mercury ratios seen in previous research, no studies of waterbirds on the GSL have shown adverse effects due to mercury or selenium toxicity (Jehl 1988, Conover and Vest 2009a).

The open waters of the GSL offer a predator-free, prey-rich environment for waterbirds during critical times of the year. The importance to birds of the two salt-tolerant invertebrates that live within the lake, brine shrimp and brine flies, cannot be overstated. Loss of water from irrigation, urbanization, or mineral extraction reduces long-term water input into the GSL. Loss of water and the subsequent increase in salinity decreases phytoplankton abundance in the GSL, which in turn decreases brine shrimp and brine fly abundance (Belovsky et al. 2011). Lower densities of these invertebrate species would likely impact all avian species using the GSL.
One striking example of the adverse impact that higher salinity can have on the avian community is provided by the separated Gunnison Bay of the GSL (Fig. 1-1). A railroad causeway was completed in 1959 across the GSL, cutting Gunnison Bay off from the rest of the GSL. Gunnison Bay receives only small amounts of freshwater inflow and soon after the causeway construction it increased in salinity to near saturation (25%). The resulting salinity was too high for brine fly and brine shrimp populations to persist, and there are no other food sources available for birds in Gunnison Bay (Aldrich and Paul 2002). Aerial surveys of Gunnison Bay from 2006 to 2008 found few birds in an area that may have supported hundreds of thousands of birds before alteration of the ecosystem (Vest 2009).

On the GSL, the avian community may be competing with commercial harvest for brine shrimp cysts during the critical fall and winter periods. The ecology of birds utilizing these resources needs to be fully articulated to understand the impact of avian species on the GSL food web and its associated industry. Due to their abundance and residence times, eared grebes and northern shovelers are the most dependent on cysts and the most likely to come into conflict with, or negatively impact, industrial operations. Outside of Mono Lake (Cooper et al. 1994), there have been no extensive studies of avian community impacts on saline food webs. Brine shrimp cysts are harvested from several other saline lakes around the world and other avian species such as flamingos (Phoenicopterus ruber) and shelducks (Tadorna spp.) compete with commercial harvesters for the cysts (Savage 1967, MacDonald 1980). Despite the importance of the GSL to avian species, surprisingly little is known about the avian ecology on the GSL.
Continued research on the GSL and other saline lakes around the world is needed so that humans can use and manage these resources in a sustainable and ecological responsibility manner.

**RESEARCH OBJECTIVES**

I addressed six objectives in consideration of the wintering ecology of waterbirds using the GSL in association with the commercial harvest of brine shrimp cysts: 1) Estimate abundance of wintering waterfowl on GSL and determine what factors impact abundance and distribution while on the GSL. 2) Estimate monthly abundance of eared grebes on the GSL and yearly population fluctuations on the GSL and Mono Lake and environmental factors that impact population abundance and distribution. 3) Document food habits of waterfowl utilizing the GSL during fall and winter and identify overlap of brine shrimp cyst use with the commercial harvest industry. 4) Quantify food habits of eared grebes and measure the removal of brine shrimp cysts by eared grebes from the GSL. 5) Describe differences in deceased migrating eared grebes in comparison to eared grebes that still occupied the GSL ecosystem to determine potential causes of mortality, including the impact of heavy metal toxicity. 6) Examine breeding origin of waterfowl wintering on the GSL to help monitor population changes and evaluate sources of mercury and selenium outside of the GSL ecosystem.

**LITERATURE CITED**

in J. W. Gwynn, editor. Great Salt Lake: an overview of change. Utah Department of Natural Resources and Utah Geological Survey Special Publication, Salt Lake City, Utah, USA.


Caudell, J. N., and M. R. Conover. 2006. Energy content and digestibility of brine shrimp
(Artemia franciscana) and other prey items of eared grebes (Podiceps nigricollis) on the Great Salt Lake, Utah. Biological Conservation 130:251–254.


Darnall, N. L., and Miles, K. 2009. Dynamics of mercury in eared grebes on Great Salt
Lake. Page 50 in Saline lakes around the world: unique systems with unique values, A. Oren, D. Naftz, P. Palacios, and W. A. Wurtsbaugh, editors. Natural Resources and Environmental Issues No. 15, Salt Lake City, Utah, USA.


Naftz, D., C. Angeroth, T. Kenney, B. Waddell, N. Darnell, S. Silva, C. Perschon, and J.

Paul, D. S. 1996. 1996 eared grebe progress report. Utah Department of Natural Resources, Division of Wildlife Resources, Salt Lake City, Utah, USA.


Vest, J. L. 2009. Overwinter ecology of ducks and other waterbirds. Performance report to Utah Division of Wildlife Resources. Salt Lake City, Utah, USA.


Figure 1-1. Map of the Great Salt Lake, Utah, including principle bays and islands.
CHAPTER 2
ENVIRONMENTAL INFLUENCES ON WINTERING DUCK ABUNDANCE AND DISTRIBUTION AT A HYPERSALINE LAKE

ABSTRACT North American waterfowl winter throughout a large geographic area and the choice of wintering site has a direct impact on survival and fitness. Climatic and food variables are the most commonly cited factors influencing abundance and distribution of wintering migratory birds, including waterfowl. I conducted stratified aerial surveys at a northern latitude wintering site, Great Salt Lake (GSL), Utah, to examine the influence of weather, salinity, and food over 5 winters on the density and distribution of total ducks, northern shovelers (*Anas clypeata*), and goldeneye (common [*Bucephala clangula*] and Barrow’s [*Bucephala islandica*]). Total duck ($r^2 = 0.06$) and northern shoveler ($r^2 = 0.07$) density was most influenced by air temperature, within the variables I examined, with colder weather associated with decreased density. Goldeneye are more resilient to both higher salinity and colder temperatures than northern shovelers, and density of food in the water column was relatively more important in models of goldeneye density. Distribution of total ducks was best explained by low salinity and access to freshwater, which is vital in the ability of birds to osmoregulate in a hypersaline system. Ice cover does not occur on hypersaline bays of the GSL and does not limit winter food and habitat availability, contrary to studies conducted previously at other North American wintering areas. My results are consistent with previous findings that ambient air temperature is a primary factor influencing the abundance of wintering waterfowl. I hypothesize that ducks endure the cold, hypersaline conditions on the GSL to exploit the abundant food supply and
remain close to breeding areas to optimize energetic costs associated with wintering, migrating, and breeding.

**INTRODUCTION**

Wintering waterfowl abundance and distribution can be impacted by numerous factors including food (Miller et al. 2009, Dalby et al. 2012), weather (Nichols et al. 1983, Hepp and Hines 1991, Schummer et al. 2010), ice cover (Ouellet et al. 2010), and interspecific competition (DuBowy 1988). Many ducks winter in North America where there are large areas of habitat with relatively warm temperatures and abundant food sources such as the Central Valley of California, the Gulf Coast, and the Mississippi Alluvial Valley. Migration is an energetically demanding activity and can reduce survival, so reducing migration distance by wintering at northern latitudes with abundant food sources may increase annual survival. The ability of many waterfowl species to winter at more northerly latitudes is likely limited by increased energetic demands of thermoregulation at colder ambient temperatures or by food availability, particularly as ice and snow cover limit access to aquatic or agricultural foods. Isolating the role of lower ambient temperatures from reduced food availability is often difficult. Prior studies of the effect of temperature and food availability on wintering abundance were confounded by ice and snow cover that limit available food (Nichols et al. 1983, Schummer et al. 2010). The Great Salt Lake (GSL), Utah, provides a unique opportunity to examine these competing variables in that there is no loss of habitat or food availability due to weather on open waters of the GSL during periods of below freezing temperatures due to hypersaline water.
The GSL and its associated wetlands provide habitat for waterfowl using multiple flyways, and large populations of ducks use pelagic areas of the GSL in winter (Aldrich and Paul 2002). Interspecific competition among ducks is low on the GSL; mid-winter waterfowl species are primarily northern shoveler (*Anas clypeata*) and common goldeneye (*Bucephala clangula*), 2 species with very different feeding habits and habitat associations. Predator abundance is also low, consisting mostly of bald eagles (*Haliaeetus leucocephalus*), and mortality from hunters on pelagic areas of the GSL is minimal compared to primary wintering areas in California’s Central Valley or the Mississippi Aluvial Valley (personal observation). For northern shovelers and other dabbling ducks (*Anas* spp.) the GSL is in closer proximity to primary breeding areas than southern wintering areas. However, trade-offs associated with foraging in highly saline water and increased thermoregulatory demands associated with northern latitude climatic conditions may make it difficult for some ducks to survive the winter.

The objective of this research was to determine primary variables that influence density and distribution of duck populations on the GSL, a northern latitude waterfowl wintering area. I used 5 years of aerial survey data to evaluate wintering duck abundance and distribution throughout open water areas of the GSL. I hypothesized salinity and ambient air temperatures during winter would have a larger impact on duck abundance on the GSL than food quantity.
STUDY AREA

The GSL is a large, terminal lake in northern Utah. The entire ecosystem covers nearly 780,000 ha when at a lake elevation of 1,280 m and consists of saline open water and brackish and freshwater wetlands (Aldrich and Paul 2002). Salinity across the GSL is variable due to concentrated areas of freshwater inflow and anthropogenic alterations of water exchange. By mid-December most years, freshwater wetlands and low salinity bays, such as Bear River Bay, are frozen and habitat availability is restricted to hypersaline open water bays. The high salinities of the GSL’s Gilbert Bay support populations of only 3 species of aquatic macroinvertebrates; brine shrimp (*Artemia franciscana*) and 2 species of brine flies (*Ephydra* spp.). Densities of brine shrimp and their cysts vary spatially with the lowest densities in areas with less saline water. Brine fly larvae are found primarily along hard substrates above an anoxic, hypersaline deep water layer (deep brine layer) and larval densities are 10 times higher on bioherm and mud substrates than on sand substrates (Collins 1980, Wurtsbaugh 2007). Bioherms are a carbonate, reef-like structure formed by algae in shallow water portions of Gilbert and Ogden bays and are also known as biostromes or stromatolites. A large commercial harvest of brine shrimp cysts (i.e. eggs) takes place throughout the GSL annually October–January. Harvested cysts are used around the world in aquaculture where they are hatched and fed to young shrimp and fish. An average of 9.5 million kg of biomass is harvested annually from the GSL (Great Salt Lake Ecosystem Program 2012), mostly from large floating masses, known as streaks, which provide easy access to large amounts of cyst biomass for both commercial harvest boats and avian species (Aldrich and Paul...
Harvest occurs throughout Gilbert Bay but is concentrated in the northwest portion of the GSL.

The most abundant waterfowl species during winter on the GSL are northern shoveler and goldeneye (common and Barrow’s [Bucephala islandica]), and my analysis focused on these species. Prior research (Vest and Conover 2011) and ongoing studies have demonstrated that these species feed on salt-tolerant invertebrates and do not use the GSL strictly as a resting area away from predators and hunters. Other prevalent waterfowl species on the GSL during late fall and winter include mallard (Anas platyrhynchos), gadwall (Anas strepera), northern pintail (Anas acuta), and green-winged teal (Anas crecca).

METHODS

To examine population size and temporal and spatial distribution, I stratified the GSL into 7 strata based on salinity and geographic area of the lake. Strata were Bear River, Carrington, Central, Farmington, Northern, Ogden, and Southern (Fig. 2-1). I did not survey Gunnison Bay during 2009–2012 as initial survey work (2004–2006) determined there was sparse use of this region by avian species during winter due to salinities around 27%, near saturation, and counts from Gunnison Bay during 2004–2006 were not used in this analysis. I conducted monthly aerial surveys of waterfowl during 5 winters, from the first week of December through the first week of March: 2004-2005, 2005-2006, 2009-2010, 2010-2011, and 2011-2012. Surveys were flown in a fixed-wing aircraft at approximately 150 km/hr as recommended by Pearse et al. (2008). Within each stratum, transects were placed 500 m apart, running east to west. Each month, transects
were chosen randomly without replacement and constrained so adjacent transects were not surveyed during the same month. I visually counted all ducks by species within the 500 m wide transect. I considered common and Barrow’s goldeneye as a single group (i.e. goldeneye) due to morphological similarities, but few Barrow’s goldeneye have been observed on the GSL (Vest and Conover 2011).

Limnological data including salinity and invertebrate density were collected twice a month at 17 sites across the GSL (Fig. 2-1) by the Utah Division of Wildlife Resources as described by Belovsky et al. (2011). Although brine fly larvae densities are highest on substrates, measurements of densities on substrate were unavailable during this study. Instead, I assumed that density of brine fly larvae in the water column was representative of relative substrate density. Brine fly larvae densities within the water column are likely a fraction of what is found on substrates, so this may be a major assumption. In addition, the 17 regularly sampled sites did not include the Bear River or Farmington strata, so monthly salinity measurements were taken at 2 sites in each of these strata during the final 3 years of this study to categorize the salinity of those bays relative to the remaining strata (Fig. 2-1). I did not measure invertebrate prey availability in the Bear River or Farmington strata due to sparse use of these areas by ducks during winter months and mostly frozen water from December through March that did not allow for sampling. December counts indicated ducks are using those bays early in some winters so the lack of prey availability data may bias the interpretation of my results.

I used Program R for all statistical analysis (R Core Team 2012) and analyzed aerial stratified survey data with individual transects as sample units. Total population
abundance estimates and standard errors were calculated for total ducks, northern shoveler, and goldeneye for each survey using the SURVEY package (Lumley 2004). I provide estimates of population abundance to illustrate the importance of the GSL to wintering ducks and portray relative changes in abundance within a year on the GSL.

To model factors influencing change in duck density on the GSL, I used raw counts of change in duck density (ducks/km$^2$) between months within each stratum as the dependant variable in generalized linear models. I used both biotic and abiotic variables as independent variables in my models to evaluate change in duck density. Biotic variables were the lake-wide mean density of brine shrimp adults, brine shrimp cysts, and brine fly larvae averaged across all 17 sampling sites during the 7 days immediately preceding each aerial survey. Other prey species are available in Bear River and Farmington bays but were not sampled in my study. Interpretations of the impact of food or weather variables must account for the lack of data for certain prey items. Abiotic variables included Gilbert and Ogden Bay salinities averaged across all 17 sampling sites and average daytime (0900–1800) temperature (°C) during the 30 days immediately preceding each survey, and a winter severity index. Weather data were obtained from a weather station based on Hat Island on the western half of the GSL. Winter severity was calculated using the daily average air temperature and daily average wind speed (km/hr) over the 30 days immediately preceding the survey. I used the temperature and wind severity equations of Leckenby and Adams (1986), adjusted for months and days rather than weeks and hours, and used the sum of temperature and wind variables to calculate severity. Wind speed combined with temperature may be a better indicator of severity.
than snow cover on lakes because wind increases thermoregulatory costs and ducks must expend energy during windy conditions to hold their position within a flock or over food sources (McKinney and McWilliams 2005).

In a separate analysis, each aerial survey stratum was assigned a set of categorical variables including freshwater access, harvest boat density, and salinity that did not change among years for use in analysis of duck distribution on the GSL. Freshwater access categories were brackish (freshwater inflow directly into the stratum and average salinity < 5%), adjacent (freshwater inflow directly into the stratum and average salinity ≥ 5%), and non-adjacent (not adjacent to freshwater inflow sources and average salinity ≥ 5%). Harvest boat densities were calculated using observed counts of cyst harvest boats conducted by the Utah Division of Wildlife Resources. The number of all boats counted in each stratum were averaged over the 3-5 years of the study and were categorized as high (≥ 60% of surveyed activity), medium (≤ 40% of surveyed activity), and zero (inaccessible to harvest boats or harvest not allowed by rule). Salinity was categorized as high (≥ 8%), medium (3–8%), or low (≤ 3%) for each stratum. Though salinity may vary greatly within a year or spatially across the bays in some strata (i.e. Bear River, Farmington), I used the average winter salinity over the 3-5 years of this study measured either at the 17 Utah Division of Wildlife Resources sampling sites (Carrington, Central, Northern, Ogden, and Southern) or the 4 supplementary sites (Bear River and Farmington) to categorize salinity. Categorical assignments for each stratum were 1) Bear River–brackish water, zero boat density, and low salinity; 2) Carrington–non-adjacent to freshwater, high boat density, and high salinity; 3) Central–non-adjacent to freshwater,
medium boat density, and high salinity; 4) Farmington–brackish water, zero boat density, and medium salinity; 5) Northern–non-adjacent to freshwater, medium boat density, and high salinity; 6) Ogden–adjacent to freshwater, zero boat density, and medium salinity; 7) Southern–adjacent to freshwater, medium boat density, and high salinity.

I modeled the distribution of ducks on the GSL as the proportion of each species within each stratum. Proportion of total ducks, northern shovelers, and goldeneye were calculated using raw counts standardized by transect length surveyed, and proportions were calculated relative to the standardized total count during each survey. I used those proportions as dependent variables in regression models using a beta distribution in the BETAREG package (Cribari-Neto and Zeileis 2010). I modeled the effect of the categorical variables month, year, freshwater access, harvest boat density, and salinity on distribution of ducks.

I was most interested in the individual variables that were important to duck density and distribution, not an individual predictive model for the GSL. Therefore, I evaluated a set of biologically relevant *a priori* models for both change in density and distribution of northern shovelers, goldeneye, and total ducks (Arnold 2010). Models included all individual predictor variables and various additive and multiplicative models. I used a total of 18 models of density and 9 models of distribution (Table 2-1), included all variables in an equal number of models, and used second order Akaike’s Information Criterion (AICc) to rank models (Burnham and Anderson 2002). I summed AICc model weights for all variables of interest from all models to calculate relative variable importance and therefore evaluate the importance of each variable on density and
distribution. I ranked the relative variable importance according to combined AICc weights and then calculated a weighted average for parameter estimates from all models that included the specific variable (Burnham and Anderson 2002).

RESULTS

I was able to conduct survey flights 19 of the 20 months available during the 5 winters of this study. The estimated abundance of total ducks on the GSL December–March ranged from a high of 270,000 to a low of near 10,000 (Table 2-2). Estimated northern shoveler abundance ranged from none detected to 200,000, and goldeneye abundance estimates ranged from about 5,000 to 44,000.

I evaluated the influence of 6 variables on change in density. Change in total duck density was most influenced by temperature during the previous month (Fig. 2-2), which was a positive relationship, followed by a positive relationship with density of brine shrimp cysts (Table 2-3). The variable with the highest measure of relative importance for northern shoveler density was temperature during the previous month, with a positive relationship. Change in density of goldeneye was influenced by density of brine fly larvae followed by temperature during the previous month (Table 2-3).

I evaluated the influence of 5 variables on duck distribution. Freshwater access was the most important variable in models of total duck \(w = 0.64\) distribution. Higher proportions of total ducks occurred in strata with the categories of brackish water and adjacent to freshwater compared to strata categorized as non-adjacent to freshwater sources (Fig. 2-3). Percent of total survey area in the access to freshwater categories were 20\% (brackish), 23\% (adjacent), and 57\% (non-adjacent). Mean percent of total ducks
estimated throughout this study in each category were 50%, 37%, and 13%, respectively. In order of relative variable importance influencing total duck distribution following access to freshwater were salinity \( (w = 0.32) \), month \( (w = 0.16) \) and boat density \( (w = 0.11) \). No models including year received any weight in my analysis \( (w = 0.00) \). Most harvest boat activity occurred in the Carrington and Northern strata of the GSL while total duck abundance was concentrated in the Southern and Ogden strata (Fig 2-4).

Northern shoveler distribution also had freshwater access as the variable with the highest relative importance \( (w = 1.0) \). Aerial survey observations found northern shovelers concentrated in the Southern and Ogden strata during winter months. Averaged across the entire study period northern shovelers were observed in strata with brackish water and adjacent to freshwater inflow sites; mean monthly percent was 42% and 54%, respectively. Few birds were seen in strata not adjacent to freshwater inflow (4%; Fig. 2-3). Freshwater access was followed by month \( (w = 0.25) \) in measure of relative importance for northern shoveler distribution. Boat density, salinity, and year received no weight in models of northern shoveler distribution.

The variable with the highest relative importance in goldeneye distribution was salinity \( (w = 0.82) \). The highest mean percent of goldeneye occurred in the medium salinity strata (55%) and the mean proportion of goldeneye each month was minimal in both low (15%) and high (30%) salinity strata (Fig. 2-5). Medium salinity areas were Ogden and Farmington strata and I observed most goldeneye in the Ogden stratum, followed by the Carrington stratum. Percent of total area surveyed in the salinity categories were 68% (high), 24% (medium), and 8% (low). The only other variable to
receive any measure of relative importance in models of goldeneye distribution was
harvest boat density ($w = 0.78$) where a greater than expected proportion of goldeneye
occurred in strata with high and medium harvest boat densities.

**DISCUSSION**

High estimates of duck abundance during December and January indicate the
GSL is a notable wintering site, in addition to its significance to migrating waterfowl.
The estimated population of wintering northern shoveters on the GSL (up to 200,000)
represented 1–2% of the continental northern shoveler population and about 4% of the
Pacific Flyway wintering population of northern shoveters (Olson and Trost 2012). My
estimates of wintering goldeneye populations (yearly peaks of 9,000–44,000) indicate the
GSL hosts on average 30% of the Pacific Flyway wintering goldeneye (Olson and Trost
2012). Pacific Flyway mid-winter surveys do not fly over open waters of the GSL (B.
Stringham personal communication) so estimates from Pacific Flyway counts are likely
low considering the numbers of goldeneye seen in my study that are in open water areas.

The GSL is an ideal system to examine the influence of weather and food
abundance on wintering duck abundance as habitat and food availability is relatively
constant during winter due to the absence of ice cover in the hypersaline water. Previous
research on wintering abundance of ducks in North America has focused on wintering
mallards, using that species as a surrogate for overall dabbling duck (*Anas* spp.)
abundance. In the Mississippi Alluvial Valley, precipitation and cold weather (Nichols et
al. 1983), habitat availability (Reinecke et al. 1987), and habitat complexity (Pearse et al.
2012) have all been shown to influence mallard abundance and distribution during
winter. My results support the influence of ambient temperature on total duck abundance. Other research has shown winter severity indices that include snow cover, rather than temperature alone, may best explain duck abundance (Schummer et al. 2010). However, ice and snow on the GSL generally does not limit food availability after freshwater marshes freeze, and my results suggest thermoregulatory demands are more important than food abundance in the choice to continue migration for a portion of Pacific Flyway wintering ducks.

There are some limitations to my results based on my methods. My results have limited predictive ability as shown by the low fit of the relationship among temperature and total duck abundance. The objective of this paper was not to predict duck abundance on the GSL, rather to determine which factor was most important given the variables I examined. In addition, prey items were not sampled in 2 strata, Bear River and Farmington and were only sampled at one site in the Ogden stratum, therefore prey density estimates did not include large areas of the GSL or prey items other than brine shrimp and brine flies. The former 2 strata were usually frozen during my surveys (17 of 19 surveys) except for small patches of open water and not completely available to ducks during winter. I was interested in whole lake levels of prey density for models of change in density, rather than within stratum changes, so a 17 site average is likely representative of prey densities available to ducks wintering on the GSL. Alternatively, the prey species not sampled may have been important in duck abundance but were not sampled and therefore not seen in my models. Categorization of Ogden Bay as a medium salinity stratum was based on a single monitoring site near a freshwater inflow point. This may or
may not represent the entire bay, though there are multiple inflow sites to Ogden Bay (Bear River, Farmington Bay, and Weber River inflows), which suggests salinities were lower than open water areas of Gilbert Bay. Finally, duck abundance was estimated from counts on transects while biotic and abiotic variables were measured at points throughout the GSL. Different spatial scales of data collection may make it difficult to link changes in influencing factors to changes in duck numbers.

With the exception of mallards, species-specific factors influencing wintering duck abundance are not well studied. Northern shovelers are a holarctic species with unique bill morphology and feeding style (DuBowy 1996) that may allow them to take advantage of floating masses of brine shrimp adults and cysts on the GSL (Vest and Conover 2011). Within the range of food levels observed, my study provided little evidence of food limitation on northern shoveler abundance during winter on the GSL. My measures of cyst abundance are constrained by a lower bound because regulated cyst harvest demands suspension of cyst removal once densities drop to 21 cysts/L. GSL monitoring data show that cysts density does not decrease from January to March after the discontinuation of harvest (Belovsky et al. 2011), indicating minimal additional removal by wintering ducks. The model averaged parameter estimate of the relationship between cyst density (most common food of northern shovelers during winter on the GSL; Vest and Conover 2011) and change in northern shoveler abundance showed a small positive trend but did not have the highest relative variable importance. DuBowy (1988) also reported northern shovelers are less affected by food abundance during winter than other Anas species. In contrast to my results, populations of northern shovelers
wintering in western France were limited by food abundance (Guillemain et al. 2000). Limited food may have been the result of smaller wetland area available to ducks during winter. The largest wetland studied was 30 ha (Guillemain et al. 2000) compared to thousands of ha available during winter on the GSL. Discrepancy in results between studies is likely related to differences in spatial scale and overall magnitude of available resources.

My calculations of relative variable importance suggest temperature is more important than food abundance (brine shrimp cysts) in influencing changes in northern shoveler abundance. This finding supports the importance of temperature on northern shoveler abundance at wintering sites. Guillemain et al. (2000) observed a decrease in northern shoveler abundance during an abnormally cold period in western France, and birds returned to the site the same winter as temperatures warmed. Temperature may be a surrogate for habitat loss on the GSL in some years, though after December, habitat loss is minimal. Some small pockets of freshwater near inflow/outflow sites or mining tailings ponds may stay ice-free in average temperature months, but may become unavailable in the coldest years and remove an important source of freshwater.

The energetic challenges of wintering at more northern latitudes such as the GSL for northern shovelers may be offset by relatively close proximity to primary breeding areas and potential increased fitness by early arrival to the breeding grounds. The GSL is near the northern latitude of northern shoveler’s winter range and the southern latitude of their breeding range, likely resulting in a shorter spring migration flight and more favorable body condition upon arrival at breeding areas compared to those wintering
further south. Late winter and spring body condition are positively associated with breeding success and subsequent recruitment in many waterfowl species (Devries et al. 2008, Guillemain et al. 2008). Lipid levels upon arrival on the breeding grounds limited egg production among northern shovlers nesting in southern Manitoba (Ankney and Afton 1988). If individuals realize greater fitness due to shorter migration distance, they may show more wintering site fidelity than conspecifics. Winter site fidelity of northern shovlers has not been documented, but northern pintails wintering in and around the GSL displayed some of the highest wintering site fidelity compared to other northern pintail wintering populations (Hestbeck 1993).

Research on wintering goldeneye species is more extensive than that on shovelers. Goldeneyes, being larger than northern shovelers, have a greater capacity to store lipids and can withstand colder temperatures (Calder 1974), and their wintering range extends further north than most dabbling duck species. Unlike northern shovelers, goldeneyes occur in saline habitats in much of their wintering range (Bellrose 1976). Wintering goldeneye distribution and lipid reserves were impacted by amount of ice cover at 2 wintering sites at latitudes north of the GSL (Ouellet et al. 2010, Schummer et al. 2012). This suggests goldeneye’s ability to obtain food may be a more important factor influencing abundance than their ability to thermoregulate. Another diving duck species has shown a similar pattern: canvasbacks (Aythya valisineria) wintering in Maryland decreased in abundance after increased ice cover limited plant tuber availability (Lovvorn 1989). My results suggest that prey density is an important factor for goldeneye on the
Great Salt Lake, as there was a weak correlation of bird densities with densities of their primary prey, brine fly larvae (Vest and Conover 2011).

Ouellet et al. (2010) found goldeneye species prefer areas near freshwater inflow sites and attributed that in part to higher nutrients deposited at river mouths resulting in greater food availability. In the GSL, the primary food of goldeneye is not found at higher densities near freshwater inflows, and our models showed goldeneye occurred at greater proportions in medium and high salinity strata, not low salinity areas, suggesting osmoregulatory costs were not high enough to impact spatial use of the GSL. In addition, brine fly larvae densities are highest in saline areas, not the low salinity bays (Collins 1980). Alternatively, goldeneye may have been seen in medium salinity strata, particularly Ogden, because they were obtaining freshwater for osmoregulation. The sampling site in the Ogden stratum was a non-randomly chosen site placed due to its proximity to freshwater inflows from Bear River Bay. Commercial harvest boat density also had high relative variable importance in goldeneye distribution. That relationship was likely due to the distribution of brine shrimp cysts and access conditions for harvest boats. Large concentrations of cysts are not found in Bear River and Farmington bays, the areas of low salinity. Harvest boats are also not allowed to harvest from the Ogden stratum, an area of low densities of goldeneye.

I found salinity and freshwater access influence duck distribution on the GSL, depending on the species. Total ducks and shovelers utilized strata adjacent to freshwater inflow sites more than was available, while goldeneye used medium salinity strata more than low or high salinity strata. Birds use a variety of physiological and behavioral
adaptations to reduce osmoregulatory costs (Mahoney and Jehl 1985, Bennett and Hughes 2003), and access to fresh drinking water is important to dilute ingested salt for avian species living in hypersaline environments (Sabat 2000). Wintering northern shovelers and northern pintails use both freshwater and saltwater habitats on the Texas coast (Tietje and Teer 1988, Ballard et al. 2004) though birds were more abundant on freshwater wetlands. During a record cold period, northern shovelers using Texas coastal saltwater habitats were in better body condition than freshwater-inhabiting conspecifics, indicating the importance of the marine invertebrate food during harsh conditions (Tietje and Teer 1988). The invertebrates found in the GSL are higher in energy content than many wetland plant seeds found in other wintering areas (Caudell and Conover 2006, Dugger et al. 2007). High energy foods, along with increased foraging effort, can reduce the rate of lipid loss during extended cold periods (Schummer et al. 2012) and within species, heavier individual ducks have higher survival rates (Heitmeyer 1995).

**MANAGEMENT IMPLICATIONS**

Despite the lack of snow and ice cover on the GSL, both food and weather were observed to influence abundance of wintering ducks. The primary winter food of northern shovelers using the GSL is brine shrimp cysts and abundance of cysts may be impacted by commercial harvest. However, the influence of cyst density on northern shoveler abundance was relatively small within the range of cyst densities observed during this study. The current cyst harvest management strategy implemented by the Utah Division of Wildlife Resources maintains a density of $\geq 21$ cysts/L through winter (Belovsky et al. 2011). My results suggest this management objective provides adequate food resources
for northern shovelers during winter on the GSL. Goldeneyes are adapted to cold weather and saline habitats found on the GSL, and my results indicate food abundance was an important variable influencing their local density. Brine fly larvae are important to goldeneye, but factors influencing brine fly larvae abundance are not well studied on the GSL. Thus, improved understanding of factors influencing brine fly populations is needed to inform GSL management decisions relative to the needs of goldeneye and other aquatic birds that feed on brine fly larvae.

**LITERATURE CITED**


Table 2-1. Models of total duck, northern shoveler, and goldeneye abundance on the Great Salt Lake, Utah, used to determine relative variable importance. K is the number of parameters estimated in the model and AICc is the second order Akaike’s Information Criterion used to rank models. AICc weights were used to determine which variables had the most influence on duck abundance on the Great Salt Lake over 5 winters from 2005 through 2012. Variables are lake-wide mean density of brine shrimp adults (bsadults), brine shrimp cysts (cysts), and brine fly larvae (bflarvae) during the week preceding each survey, and salinity (salinity) and average daytime (0900–1800) temperature (°C; prevtemp) during the month preceding each survey, and the sum of temperature and wind severity measures during the month preceding each survey (severity). Adjusted $r^2$ values for each model show the percentage of the variance in the change in duck density accounted for by the predictive variables.

<table>
<thead>
<tr>
<th>Variable(s)</th>
<th>K</th>
<th>AICc</th>
<th>$\Delta$ AICc</th>
<th>Mode</th>
<th>Adj. $r^2$</th>
<th>AICc</th>
<th>$\Delta$ AICc</th>
<th>Mode</th>
<th>Adj. $r^2$</th>
<th>AICc</th>
<th>$\Delta$ AICc</th>
<th>Mode</th>
<th>Adj. $r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>prevtemp</td>
<td>3</td>
<td>1002.35</td>
<td>0.00</td>
<td>0.25</td>
<td>1</td>
<td>0.064</td>
<td>947.55</td>
<td>0.00</td>
<td>0.40</td>
<td>1</td>
<td>0.070</td>
<td>712.27</td>
<td>4.33</td>
</tr>
<tr>
<td>prevtemp+</td>
<td>4</td>
<td>1003.17</td>
<td>0.82</td>
<td>0.17</td>
<td>2</td>
<td>0.062</td>
<td>949.14</td>
<td>1.59</td>
<td>0.18</td>
<td>2</td>
<td>0.060</td>
<td>710.00</td>
<td>2.05</td>
</tr>
<tr>
<td>prevtemp+</td>
<td>4</td>
<td>1004.34</td>
<td>1.99</td>
<td>0.09</td>
<td>3</td>
<td>0.056</td>
<td>949.39</td>
<td>1.85</td>
<td>0.16</td>
<td>3</td>
<td>0.057</td>
<td>708.10</td>
<td>0.16</td>
</tr>
<tr>
<td>prevtemp+</td>
<td>4</td>
<td>1004.49</td>
<td>2.14</td>
<td>0.09</td>
<td>4</td>
<td>0.051</td>
<td>949.69</td>
<td>2.14</td>
<td>0.14</td>
<td>4</td>
<td>0.042</td>
<td>709.68</td>
<td>1.73</td>
</tr>
<tr>
<td>severity</td>
<td>3</td>
<td>1004.56</td>
<td>2.21</td>
<td>0.08</td>
<td>5</td>
<td>0.050</td>
<td>952.07</td>
<td>4.53</td>
<td>0.04</td>
<td>5</td>
<td>0.051</td>
<td>711.88</td>
<td>3.94</td>
</tr>
<tr>
<td>cysts</td>
<td>3</td>
<td>1005.44</td>
<td>3.09</td>
<td>0.05</td>
<td>6</td>
<td>0.042</td>
<td>956.00</td>
<td>8.46</td>
<td>0.01</td>
<td>12</td>
<td>0.023</td>
<td>716.91</td>
<td>8.96</td>
</tr>
<tr>
<td>bsadults</td>
<td>3</td>
<td>1006.04</td>
<td>3.69</td>
<td>0.04</td>
<td>7</td>
<td>0.042</td>
<td>955.86</td>
<td>8.31</td>
<td>0.01</td>
<td>11</td>
<td>0.022</td>
<td>713.93</td>
<td>5.98</td>
</tr>
<tr>
<td>Term</td>
<td>Degree</td>
<td>Mean</td>
<td>Std. Dev</td>
<td>F Value</td>
<td>df1</td>
<td>df2</td>
<td>Significance</td>
<td>Mean</td>
<td>Std. Dev</td>
<td>F Value</td>
<td>df1</td>
<td>df2</td>
<td>Significance</td>
</tr>
<tr>
<td>----------------------</td>
<td>--------</td>
<td>--------------</td>
<td>----------</td>
<td>---------</td>
<td>-----</td>
<td>-----</td>
<td>--------------</td>
<td>------</td>
<td>----------</td>
<td>---------</td>
<td>-----</td>
<td>-----</td>
<td>--------------</td>
</tr>
<tr>
<td>bflarvae severity+</td>
<td>3</td>
<td>1006.06</td>
<td>3.70</td>
<td>0.04</td>
<td>8</td>
<td>0.042</td>
<td>954.87</td>
<td>7.33</td>
<td>0.01</td>
<td>8</td>
<td>0.041</td>
<td>707.95</td>
<td>0.00</td>
</tr>
<tr>
<td>salinity</td>
<td>4</td>
<td>1006.74</td>
<td>4.39</td>
<td>0.03</td>
<td>9</td>
<td>0.032</td>
<td>953.94</td>
<td>6.40</td>
<td>0.02</td>
<td>6</td>
<td>0.050</td>
<td>712.92</td>
<td>4.97</td>
</tr>
<tr>
<td>cysts*severity</td>
<td>5</td>
<td>1006.90</td>
<td>4.54</td>
<td>0.03</td>
<td>10</td>
<td>0.028</td>
<td>954.21</td>
<td>6.67</td>
<td>0.01</td>
<td>7</td>
<td>0.041</td>
<td>716.06</td>
<td>8.11</td>
</tr>
<tr>
<td>salinity</td>
<td>3</td>
<td>1007.21</td>
<td>4.86</td>
<td>0.02</td>
<td>11</td>
<td>0.028</td>
<td>956.95</td>
<td>9.40</td>
<td>0.00</td>
<td>14</td>
<td>0.008</td>
<td>716.72</td>
<td>8.77</td>
</tr>
<tr>
<td>prevtemp²</td>
<td>3</td>
<td>1007.21</td>
<td>4.86</td>
<td>0.02</td>
<td>12</td>
<td>0.026</td>
<td>956.42</td>
<td>8.88</td>
<td>0.00</td>
<td>13</td>
<td>0.009</td>
<td>711.00</td>
<td>3.05</td>
</tr>
<tr>
<td>cysts+salinity</td>
<td>4</td>
<td>1007.56</td>
<td>5.20</td>
<td>0.02</td>
<td>13</td>
<td>0.008</td>
<td>958.13</td>
<td>10.59</td>
<td>0.00</td>
<td>17</td>
<td>0.001</td>
<td>718.56</td>
<td>10.62</td>
</tr>
<tr>
<td>bsalts+</td>
<td>3</td>
<td>1008.04</td>
<td>5.69</td>
<td>0.01</td>
<td>14</td>
<td>0.009</td>
<td>958.04</td>
<td>10.49</td>
<td>0.00</td>
<td>16</td>
<td>0.002</td>
<td>715.95</td>
<td>8.01</td>
</tr>
<tr>
<td>bflarvae+</td>
<td>4</td>
<td>1008.18</td>
<td>5.83</td>
<td>0.01</td>
<td>15</td>
<td>0.006</td>
<td>957.00</td>
<td>9.46</td>
<td>0.00</td>
<td>15</td>
<td>0.004</td>
<td>713.98</td>
<td>6.03</td>
</tr>
<tr>
<td>salinity</td>
<td>4</td>
<td>1008.37</td>
<td>6.02</td>
<td>0.01</td>
<td>17</td>
<td>0.001</td>
<td>955.69</td>
<td>8.15</td>
<td>0.01</td>
<td>10</td>
<td>0.023</td>
<td>709.99</td>
<td>2.04</td>
</tr>
<tr>
<td>bflarvae+</td>
<td>5</td>
<td>1008.41</td>
<td>6.49</td>
<td>0.01</td>
<td>18</td>
<td>0.001</td>
<td>958.57</td>
<td>11.02</td>
<td>0.00</td>
<td>18</td>
<td>0.000</td>
<td>715.73</td>
<td>7.79</td>
</tr>
</tbody>
</table>

Note: The table contains a list of variables and their corresponding statistical values. The values include degrees of freedom (df1 and df2), mean, standard deviation, F values, and significance levels.
Table 2-2. Estimated abundance (± SE) of total ducks, northern shoveler, and goldeneye (common and Barrow’s) species on the Great Salt Lake, Utah, during 5 winters from 2004-05 to 2011-12. Estimates were derived from monthly stratified aerial survey counts.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total ducks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec</td>
<td>100,300 ± 39,400</td>
<td>128,400 ± 43,200</td>
<td>73,500 ± 40,400</td>
<td>31,900 ± 10,700</td>
<td>270,500 ± 96,600</td>
</tr>
<tr>
<td>Jan</td>
<td>95,300 ± 29,900</td>
<td>98,100 ± 32,400</td>
<td>16,000 ± 10,700</td>
<td>63,200 ± 21,900</td>
<td>63,500 ± 20,200</td>
</tr>
<tr>
<td>Feb</td>
<td>33,400 ± 16,800</td>
<td>30,900 ± 9,400</td>
<td>NA</td>
<td>11,400 ± 8,200</td>
<td>48,300 ± 16,900</td>
</tr>
<tr>
<td>Mar</td>
<td>83,500 ± 47,700</td>
<td>145,900 ± 42,500</td>
<td>29,600 ± 21,300</td>
<td>145,900 ± 86,700</td>
<td>187,700 ± 78,700</td>
</tr>
<tr>
<td></td>
<td>Northern shoveler</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec</td>
<td>23,000 ± 15,900</td>
<td>21,000 ± 8,000</td>
<td>60,900 ± 39,400</td>
<td>200 ± 100</td>
<td>203,300 ± 84,000</td>
</tr>
<tr>
<td>Jan</td>
<td>4,500 ± 3,100</td>
<td>5,600 ± 2,400</td>
<td>700 ± 500</td>
<td>13,900 ± 8,000</td>
<td>36,700 ± 13,500</td>
</tr>
<tr>
<td>Feb</td>
<td>0 ± 0</td>
<td>5,200 ± 3,500</td>
<td>NA</td>
<td>2,800 ± 2,000</td>
<td>12,000 ± 5,300</td>
</tr>
<tr>
<td>Mar</td>
<td>1,700 ± 1,100</td>
<td>22,900 ± 6,300</td>
<td>200 ± 200</td>
<td>8,300 ± 6,600</td>
<td>11,800 ± 7,000</td>
</tr>
<tr>
<td></td>
<td>Goldeneye</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec</td>
<td>26,000 ± 6,200</td>
<td>36,300 ± 11,800</td>
<td>8,900 ± 5,000</td>
<td>22,400 ± 8,800</td>
<td>30,100 ± 14,200</td>
</tr>
<tr>
<td>Jan</td>
<td>44,300 ± 15,500</td>
<td>43,600 ± 12,800</td>
<td>11,700 ± 9,300</td>
<td>44,900 ± 18,500</td>
<td>22,800 ± 14,400</td>
</tr>
<tr>
<td>Feb</td>
<td>21,300 ± 6,100</td>
<td>24,300 ± 8,000</td>
<td>NA</td>
<td>7,200 ± 5,900</td>
<td>15,600 ± 6,900</td>
</tr>
<tr>
<td>Mar</td>
<td>13,400 ± 3,900</td>
<td>28,400 ± 8,900</td>
<td>9,400 ± 9,200</td>
<td>24,700 ± 16,800</td>
<td>28,800 ± 12,700</td>
</tr>
</tbody>
</table>
Table 2-3. Relative variable importance and their associated parameter estimates for variables influencing density of total ducks, northern shoveler, and goldeneye species wintering on the Great Salt Lake, Utah. Abiotic variables are average temperature during the preceding month (TEMP), average temperature (rescaled to a minimum of 0) multiplied by average wind speed during the preceding month (SEVERITY), and average salinity during the preceding month (SALINTY). Biotic variables are current water column density of adult brine shrimp (BRINESHRIMP), brine shrimp cysts (BSCYSTS), and brine fly larvae (BFLARVAE).

<table>
<thead>
<tr>
<th>Cumulative model weight</th>
<th>Parameter estimate</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total ducks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEMP</td>
<td>0.62</td>
<td>3.75</td>
</tr>
<tr>
<td>BSCYSTS</td>
<td>0.28</td>
<td>0.24</td>
</tr>
<tr>
<td>SEVERITY</td>
<td>0.16</td>
<td>0.10</td>
</tr>
<tr>
<td>BRINESHRIMP</td>
<td>0.16</td>
<td>57.96</td>
</tr>
<tr>
<td>BFLARVAE</td>
<td>0.16</td>
<td>0.80</td>
</tr>
<tr>
<td>SALINTITY</td>
<td>0.09</td>
<td>-0.49</td>
</tr>
<tr>
<td><strong>Northern shoveler</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEMP</td>
<td>0.88</td>
<td>4.04</td>
</tr>
<tr>
<td>BSCYSTS</td>
<td>0.20</td>
<td>0.11</td>
</tr>
<tr>
<td>BFLARVAE</td>
<td>0.18</td>
<td>0.59</td>
</tr>
<tr>
<td>BRINESHRIMP</td>
<td>0.16</td>
<td>-10.00</td>
</tr>
<tr>
<td>SEVERITY</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td>SALINTITY</td>
<td>0.02</td>
<td>0.84</td>
</tr>
<tr>
<td><strong>Goldeneye</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BFLARVAE</td>
<td>0.55</td>
<td>0.40</td>
</tr>
<tr>
<td>TEMP</td>
<td>0.53</td>
<td>1.07</td>
</tr>
<tr>
<td>BRINESHRIMP</td>
<td>0.22</td>
<td>19.02</td>
</tr>
<tr>
<td>SEVERITY</td>
<td>0.18</td>
<td>0.03</td>
</tr>
<tr>
<td>BSCYSTS</td>
<td>0.10</td>
<td>0.01</td>
</tr>
<tr>
<td>SALINTITY</td>
<td>0.03</td>
<td>0.48</td>
</tr>
</tbody>
</table>
Figure 2-1. Map of the Great Salt Lake, Utah, and the strata used in aerial surveys of wintering duck populations. Gunnison Bay was not surveyed or used in analysis as it is hypersaline and does not support populations of birds or salt-tolerant invertebrates. Green circles are the 17 sampling sites used by Utah Division of Wildlife Resources to sample limnological measurements at a weekly basis. Red triangles were used to supplement UDWR data and determine salinity measurements of the Bear River and Farmington aerial survey strata.
Figure 2-2. Average temperature during the 30 days preceding an aerial survey had a positive influence on the change in density of total waterfowl on the Great Salt Lake, Utah. Data were collected during 5 winters from 2004-05 to 2011-12. Change in density is the difference from the previous month within each of 7 strata.
Figure 2-3. Proportion of birds that occurred in 3 categories of access to freshwater for (a) total ducks and (b) northern shovelers on the Great Salt Lake, Utah. Proportion of total ha of the Great Salt Lake within each category were 0.20 (brackish), 0.23 (adjacent), and 0.57 (non-adjacent). Access to freshwater categories were assigned brackish (adjacent to freshwater inflow and average salinity <5%), adjacent (adjacent to freshwater inflow and average salinity >5%), and non-adjacent (not adjacent to freshwater inflow sources). Bold lines are the means of all months surveyed (n = 19, December–March, 2004-2012), box boundaries are 25% and 75% of total observations, and whisker extents are lowest and highest observed proportions.
Figure 2-4. Distribution of harvest boats and total ducks on the Great Salt Lake during December of 2011 that illustrates the average distribution of both. Gray scale is the density of harvest boats (#/km²) measured by the Utah Division of Wildlife Resources during aerial surveys. Lines are random transects used during December 2011 aerial surveys and darker colors represent more total ducks observed during aerial surveys.
Figure 2-5. Influence of 3 levels of salinity on wintering distribution of goldeneye species on the Great Salt Lake, Utah. Salinity categories were long-term salinity measurements within strata that were high (≥8%), medium (3-8% salinity), or low (≤3%). Proportion of total ha within the Great Salt Lake of each category were 0.68 (high), 0.24 (medium), and 0.08 (low). Data were collected during 5 winters from 2004-05 to 2011-12. Bold lines are the means of all months surveyed (n = 19, December–March, 2004-2012), box boundaries are 25% and 75% of total observations, and whisker extents are lowest and highest observed proportions.
CHAPTER 3
DIET AND BODY CONDITION OF DUCKS IN ASSOCIATION WITH COMMERCIAL HARVEST OF BRINE SHRIMP CYSTS

ABSTRACT Commercial fisheries may reduce food abundance for birds or aquatic birds may impact fisheries when they forage on the commercial resource and reduce harvestable biomass. Large populations of waterfowl use the hypersaline Great Salt Lake (GSL), Utah and temporal use of the GSL by ducks coincides with a commercial harvest of brine shrimp (*Artemia franciscana*) cysts (i.e. eggs). I collected northern shoveler (*Anas clypeata*) and green-winged teal (*Anas crecca*) during the nonbreeding season in 2009-2010, 2010-2011, and 2011-2012 to examine diet and body condition of birds foraging on the GSL. I also calculated the total cyst removal by ducks and commercial harvesters during this time. Diets of both duck species changed seasonally. Both duck species consumed wetland plant seeds and freshwater invertebrates in higher quantities than other foods during fall and spring; during early and late winter, GSL invertebrates (brine shrimp adults and cysts, brine fly [*Ephydra* spp.] larvae) made up 75–100% aggregate wet weight mass consumed. Body weight of both species of ducks was highest in fall, decreased through winter, and increased again in the spring: a pattern seen in many duck species during the nonbreeding season. The saline habitats of the GSL contain abundant food resources and support large populations of ducks during the nonbreeding season. Estimates of cyst removal from the GSL by ducks and commercial harvesters suggest ducks consume less than 3% of the yearly mass removed by ducks and commercial harvesters combined.
INTRODUCTION

Interactions between avian populations and commercial fisheries are most often associated with ocean fisheries and seabird populations (Tasker et al. 2000) or aquaculture facilities and piscivorous birds (Price and Nickum 1995). On the Great Salt Lake (GSL), Utah, a commercial harvest of aquatic invertebrates occurs October–January. Brine shrimp (*Artemia franciscana*) cysts (i.e. eggs) are harvested from the water surface and shorelines. Harvested cysts are used around the world in aquaculture facilities where they are hatched and fed to larval shrimp and fish. An average of 9.5 million kg of cysts is harvested annually from the GSL, providing an annual economic effect to the region of >$56 million (Bioeconomics 2012). Alongside this commercial harvest, hundreds of thousands of waterfowl use the marshes and open waters of the GSL during migration and wintering periods.

Both commercial harvesters and avian consumers of brine shrimp cysts may adversely impact each other’s use of this resource. The commercial fishery may reduce cyst abundance which may be an important winter food of ducks. In turn, aquatic birds may impact the fishery industry when they forage on concentrated masses of cysts, known as streaks, and reduce harvestable biomass. Commercial fisheries in other areas have had both positive and negative impacts on avian populations. Increased food abundance at aquaculture facilities in the southeastern U.S. had a positive impact on birds; increased populations of wading birds were attributed to increases in the number of aquaculture facilities (Fleury and Sherry 1995). Increases in anthropogenic food distribution through commercial fisheries discards are an important food source for some
seabirds (Votier et al. 2004). Alternatively, marine fisheries may reduce seabird abundance by changing prey composition and abundance (Furness 2003).

The primary objective of this study was to determine the extent of cyst consumption by ducks during and after the commercial cyst harvest season. I examined changes in diet and body condition during fall and winter at the hypersaline GSL. I was interested in the potential impact of avian species on the harvest industry and if commercial harvest was negatively impacting duck food sources. If body condition measurements and patterns during the nonbreeding season on the GSL are similar to previous research, then the GSL may be a suitable alternative to wintering areas further south. I predicted duck diets would change based on their ability to forage in freshwater areas during warmer fall and spring seasons. I also predicted duck body mass would decline each winter and increase in spring in preparation for migration, a pattern seen in many waterfowl species in winter. Finally, I hypothesized that ducks remove only a fraction of cysts removed by the commercial industry due to small populations of ducks during winter when brine shrimp cysts are the primary food source.

STUDY AREA

The GSL ecosystem covers nearly 780,000 ha when at a long-term average lake elevation of 1,280 m above sea level and consists of saline open water and freshwater wetlands, both of which support large populations of birds throughout the year (Aldrich and Paul 2002). Salinity is variable due to concentrated areas of freshwater inflow and anthropogenic alterations of water exchange. The high salinities in the pelagic areas of the GSL support populations of only 3 species of macroinvertebrates: brine shrimp and 2
species of brine flies (*Ephydra* spp.). Densities of brine shrimp and their cysts vary across the GSL; their numbers are lowest in Gunnison Bay (Fig. 3-1) where salinities approach saturation. Within the remainder of the GSL, adult brine shrimp and cyst densities are lowest in areas with less saline water, such as Farmington and Bear River bays (Stephens and Birdsey 2002). Brine shrimp hatch from overwintered cysts in the spring as water temperature increases. Adult brine shrimp graze on phytoplankton and reach peak numbers in early summer, before decreasing as they deplete their food source (Stephens and Birdsey 2002). Throughout summer, most brine shrimp reproduction is ovoviviparous where eggs hatch in the ovisac and young are released into the water. When food levels drop in the fall to levels too low for juvenile or adult survival, oviparity, or the production of diapausing cysts, is the primary reproductive mechanism. Large concentrations of cysts, known as streaks, provide easy access to large amounts of cyst biomass for both commercial harvesters and avian species. Adult brine flies emerge from the waters of the GSL throughout summer and females deposit single eggs on the water’s. Larvae hatch 5 to 6 days later and are found primarily on substrates of the GSL above an anoxic, highly saline, deep water layer; larvae densities are 10 times higher on bioherms and mud substrates than on sand substrates (Collins 1980, Wurtsbaugh 2007). Bioherms are a carbonate, reef-like structure formed by algae in shallow water portions of Gilbert and Ogden bays and are also known as biostromes or stromatolites.
METHODS

Field Methods

Previous and ongoing research has shown northern shoveler (*Anas clypeata*; henceforth shoveler), green-winged teal (*Anas crecca*; teal), and common goldeneye (*Bucephala clangula*) comprise the majority of waterfowl using saline areas of the GSL during winter. Common goldeneye's winter diets comprise < 4% aggregate dry weight biomass of cysts (Vest and Conover 2011) so I did not include them in my study. During 2 winters, cysts comprised >50% aggregate dry weight of shoveler and teal diets (Vest and Conover 2011) so my research focused on these species. I collected shovelers and teal October–April during 2009-2010, 2010-2011, and 2011-2012. I collected birds from each of 3 areas of the GSL based on concentrations observed during monthly aerial surveys: the southern portion of Gilbert Bay, Farmington Bay, and Ogden Bay (Fig. 1). The collection period was divided into 4 seasons based on timing of waterfowl migration, changing food availability due to changing temperatures, and ice up of freshwater marshes. Seasons were fall (1 Oct–18 Nov), early winter (19 Nov–28 Dec), late winter (29 Dec–28 Feb), and spring (1 March–15 April).

I collected birds using steel shot over decoys (92%) and by jump shooting (8%) under authority of federal (MB693616I) and state (1COLL6550) scientific collection permits and protocol approved by Utah State University Institutional Animal Care and Use Committee (approval number 1309). Collected birds were frozen and were later thawed, at which time I aged and sexed each bird using plumage characteristics and recorded several measurements including body and wing length and body weight. I
removed the contents of the esophagus and gizzard for diet analysis. Food items were
sorted by species, and wet weights were taken to the nearest 0.01g. Wet weight was used
in place of dry weight to more easily compare with reported wet weight biomass removed
from the GSL during the commercial harvest of cysts. Cyst harvest statistics were
obtained directly from the Utah Division of Wildlife Resources: the regulatory agency in
charge of cyst harvest management.

Laboratory and Statistical Analysis

I used Program R for all statistical analysis (R Core Team 2012), and I considered
an alpha value of < 0.05 to be statistically significant. I calculated frequency of
occurrence and aggregate wet weight proportion of esophagus food contents for each
season and year. Aggregate proportion of food items from individual birds were used as
dependent variables in a permutational multivariate analysis of variance (PerMANOVA;
Anderson 2001, McArdle and Anderson 2001) with season (fall, early winter, late winter,
spring), year collected (2009-2010, 2010-2011, 2011-2012), bird age, and sex as
independent factors. PerMANOVA is a permutation-based ANOVA procedure that uses
pseudo $F$-tests on distance matrices to assess the difference among multivariate groups. I
used the Bray-Curtis method of distance, stratified on area, and ran 9,999 permutations.
Multiple pair-wise comparisons were conducted on significant factors. In addition, I
compare total food mass consumed in this study to that found in previous work to
evaluate food consumption among the GSL and other wintering areas.

Diet data from all age and sex classes were combined to determine the mass of
cysts consumed by shovelers and teal overwinter on the GSL. I calculated the mean mass
of cysts ingested by an individual bird during each year and season from the GSL using the following formula: (food mass in the esophagus + food mass in the gizzard) x (proportion of food in the esophagus that was cysts) x (hours of daylight + 1 hour twilight + 4 hours required for food to pass through the digestive system [Charalambidou et al. 2005]) / (4 hours for food to pass through digestive system) x (number of days per season). Hours of daylight were calculated as sunrise to sunset and averaged among all days in each period, and one half hour of twilight was added in the morning and evening to account for duck feeding during crepuscular hours. To determine how many birds were consuming cysts, I used aerial survey data conducted concurrent to this study (Chapter 2 this document) to determine the peak population of each species during each year and season. I then took the product of mean mass of cysts consumed by an individual during a season and the peak population estimate during that season to determine total cyst removal from the GSL by shovelers and teal. For example, in early winter of 2009-2010, I found an average of 3.1 g of food in shoveler esophagi and gizzards and 25% of food biomass in the esophagus was cysts, resulting in about 0.8 g of cysts consumed in an average bird. Average daylight, twilight, and food passage time divided by food passage rate resulted in 3.25 feeding periods and daily consumption of cysts per shoveler of just over 2.5 grams. There were 39 days in the period so each shoveler consumed about 100 g of cysts during early winter 2009-2010. The peak population during that period was 188,212 shovelers producing a total cyst consumption estimate of nearly 18,500 kg during early winter 2009-2010. Estimates of cyst removal are liberal due to the use of all
daylight hours rather than observed feeding time and the use of peak population rather than an average or daily count.

I used body mass to examine the condition of wintering shovelers and teal on the GSL and how body condition changes during the nonbreeding season on the GSL. Body mass alone is often a poor predictor of condition, but using morphometric measurements to correct for individual structural differences improves the value of body mass as a condition index (Johnson et al. 1985). I standardized body mass by the structural index given by DuBowy (1980) and Tietje and Teer (1988) to correct for structural size in body weight measurements and to compare to previous research. Average body length and wing length for each age (adult and juvenile) and sex (male and female) class were used to standardize body mass to body condition. The product of body length and wing length for each individual’s age and sex class was divided by the product of the individual’s body and wing length to create a structural index. I then divided a bird’s mass by its structural index to obtain each bird’s body condition where larger body condition measurement indicates better condition. I used ANOVA to compare body condition across seasons and years. Pair-wise comparisons of significant factors were tested using Tukey’s HSD test (Zar 1999).

RESULTS

I collected 720 shovelers during 2009-2010, 2010-2011, and 2011-2012, from October through April and 391 (55%) had food in their esophagus and were available for analysis. Most common food items were large brine shrimp and cysts, brine fly adults and larvae, wetland plant seeds and vegetative parts, and freshwater invertebrates (Table 3-1).
Diet did not differ by duck age or sex so final PerMANOVA models included collection year ($F_{2,379} = 5.47, P < 0.001$), season ($F_{3,379} = 39.92, P < 0.001$), and their interaction ($F_{6,379} = 2.39, P = 0.002$). Shoveler diets were different in 2009-2010 from both 2010-2011 ($F_{1,250} = 7.04, P < 0.001$) and 2011-2012 ($F_{1,276} = 5.16, P = 0.002$). Shovelers consumed more aggregate wet weight plant material and fewer freshwater invertebrates in 2009-2010 than the subsequent two years. Shoveler diets were different among all seasons. Shoveler diets in fall included all food types, though wetland plant seeds were encountered most often. Large brine shrimp composed much of shoveler’s diet in early winter, brine shrimp cysts in late winter, and wetland plant seeds in spring (Fig. 3-2). Total wet weight biomass (Table 3-1) and cyst biomass (Table 3-2) consumed by shovelers peaked each year in late winter and was lowest in spring.

The general pattern of shoveler body condition while on the GSL was a decrease from fall through early and late winter, then an increase in spring (Fig. 3-3). Body condition varied by year ($F_{2,379} = 22.07, P < 0.001$) and season ($F_{3,379} = 50.75, P < 0.001$). For males ($F_{2,223} = 15.30, P < 0.001$) and females ($F_{2,143} = 19.17, P < 0.001$), body condition in 2011-2012 was lower than 2009-2010 and 2010-2011. Season was also a significant factor in male body condition ($F_{3,223} = 58.10, P < 0.001$) and female body condition ($F_{3,143} = 19.02, P < 0.001$); the spring and early winter contrast was the only non-significant among season comparison.

I collected 534 green-winged teal of which 133 (25%) had food in their esophagi. Primary food items were similar to shovelers (Table 3-1). Teal diets did not differ by age or sex so final models included collection year, season, and their interaction. Only the
difference among seasons was significant ($F_{3, 120} = 3.61, P = 0.002$). Teal diets in fall were different than both early winter ($F_{1, 38} = 5.423, P = 0.003$) and late winter ($F_{1, 38} = 5.496, P < 0.001$), and teal diets in spring were also different than both early winter ($F_{1, 88} = 4.727, P = 0.004$) and late winter ($F_{1, 89} = 4.971, P = 0.003$). Teal consumed mostly wetland plant seeds in both fall and spring, and mostly brine shrimp cysts in early and late winter (Fig. 3-2). Total wet weight biomass (Table 3-1) and cyst biomass (Table 3-2) consumed by teal peaked during early and late winter. There were no significant differences among seasons and years in teal body condition in either males or females. The 2 teal collected during fall 2010 had a higher body condition than the average spring 2011 body condition of collected birds (Fig. 3-3).

During early winter and late winter, at peak brine shrimp cyst consumption, shovelers were up to 8 times more abundant than teal and as a population consumed more cyst biomass (Table 3-2). The greatest mass of cyst consumption by ducks occurred during the 2010-2011 winter. Cyst consumption by the populations of shovelers and teal ranged from about 336 kg to over 267,000 kg each year of this study (Table 3-2). Commercial brine shrimp harvest during the 3 years of this study removed 8.9, 11.1, and 9.1 million kg of brine shrimp cysts during 2009-2010, 2010-2011, and 2011-2012 respectively.

**DISCUSSION**

Brine shrimp cysts on the GSL are concentrated and abundant during winter, and their prevalence in shoveler and teal diets reflects this. The variety of food available to ducks and other birds on the GSL is reduced once fresh and brackish water areas freeze.
The few food types available to ducks on open waters of the GSL are higher in energy than foods typically utilized by wintering waterfowl making them a suitable substitute for food items found further south. Brine flies and brine shrimp offer about 22 kJ/g of dry weight in gross energy (Caudell and Conover 2006) compared to 10 kJ/g in saltwater amphipods (Ballard et al. 2004), 17 kJ/g in marine gastropods (Jorde and Owen 1988), and 5 kJ/g in the seeds of lamb’s quarter (*Chenopodium album*) and alkali bulrush (*Scirpus maritimus*; Dugger et al. 2007). The concurrent peaks of cyst consumption and total food consumption in late winter is likely related to cysts being difficult to digest. Though brine shrimp cysts have high protein content (64% of organic content), the shell of cysts is resilient to digestive enzymes (Horne 1966) so that ducks are unable to break the shell and utilize the energy of half the ingested cysts (MacDonald 1980). Ducks may have to increase cysts biomass consumed if they are only receiving nutrients from half the ingested biomass.

Shoveler diets on the GSL reflect seasonal changes in food availability. In the fall, there are many food types in brackish marshes and saline waters of the GSL. Shovelers consumed a variety of food items in the fall when birds are using both saline and brackish habitats. Live adult brine shrimp are still present in early winter but start to die off when water temperatures get too cold for adults to survive (Belovsky et al. 2011). Dead adult brine shrimp are concentrated along with cysts in streaks on the water’s surface, and both live and dead brine shrimp are available to shovelers throughout early winter. Shoveler abundance increases in saline areas of the GSL during early winter due to freeze up of marshes (Chapter 2 this document) and primarily large brine shrimp become their
primary food item. In late winter, only 2 food items are available in the GSL to ducks in large quantities; brine shrimp cysts and brine fly larvae. Brine fly larva are a principle component of wintering common goldeneye (Vest and Conover 2011), but they are not easily accessible to shovelers because the larva are concentrated on the lake bottom below the depth shovelers can feed. Instead, brine shrimp cysts are the primary food item of shovelers during late winter periods as cysts are concentrated on the surface. In spring as marshes thaw, shovelers resume feeding on wetland plant seeds and freshwater invertebrates as these foods become available. Vest and Conover (2011) found a similar dietary pattern of shovelers. They reported that wetland plant seeds and invertebrates dominated diets in October, but adult brine shrimp and cysts were the primary food item in December and February.

Teal were more reliant than shovelers on wetland plant seeds throughout their time on the GSL. Wetland plant seeds were consumed by teal more often than any other food item in terms of aggregate percent during every study period with the exception of early and late winter of 2011-2012. Teal have much smaller bills than shovelers and may not be as well suited to collecting large quantities of cysts and adult brine shrimp from floating concentrations. Smaller bills are more suited for picking individual food items from substrates (DuBowy 1988). Teal consume cysts during early and late winter, though wetland plant seeds are still utilized heavily during these periods. Vest and Conover (2011) found higher occurrence and aggregate percent biomass of cysts than seen in this study in teal diets in December and February and speculated teal were consuming cysts that had been concentrated near shore and on beaches while shovelers were consuming
large brine shrimp and cysts from streaks in deeper water. Brine fly larvae are also concentrated on beaches and I found higher occurrence of brine fly larvae in teal diets than in shoveler diets. I observed a similar pattern of teal occurrence in shallow water habitats near freshwater inflows where wetland plants extend into saline waters of the GSL (Roberts unpublished data).

I found food in the esophagi of collected shoveters and teal ranged from 0.5 to about 14 g with an average of 2.8 g wet weight, a similar result to previous studies of waterfowl diets. Wintering redheads (*Aythya americana*), northern pintails (*Anas acuta*), and lesser scaup (*Aythya affinis*) collected in the Laguna Madre had 1.4 to 5.2 g wet weight biomass in their esophagus (McMahan 1970). Seventeen species of waterfowl collected during the hunting season on the Louisiana coast contained in their digestive system an average of 1.2 g wet weight (Chamberlain 1959). Green-winged teal collected during the hunting season in South Carolina had an average of 1 g wet weight of food in their gizzard (McGilvrey 1966). Fall migrating teal (blue-winged [*Anas discors*] and green-winged) on the High Plains of Texas had 5.8–27.5 g wet weight in their esophagus (Rollo and Bolen 1969). Comparison to previous work suggests ducks on the GSL are consuming food at similar rates to other ducks during the nonbreeding season and the GSL provides an adequate amount of food for current waterfowl populations. My results of amount of food consumed are on the high end of previous findings, a similar pattern as other saltwater systems used by waterfowl during winter. Tietje and Teer (1996) found that wintering shoveters in Texas consumed more total mass in saltwater habitats (0.13–0.15 g wet weight) than freshwater habitats (0.05–0.06 g wet weight) and the average
mass consumed in their study during late winter was higher than previously mentioned studies in freshwater habitats.

The seasonal pattern of body condition change I documented among shovelers and teal on the GSL confirms results of waterfowl research in other areas (Baldassarre and Bolen 2006). Shovelers wintering on freshwater marshes along the Texas coast decreased in body condition through January before increasing condition in the spring (Tietje and Teer 1988). On saltwater marshes in the same study, shoveler body condition decreased earlier in the year and started to increase before conspecifics on freshwater marshes. Teal during the nonbreeding season on the Southern High Plains of Texas had their peak body condition in December, decreased through late winter, then increased in March before spring migration (Baldassarre et al. 1986). In my study, teal body condition was higher than body condition measured in the Southern High Plains of Texas, a more southern latitude wintering area (Baldassarre et al. 1986). Higher body condition throughout the winter, rather than a decrease in mid-winter, is likely needed to provide reserves during longer cold spells on the GSL compared to southern wintering areas.

Tietje and Teer (1988) observed that shoveler body weight and fat levels were higher in freshwater habitats than saltwater habitats along the Texas coast. The one exception to that finding was during the coldest observed periods of their study when shovelers in saltwater habitats were in better condition. This was thought to be a result of shovelers consuming more high-energy animal matter available in saltwater habitats during cold periods compared to the lower-energy plant matter available to shovelers in freshwater habitats (Tietje and Teer 1988). In contrast, mallards (Anas platyrhynchos)
and northern pintails (*Anas acuta*) wintering in California had consistently higher body weights in brackish habitats compared to freshwater marshes, even though birds in both areas were eating wetland plant seeds (Miller et al. 2009). Body condition measurements of shovelers in my study were similar to measurements of shoveler body condition in freshwater habitats of the Texas coast, and higher than birds in Texas coastal saltwater habitats. On the GSL, shovelers were consuming high-energy animal matter throughout the winter which may contribute to higher body condition. Freshwater habitats were not available to wintering shovelers around the GSL in winter, but the saline habitats and its high energy food sources make the GSL a suitable wintering area.

**MANAGEMENT IMPLICATIONS**

There is use of brine shrimp cysts by both commercial harvesters and ducks using the GSL during the nonbreeding season. Brine shrimp cyst removal by shovelers and teal is minimal compared to commercial harvest levels indicating shoveler and teal are not having a negative impact on cyst biomass available for commercial harvest. Furthermore, many cysts that are consumed by ducks pass through the digestive system and remain viable (Proctor 1964, Proctor and Malone 1965, van Leeuwen et al. 2012). Fifteen percent of cysts fed to and recovered from ducks hatched (MacDonald 1980) so much of the cyst biomass removed by ducks likely reenters the GSL as viable. In addition, much of the consumption by ducks occurs in southern Gilbert Bay, an area not utilized extensively by harvest boats (Utah Division of Wildlife Resources, personal communication) suggesting commercial harvest activities rarely physically overlap with foraging shovelers and teal. Consumption of cysts by shovelers and teal peaked during
the late winter period after harvest ended, indicating there is still enough biomass for feeding ducks. Cyst harvest is suspended each year if the level of cysts in the water column falls below 21 cysts/L, leaving cysts for avian consumption post-harvest and for reestablishment of adult brine shrimp during the subsequent spring. Cyst densities in the water column do not decline from February, after harvest is discontinued, through March (Belovsky et al. 2011). The lack of measurable decline in cyst densities due to consumption by birds is supported by our estimate of low cyst removal by ducks compared to commercial harvest. Current monitoring of cyst levels and regulation of commercial harvest accounts for removal by all sources, both harvesters and avian consumption, resulting in continuation of brine shrimp populations and the production of their cysts.

LITERATURE CITED


Dubowy, P. J. 1980. Optimal foraging and adaptive strategies of postbreeding male blue-
winged teal and northern shovelers. Thesis, University of North Dakota, Grand Forks, USA.


Stephens, D. W., and P. W. Birdsey, Jr. 2002. Population dynamics of the brine shrimp (brine shrimp franciscana) in Great Salt Lake and regulation of commercial of


Table 3-1. Wet weight of food consumed, % occurrence in esophagus, and aggregate wet weight % biomass in the diets of northern shoveler and green-winged teal collected from the Great Salt Lake, Utah, during the nonbreeding season (October through April) of three winters; 2009-2010, 2010-2011, and 2011-2012. Season dates are: fall (1 Oct-18 Nov), early winter (19 Nov-28 Dec), late winter (29 Dec-28 Feb), and spring (1 March-15 April).

<table>
<thead>
<tr>
<th></th>
<th>2009-2010</th>
<th></th>
<th></th>
<th>2010-2011</th>
<th></th>
<th></th>
<th>2011-2012</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fall</td>
<td>Early</td>
<td>Late</td>
<td>Spring</td>
<td>Fall</td>
<td>Early</td>
<td>Late</td>
<td>Spring</td>
<td>Fall</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>weight</td>
<td>weight</td>
<td>weight</td>
<td>weight</td>
<td>weight</td>
<td>weight</td>
<td>weight</td>
<td>weight</td>
</tr>
<tr>
<td>Mean wet weight of</td>
<td>32</td>
<td>0.5</td>
<td>2.4</td>
<td>14.3</td>
<td>0.2</td>
<td>4.6</td>
<td>2.0</td>
<td>14.4</td>
<td>0.7</td>
</tr>
<tr>
<td>food in esophagus (g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean wet weight of</td>
<td>34</td>
<td>0.7</td>
<td>0.7</td>
<td>1.1</td>
<td>0.6</td>
<td>1.2</td>
<td>0.7</td>
<td>2.6</td>
<td>0.6</td>
</tr>
<tr>
<td>food in gizzard (g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Occurrence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brine shrimp cysts</td>
<td>12.5</td>
<td>15.0</td>
<td>18.2</td>
<td>18.2</td>
<td>0.0</td>
<td>53.8</td>
<td>74.2</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Brine shrimp adults</td>
<td>6.3</td>
<td>18.8</td>
<td>32.1</td>
<td>10.7</td>
<td>63.6</td>
<td>67.9</td>
<td>36.0</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Brine fly adults</td>
<td>9.4</td>
<td>9.4</td>
<td>2.3</td>
<td>0.0</td>
<td>0.0</td>
<td>3.9</td>
<td>27.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Brine fly larvae</td>
<td>18.8</td>
<td>30.0</td>
<td>18.2</td>
<td>63.6</td>
<td>67.9</td>
<td>7.7</td>
<td>36.0</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Plant material</td>
<td>12.5</td>
<td>18.8</td>
<td>18.2</td>
<td>18.2</td>
<td>18.2</td>
<td>10.7</td>
<td>63.6</td>
<td>67.9</td>
<td>7.7</td>
</tr>
<tr>
<td>Wetland plant seeds</td>
<td>71.9</td>
<td>81.3</td>
<td>18.2</td>
<td>63.6</td>
<td>67.9</td>
<td>7.7</td>
<td>6.7</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Wetland invertebrates</td>
<td>6.3</td>
<td>14.3</td>
<td>2.9</td>
<td>5.9</td>
<td>6.3</td>
<td>5.9</td>
<td>2.9</td>
<td>5.9</td>
<td>6.3</td>
</tr>
<tr>
<td>Aggregate % biomass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brine shrimp cysts</td>
<td>12.2</td>
<td>44.8</td>
<td>7.7</td>
<td>86.0</td>
<td>18.2</td>
<td>0.0</td>
<td>19.0</td>
<td>71.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Brine shrimp adults</td>
<td>4.2</td>
<td>3.9</td>
<td>27.5</td>
<td>0.0</td>
<td>0.0</td>
<td>26.6</td>
<td>61.5</td>
<td>7.6</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>19</td>
<td>3</td>
<td>1</td>
<td>45</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>------------------</td>
<td>---</td>
<td>----</td>
<td>---</td>
<td>---</td>
<td>----</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>----</td>
</tr>
<tr>
<td><strong>Brine fly adults</strong></td>
<td>4.3</td>
<td>1.8</td>
<td>0.0</td>
<td>6.3</td>
<td>3.8</td>
<td>0.3</td>
<td>0.0</td>
<td>0.0</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>Brine fly larvae</strong></td>
<td>7.3</td>
<td>11.7</td>
<td>10.6</td>
<td>8.3</td>
<td>7.6</td>
<td>25.4</td>
<td>2.6</td>
<td>0.0</td>
<td>8.9</td>
</tr>
<tr>
<td><strong>Plant material</strong></td>
<td>8.9</td>
<td>11.4</td>
<td>8.8</td>
<td>13.5</td>
<td>2.0</td>
<td>5.8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Wetland plant seeds</strong></td>
<td>58.5</td>
<td>8.3</td>
<td>4.4</td>
<td>58.0</td>
<td>29.5</td>
<td>18.6</td>
<td>11.4</td>
<td>63.6</td>
<td>52.2</td>
</tr>
<tr>
<td><strong>Wetland invertebrates</strong></td>
<td>4.7</td>
<td>1.8</td>
<td>2.9</td>
<td>2.1</td>
<td>8.3</td>
<td>14.8</td>
<td>0.0</td>
<td>18.2</td>
<td>7.5</td>
</tr>
<tr>
<td><strong>Green-winged teal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N</th>
<th>19</th>
<th>3</th>
<th>1</th>
<th>45</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>24</th>
<th>7</th>
<th>9</th>
<th>12</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean wet weight of food in esophagus (g)</strong></td>
<td>2.3</td>
<td>0.1</td>
<td>8.0</td>
<td>0.5</td>
<td>0.3</td>
<td>0.1</td>
<td>NA</td>
<td>2.2</td>
<td>0.2</td>
<td>2.5</td>
<td>1.0</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Mean wet weight of food in gizzard (g)</strong></td>
<td>0.6</td>
<td>0.6</td>
<td>1.3</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
<td>0.5</td>
<td>0.6</td>
<td>0.4</td>
<td>0.6</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>% Occurrence</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Brine shrimp cysts</strong></td>
<td>0.0</td>
<td>33.3</td>
<td>100.0</td>
<td>6.7</td>
<td>0.0</td>
<td>0.0</td>
<td>NA</td>
<td>12.5</td>
<td>0.0</td>
<td>55.6</td>
<td>50.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Brine shrimp adults</strong></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>2.2</td>
<td>50.0</td>
<td>0.0</td>
<td>NA</td>
<td>4.2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Brine fly adults</strong></td>
<td>15.8</td>
<td>0.0</td>
<td>0.0</td>
<td>4.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>NA</td>
<td>4.2</td>
<td>14.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Brine fly larvae</strong></td>
<td>36.8</td>
<td>33.3</td>
<td>0.0</td>
<td>20.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>NA</td>
<td>29.2</td>
<td>0.0</td>
<td>11.1</td>
<td>8.3</td>
</tr>
<tr>
<td><strong>Plant material</strong></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>20.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>NA</td>
<td>4.2</td>
<td>14.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Wetland plant seeds</strong></td>
<td>73.7</td>
<td>33.3</td>
<td>0.0</td>
<td>75.6</td>
<td>50.0</td>
<td>0.0</td>
<td>0.0</td>
<td>NA</td>
<td>58.3</td>
<td>71.4</td>
<td>44.4</td>
<td>50.0</td>
</tr>
<tr>
<td><strong>Wetland invertebrates</strong></td>
<td>10.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
<td>NA</td>
<td>16.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Aggregate % biomass</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Brine shrimp cysts</strong></td>
<td>0.0</td>
<td>33.3</td>
<td>100.0</td>
<td>5.9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>12.4</td>
<td>0.0</td>
<td>53.8</td>
<td>49.1</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Brine shrimp adults</strong></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
<td>50.0</td>
<td>0.0</td>
<td>0.0</td>
<td>4.2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Brine fly adults</strong></td>
<td>10.7</td>
<td>0.0</td>
<td>0.0</td>
<td>2.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>4.1</td>
<td>14.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Brine fly larvae</strong></td>
<td>16.8</td>
<td>33.3</td>
<td>0.0</td>
<td>12.6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>19.9</td>
<td>0.0</td>
<td>1.7</td>
<td>8.3</td>
</tr>
<tr>
<td><strong>Plant material</strong></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>15.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>4.2</td>
<td>14.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Wetland plant seeds</strong></td>
<td>61.9</td>
<td>33.3</td>
<td>0.0</td>
<td>63.4</td>
<td>50.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>44.1</td>
<td>71.4</td>
<td>44.4</td>
<td>34.3</td>
</tr>
<tr>
<td><strong>Wetland invertebrates</strong></td>
<td>10.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
<td>0.0</td>
<td>11.2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Table 3-2. Amount of cysts (kg) removed by two species of ducks and the commercial harvest industry during three winters and the percent of total kg removed by each species and the harvest industry. Seasons are fall (1 Oct-18 Nov), early winter (19 Nov-28 Dec), late winter (29 Dec-28 Feb), and spring (1 March-15 April). Commercial harvest season occurred from 1 October to 31 January each year and no harvest occurred during the spring season. Duck removal was calculated with the formula: ((food mass in the esophagus + food mass in the gizzard) x (proportion of food in the esophagus that was cysts) x (hours of daylight + 1 hour twilight + 4 hours required for food to pass through the digestive system) / (4 hours for food to pass through digestive system x number of days per season)) x peak duck population during that period.

<table>
<thead>
<tr>
<th></th>
<th>Fall</th>
<th>Early winter</th>
<th>Late winter</th>
<th>Spring</th>
<th>Total</th>
<th>Percent of yearly total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Northern Shoveler</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009-2010</td>
<td>4,726</td>
<td>18,819</td>
<td>8,800</td>
<td>4</td>
<td>32,350</td>
<td>0.36</td>
</tr>
<tr>
<td>2010-2011</td>
<td>220,410</td>
<td>2,143</td>
<td>43,921</td>
<td>1,332</td>
<td>267,805</td>
<td>2.57</td>
</tr>
<tr>
<td>2011-2012</td>
<td>0</td>
<td>12,505</td>
<td>67,888</td>
<td>0</td>
<td>80,393</td>
<td>0.88</td>
</tr>
<tr>
<td><strong>Green-winged Teal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009-2010</td>
<td>0</td>
<td>6</td>
<td>300</td>
<td>0</td>
<td>336</td>
<td>0.00</td>
</tr>
<tr>
<td>2010-2011</td>
<td>0</td>
<td>0</td>
<td>1,546</td>
<td>0</td>
<td>1,546</td>
<td>0.01</td>
</tr>
<tr>
<td>2011-2012</td>
<td>0</td>
<td>4,199</td>
<td>5,899</td>
<td>0</td>
<td>10,098</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>Commercial Harvest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009-2010</td>
<td>5,669,693</td>
<td>2,768,810</td>
<td>556,437</td>
<td>NA</td>
<td>8,994,940</td>
<td>99.64</td>
</tr>
<tr>
<td>2010-2011</td>
<td>7,893,250</td>
<td>1,651,016</td>
<td>587,745</td>
<td>NA</td>
<td>10,132,010</td>
<td>97.41</td>
</tr>
<tr>
<td>2011-2012</td>
<td>3,793,894</td>
<td>3,263,328</td>
<td>2,028,509</td>
<td>NA</td>
<td>9,085,731</td>
<td>99.01</td>
</tr>
</tbody>
</table>
Figure 3-1. Map of the Great Salt Lake, Utah and principle bays mentioned in the text.
Northern shoveler

Green-winged teal
Figure 3-2. Aggregate % wet weight of diet items removed from northern shovelers and green-winged teal collected on the Great Salt Lake, Utah. Ducks were collected 1 October through 15 April in 2009-2010, 2010-2011, and 2011-2012. Seasons are fall (1 Oct-18 Nov), early winter (19 Nov-28 Dec), late winter (29 Dec-28 Feb), and spring (1 March-15 April).
a) [Graph showing body condition (g) by season for different years.]

b) [Graph showing body condition (g) by season for different years.]
Figure 3-3. Body condition (body weight standardized to body and wing length) of northern shovelers (a) and green-winged teal (b) collected on the Great Salt Lake, Utah throughout the nonbreeding season in 2009-2010, 2010-2011, and 2011-2012. No green-winged teal were measured during early and late winter 2010-2011. Seasons are fall (1 Oct-18 Nov), early winter (19 Nov-28 Dec), late winter (29 Dec-28 Feb), and spring (1 March-15 April). Error bars represent 95% confidence intervals.
CHAPTER 4

POPULATION FLUCTUATIONS AND DISTRIBUTION OF STAGING EARED GREBES (*PODICEPS NIGRICOLLIS*) IN NORTH AMERICA

**ABSTRACT:** Eared Grebes (*Podiceps nigricollis*) use saline ecosystems throughout much of their life-cycle, and greater than 90% of the North American population stage during fall at two hyper-saline lakes: Great Salt Lake (GSL), Utah, and Mono Lake, California. At the GSL, a commercial harvest of brine shrimp (*Artemia franciscana*) cysts occurs during fall and may impact Eared Grebe populations. I used photo surveys at both staging areas, and aerial counts on the GSL, to describe fall and winter population fluctuations of Eared Grebes staging on these lakes. The long-term (1997-2012) Eared Grebe population was 1.4 million on the GSL and 1.0 million on Mono Lake. Populations changed on GSL and Mono Lake in synchrony, indicating population regulation is likely occurring at wintering areas, not staging areas, and is correlated with El Niño effects. Eared Grebe abundance on the GSL was influenced by brine shrimp densities and did not overlap with concentrations of commercial harvest boats. Spatial segregation of commercial harvesters and Eared Grebes likely reduced negative impacts of anthropogenic disturbance on Eared Grebes. Knowledge of population changes within and among staging areas will help managers monitor long-term abundances and identify negative impacts between Eared Grebes and commercial harvesters.
INTRODUCTION

Many avian species use staging areas during fall or spring migration to build fat reserves or wait for favorable migration conditions. Knowledge of population distribution within and among staging areas can be used to manage population levels as well as mitigate impacts of anthropogenic disturbance on birds during a critical life-stage. Distribution can be measured both within and between major avian population concentrations to describe annual changes in population numbers and migratory connectivity among breeding sites, staging areas, and wintering sites. Nearly the entire North American population of Eared Grebes (*Podiceps nigricollis*) stages at two hyper-saline lakes during fall migration: Great Salt Lake (GSL), Utah, and Mono Lake, California. At these lakes, they exploit abundant food resources to build fat and meet energy demands of molt (Jehl 1988). After they arrive at staging areas, Eared Grebe’s flight muscles atrophy, digestive organs increase in size, and they become temporarily unable to fly (Jehl 1997). The size of the staging population at each lake varies by year and intra-year movement between staging areas is not thought to occur. The GSL and Mono Lake are subject to large swings in water levels due to variations in winter snowpack, the largest water source for both lakes. Water fluctuations result in large variations in lake surface area for Eared Grebes to utilize on the GSL, and changes in exposure of large shoals of tufa in Mono Lake along with access to the abundant brine fly (*Ephydra* spp.) larvae that occur on this tufa.

A large commercial harvest of aquatic invertebrates exists on the GSL. From October–January, commercial harvest of brine shrimp (*Artemia franciscana*) cysts (i.e.
eggs) occurs throughout the GSL. Harvested cysts are used around the world in aquaculture facilities where young brine shrimp hatched from cysts are fed to larval shrimp and fish. An average of 9.5 million kg of cysts is harvested annually, providing an economic effect to the region of over $56 million (Bioeconomics 2012). Cysts occur on the GSL in large floating masses, known as streaks, which provide easy access to large amounts of cyst biomass for both commercial harvesters and avian species. Human disturbances such as commercial boat activity can negatively impact daily energy balances of birds and alter population distributions (Owens 1977; Korschgen et al. 1985; Pfister et al. 1992). Commercial harvesters operate in pelagic areas where birds congregate and may influence population distribution of Eared Grebes both within the GSL and between the two staging areas.

Populations of Eared Grebes at staging areas go through tremendous increases and decreases among years (Jehl et al. 2002) but the reasons for these fluctuations are unknown. Weather-related downings during migration, disease, and El Niño impacts on the wintering grounds have all been implicated in Eared Grebe population fluctuations (Jehl 1996). Except for large, stochastic die-offs associated with downings, disease, and emaciation, annual survival of Eared Grebes is thought to be very high, particularly for juveniles (> 99%; Cullen et al. 1999). High survivorship along with a breeding age of 1 year old and an average brood size of 4 chicks (Cullen et al. 1999) indicates Eared Grebe populations are able to rapidly recover from large die-offs. Much of the North American population of Eared Grebes is concentrated in the fall at the two principle staging areas, GSL and Mono Lake, which makes these areas an ideal place to monitor the population
and a potential bottleneck if survivorship is severely reduced due to conditions on either lake.

I use two primary objectives to address causes of population changes. My first objective was to compare annual changes in Eared Grebe abundance on the GSL and Mono Lake to determine if conditions at staging areas or elsewhere in the annual cycle were impacting population fluctuations. There are at least three hypotheses that may explain variations among years in Eared Grebe populations at the GSL and Mono Lake. The GSL and Mono Lake populations could change in synchrony, suggesting that North American Eared Grebe populations respond to events at different places and times in their annual cycle and that events act on birds at both staging areas equally. Staging populations could change in opposite directions, with an increase in Eared Grebe numbers at one site coming at the expense of the other. Finally, there could be no pattern between staging population sizes, indicating that each site is hosting separate populations that winter and breed in different areas. My second objective was to examine whether commercial harvest of brine shrimp cysts might impact Eared Grebe abundance at the GSL. I describe the size of the Eared Grebes population on the GSL during late fall when staging coincides with commercial harvest of brine shrimp cysts to examine potential influence of harvest activities on Eared Grebe populations.

**MATERIALS AND METHODS**

**Study Area**

The GSL is a large, terminal lake in the eastern Great Basin. Open waters of the GSL cover over 440,000 ha when at a lake elevation of 1280 m above sea level (Baskin
Salinity across the GSL is variable due to concentrated areas of freshwater inflow and anthropogenic alterations of water exchange. Mono Lake is smaller but deeper than the GSL, and is located on the eastern slope of the Sierra Nevada Mountains in California. Mono Lake surface area is 18,260 ha when at an elevation of 1,950 m above sea level. It receives most of its inflow from five streams along its western shore. Since 1941, Mono Lake's level has been dropping as much as 60 cm a year due to diversion of four streams by the City of Los Angeles, causing the lake's salinity to increase 1.5-2% per year for three decades (Loeffler 1977). Unique hard substrate formations occur in both lakes. At the GSL, calcareous structures known as bioherms form reef-shaped substrate at various depths (Eardley 1938). At Mono Lake, calcareous tufa shoals form towers or mushroom-shaped formations near ancient springs and inflow sites (Dunn 1958). The high salinities in both systems support populations of only two macroinvertebrates, brine shrimp (*Artemia franciscana* in GSL, *A. monica* in Mono Lake) and brine flies. Densities of brine shrimp and their cysts vary in relation to salinity; their numbers are lowest in Gunnison Bay and in areas with the least saline water. In the GSL, many brine shrimp cysts float and form large streaks; in Mono Lake all the cysts sink and are not readily available to avian consumers. Brine fly larvae are found primarily along hard substrates above an anoxic, highly saline, bottom water layer (deep brine layer). In the GSL, larvae densities are ten times higher on bioherms and mud substrates than on sand substrates (Collins 1980; Wurtsbaugh 2007). In Mono Lake, brine fly larvae densities are highest on and near tufa formations (Herbst 1990). Individual larvae of Mono Lake brine flies are larger than GSL brine fly species, thus providing more mass when consumed.
Field Methods

The Utah Division of Wildlife Resources (UDWR) has conducted aerial photographic surveys of Eared Grebes on GSL each October since 1997, with some exceptions. Photo surveys have also been conducted on Mono Lake by the Mono Lake Committee and the Canadian Wildlife Service each October since 1995, with a few exceptions. Methods for photo surveys are described in detail in Boyd and Jehl (1998). Mono Lake is smaller than the GSL, and observers were able to completely survey and photograph the entire lake from the air; on the GSL surveys covered an average of 30% of the surface area using the following methods. Two surveyors and a pilot conducted initial surveys to determine areas of large concentrations of Eared Grebes. Transects were then established 1 km apart within areas of high Eared Grebe concentrations and the subsequent survey flight was flown the following day. Transects were flown over concentrations of birds using a fixed wing aircraft at approximately 380 m above the lake surface at 185 km/hr. During each transect, photos were taken every 10 seconds using a Canon EOS-1N single-lens reflex camera with a 35–100 mm lens and 800 ASA print film. The zoom lens was set at 100 mm to consistently photograph an area of equal size. The autofocus function of the lens was also disabled once the focal length from the plane to the lake surface was established. Photos are taken from a 10–cm diameter opening in the floor of the aircraft in such a way that the surface of the lens was parallel to the water surface. At the beginning and end of the survey, photos were taken of rectangular evaporation ponds of known dimensions near the shore of the GSL which were used to
determine the mean pond area, and subsequently, through comparison, the actual area for each photo.

Every photo was visually scanned, and individual Eared Grebes were counted. For each area of high Eared Grebe concentration, the mean number of grebes per photo was calculated. Mean grebes per photo and mean photo areas were used to extrapolate grebe density for each survey area, and subsequently, the total number of grebes within the survey area. For each estimate of Eared Grebe abundance from photo counts, a percentage of the total (15% for Mono Lake, 18% for GSL) was added to account for birds that were submerged when the photo was taken, based on behavioral data from Boyd and Jehl (1998) for Mono Lake and from Boyd and Paul (unpublished data) for GSL.

In addition to photo surveys, I conducted stratified random aerial counts of Eared Grebes on the GSL from October–January. I stratified the GSL based on salinity and geographic area of the lake to examine temporal and spatial distribution within the GSL. Transects were placed 500 m apart, running east to west, throughout each of seven strata: Carrington, Northern, Ogden, Central, Southern, Farmington, and Bear River (Fig. 4-1). I did not conduct surveys in Gunnison Bay as previous surveys had determined there was sparse use of this region by avian species due to salinities at or near saturation (> 25%; J. Vest unpublished data). I did not observe Eared Grebes in the Bear River stratum during any survey and only twice in the Farmington stratum. Each of the two surveys where Eared Grebes were present in Farmington the population represented less than 1% of the total observed so neither the Bear River or Farmington strata were used in further
interpretation or analysis. Each month transects were chosen randomly without replacement and constrained so that two adjacent transects were not surveyed in a single month. Aerial survey methodology followed Pearse et al. (2008). Transects were 1–km wide and flown at approximately 150 km/hr while an observer on each side of a fixed-wing aircraft counted all birds seen within 250 m.

Limnological data and density of invertebrates were collected twice a month at 17 sites in Gilbert and Ogden bays by UDWR. A description of this data collection can be found in Belovsky et al. (2011). Locations of commercial harvest boats were also collected at least twice a month during the harvest season by UDWR during harvest compliance checks. GPS coordinates were recorded for each boat seen during a 2–4 hour afternoon flight. Surveys of commercial harvest boats were limited to the Carrington, Northern, Central, and Southern strata as the Ogden stratum is closed to harvest.

**Statistical Analysis**

I calculated among year change in population size using photo surveys at each staging area to determine size and direction of change and compare among the two lakes. The GSL stratified aerial survey data were analyzed with individual transects as sample units. Overall and strata-specific population abundance and standard errors were calculated using the SURVEY package (Lumley 2004); these abundance estimates were converted to density estimates (birds per km$^2$) for each month and stratum and compared to commercial harvest boat densities for each stratum calculated on a monthly basis. Number of boats observed was standardized based on survey effort (number of days
surveyed) for the month and divided by total strata area to get a density (boats per day per km²).

I modeled Eared Grebe change in abundance on the GSL using log transformed counts for each stratum and each month. I constructed a set of biologically relevant generalized linear models and assessed them in Program R (R Core Team 2012), then ranked the models based on Akaike Information Criterion (AIC; Burnham and Anderson 2002). I used both biotic and abiotic variables to model the change in abundance of Eared Grebes among months and strata. Biotic variables were the density of brine shrimp adults, cysts, and all stages (naupuli, juveniles, and adults). Densities of different stages of brine shrimp were averaged across sampling sites within each stratum for each aerial survey period for use in models. Abiotic variables were average salinity, average daytime (0900 to 1800; °C) and daily low air temperatures during the 30 days preceding the survey, and the density of commercial cyst harvest boats. Harvest boat densities were calculated using survey data mentioned previously. Weather data were from the monitoring station located on Hat Island in the GSL (MesoWest 2013).

RESULTS

Combined Eared Grebe populations at the GSL and Mono Lake fluctuated between 1.0 and 4.5 million birds, as described by photo surveys 1997–2012 (Table 4-1). The long-term (1997–2012) average Eared Grebe population size on the GSL was 1.4 million; numbers varied from a low of 0.2 million birds during 2004 to a high of 3.4 million during 2012. The Mono Lake long-term average was 1.0 million Eared Grebes ranging from 0.2 million during 2008 to 1.8 million during both 1997 and 2000. Mono
Lake hosted a higher percentage of the Eared Grebe population through 2000, but since 2008 the GSL accounted for over 60% of the population each fall. Eared Grebe populations on the GSL and Mono Lake generally showed synchronous patterns of increasing and decreasing Eared Grebe abundance between years (Fig. 4-2). In 7 of the 9 years in which between-year differences could be calculated, the population changed synchronously (Table 4-1, Fig. 4-2).

Aerial strata survey data showed within year populations of Eared Grebes on the GSL ranged from about 0.4 to 3.8 million during the months of October–December, 2009–2011 (Table 4-2). No Eared Grebes were detected during this study in January, the final month of the brine shrimp cyst harvest. Yearly population fluctuations observed in October using aerial strata counts matched fluctuations seen in aerial photo surveys. Eared Grebe population size on the GSL peaked during December during the each of the 3 years of stratified aerial surveys.

The highest average densities of Eared Grebes occurred in the Ogden (1632 birds per km²) and Central (1284 birds per km²) strata of the GSL (Table 4-3). Commercial harvest boat densities were highest in the Carrington (0.024 boats per day per km²) and Northern (0.008 boats per day per km²) strata (Table 4-3). Densities of Eared Grebes within years decreased from October through December in the Ogden strata and exhibited large increases in the Central and Southern strata in December with the exception of 2009 when the Southern stratum had decreased Eared Grebe abundance into December (Table 4-3). Average adult brine shrimp densities in the GSL from October–November were higher during 2009 (1.13 brine shrimp/L) than during 2010 (0.34 brine shrimp/L, t₁₅ =
3.57, \( P = 0.008 \) or 2011 (0.45 brine shrimp/L, \( t_{15} = 4.39, P = 0.004 \)). Within year density of adult brine shrimp was highest in November of 2009, but highest in October the subsequent two years (Table 4-3).

Three of the top 5 competitive models (delta AIC \( \leq 2 \)) of Eared Grebe change in abundance on the GSL included either the density of brine shrimp adults or all stages, usually in conjunction with average low temperature the previous month (Table 4-4). The best predictor of change in Eared Grebe abundance was a negative relationship with the density of adult brine shrimp. The highest change in Eared Grebe density within a stratum occurred at the lowest brine shrimp densities. Alternatively, the highest brine shrimp densities resulted in the smallest changes in abundance. Change in abundance is a surrogate for population movement so this result can be interpreted as Eared Grebes left strata when brine shrimp densities were low, but remained within strata when brine shrimp densities were high. The relationship among Eared Grebe abundance and density of harvest boats was also a competitive model. This was a positive relationship where an increase in the density of harvest boats correlated with higher change in Eared Grebe abundance.

**DISCUSSION**

I examined three hypotheses that may explain population variations within and among years on the two staging areas, the GSL and Mono Lake: the two populations would change in synchrony, populations would change in opposite directions, or there would be no pattern between populations. Populations on the GSL and Mono Lake changed in synchrony most years, and exhibited no pattern in other years (Fig 4-2).
Though survey methods at the two staging areas were slightly different, they were consistent over time, so trends in the data should reflect actual patterns. Telemetry research on a few colonies in British Columbia, Canada, showed that Eared Grebes from the same breeding colony stage on both the GSL and Mono Lake (Boyd et al. 2000). Banding data also support this. Individual Eared Grebes banded in the same geographic area were recovered at both staging areas (Jehl and Yochem 1986). The pattern of synchronous population changes implies that birds from the same breeding and wintering areas stage at the two staging areas rather than GSL and Mono Lake drawing from different populations.

My data on staging areas indicate that conditions on the breeding or wintering grounds had a higher impact on fall staging population sizes than conditions at the GSL and Mono Lake. This is in contrast to the finding of Belovsky et al. (2011) who stated that the abundance of brine shrimp at the GSL one year affects Eared Grebe abundance on the GSL the following year. Jehl (1996) and Jehl et al. (2002) hypothesize that large stochastic events that impact migration to, and survival on, the southern wintering areas may be the primary population regulation mechanism in Eared Grebes; my longer data set confirms this. At Mono Lake, beach counts of Eared Grebe mortality indicated the relative risk of mortality was lower during fall staging (November and December) than during spring migration (March) or during summer (June; Jehl 1988). Food shortage in winter (Jehl et al. 2002) has been implicated as the primary factor in population regulation, and our data show population lows on the GSL following El Niño years of 1997, 2003, 2006, and 2009 (noaa.gov, accessed 29 October, 2012). On Mono Lake,
Eared Grebe populations dropped following the El Niño of 1997 and remained steady after 2009. Unfortunately, Eared Grebe surveys during the other two El Niño events were not conducted directly before and after those events. Eared Grebe populations did increase during the years after the 2003 and 2006 El Niño events implying that the Eared Grebe staging population on Mono Lake may have been decreased after those events. El Niño events produce warmer water in the California Current, including the principle Eared Grebe wintering areas in the Gulf of California, resulting in elevated surface water temperatures (Kahru and Mitchell 2000). This reduces primary productivity overall (Garate-Lizárraga and Soqieiros Beltrones 1998; Kahru and Mitchell 2002) and may push remaining invertebrate prey species below the depth Eared Grebes feed. The relationship among El Niño effects and reduced survival of marine birds around Baja California has been shown for various species during multiple El Niño events (Veit et al. 1996; Velarde et al. 2004). Large numbers of dead Eared Grebes were found along the coast of Baja California during an El Niño event in the winter of 1982-1983 (Nishikawa et al. 1984). The El Niño event of 1997 was considered one of the strongest in the last century (Wolter and Timlin 1998), and my data showed the next year had the second to largest single decrease in total Eared Grebe staging population size, behind only the 2006 El Niño year. The decline of Eared Grebes during the 1997 El Niño event has been described by Jehl et al. (2002) who reported finding thousands of dead Eared Grebes in their principal wintering area in the Gulf of California. Jehl et al. (2002) estimated a minimum mortality of 400 000 Eared Grebes, likely the result of a reduction in food.
I found that Eared Grebe populations on North America’s two staging areas during October exhibited large fluctuations among years, including two instances of over 100% changes between two consecutive years, and one of those differences being a change over 400%. Eared Grebes have an average brood size of 4 and recruitment rate of about 1 (Cullen et al. 1999), so a one year change from 230 000 to 1 300 000 would seem too large to be possible. Population increases of over 50% are plausible due to low annual mortality (Cullen et al. 1999), particularly juvenile survivorship that can reach 99% during fall staging (Jehl 1988; Jehl et al. 2002). Low annual mortality cannot account for the largest changes that may instead be explained by incomplete migration by the time photo surveys were conducted or unrepresentative areas photographed during surveys. In addition, there were large standard errors involved in my population estimates on different dates (32-60% of mean), so this variability likely influenced my interpretation.

On the GSL, aerial survey counts showed Eared Grebe populations changed in size and distribution within a single year, with the largest and densest populations occurring in December. Stratified aerial transect counts showed increased abundance through December which may be explained by one of three factors. First, Eared Grebes continue to migrate to the GSL from breeding areas throughout the fall. This seems unlikely given that previous research has shown migration to the GSL is completed by mid-October and has not been shown to extend past early November (Jehl and Johansson 2002; Jehl and Henry 2010). Second, Eared Grebes are migrating to the GSL from Mono Lake. Movements between the two staging areas have not been shown in the past and once Eared Grebes reach staging areas they lose the ability to fly, so this explanation also
seems unlikely. Finally, there may be fewer Eared Grebes foraging under water in December resulting in more Eared Grebes available to be counted. As the fall progresses, brine shrimp numbers decline and Eared Grebes consume less food (Chapter 5 this manuscript), so more Eared Grebes are likely on the surface during aerial surveys in December compared to October. Our aerial survey counts in October were more conservative than photo surveys which is understandable given that visual counts during aerial surveys tend to undercount individuals (Caughley 1974; Savard 1982), particularly in relation to the photo surveys conducted in this research. For example, in October 2010 photo surveys produced a count of 895 000 birds while aerial surveys estimated 801 000 Eared Grebes.

Change in abundance of Eared Grebes among strata on the GSL in a year was influenced by GSL adult brine shrimp densities. High brine shrimp densities were associated with small changes in Eared Grebe abundance. Small changes in abundance indicate Eared Grebes were not moving among strata suggesting food availability was adequate and there was no need to search for food. The largest changes in Eared Grebe abundance, and hence largest movements, among strata occurred when brine shrimp densities were low in December. This may indicate that Eared Grebes were searching for food at low brine shrimp densities. Alternatively, the relationship among change in Eared Grebe abundance within strata and brine shrimp densities may not be associated with brine shrimp density, rather, during late winter when brine shrimp densities were decreasing, Eared Grebes were preparing for migration and stopped looking for food. Average low temperature the previous month was present in both the top models,
supporting the hypothesis that preparation for migration in December was more important than searching for food.

My inference from these models may be limited by data measurements within the GSL. Prey availability data were not obtained from the same number of sites within each strata, and only from one site in the Ogden strata. This may not represent the actual prey availability, but the methods were consistent over time so trends are likely accurate. In addition, Eared Grebe abundance was estimated from counts on transects while other model variables were measured at points throughout the GSL. Different spatial scales of data collection may make it difficult to link changes in influencing factors to changes in Eared Grebe densities. The models used may be limited and have low predictability, but they represent the variables of interest to this study.

Studies of waterfowl (Korschgen et al. 1985) and shorebirds (Pfister et al. 1992) on migratory staging areas showed that boat activity increases movement and alters population distribution of birds, with avoidance of boats being the principle finding. Unlike other staging birds, Eared Grebes are not able to fly during the staging period due to decreased breast muscle size and increased digestive organ mass, therefore they are unable to immediately move away from disturbances. In contrast, my model of change in Eared Grebe abundance in relation to harvest boat density show that birds are increasing their movement into strata with increased boat density, likely as birds congregate in open waters before migration. The Ogden Bay stratum is closed to commercial harvesters, removing a source of disturbance in an area where Eared Grebe densities were high in October and November. Eared Grebes left the Ogden Bay stratum in December and
congregated in the Central and Southern strata, despite the higher density of harvest boats in those strata compared to Ogden. In early fall, disturbance is minimal as the highest densities of harvest boats and Eared Grebes occurred in separate strata. Movement of Eared Grebes from strata lacking disturbance by commercial boats to strata with harvest boat activity indicates that the disturbance factor of commercial harvesters in the GSL is minimal.

North American breeding populations of Eared Grebes increased from 1983-2005 (Anderson et al. 2007), and populations on the GSL increased from 2010-2012, during which the commercial brine shrimp cyst harvest twice set records for the amount of biomass removed. Our results indicate that associations with commercial harvesters of brine shrimp cysts do not negatively impact Eared Grebe abundances on the GSL. Jehl et al. (1999) argued that Mono Lake hosts more Eared Grebes due to a safer migration corridor, but our data suggest that more birds are using the GSL in recent years, despite constant brine shrimp cyst harvest. In addition, my data further supports population regulation of Eared Grebes at wintering areas or breeding areas, rather than at the GSL or Mono Lake during the fall staging period.

REFERENCES


Jehl, J.R., Jr., and Yochem, P.K. 1986. Movements of Eared Grebes indicated by banding
recoveries. J. Field Ornithol. 57(3): 208–212.


Table 4-1. Estimated population size of fall staging Eared Grebes based on photo counts corrected for submerged birds from Great Salt Lake, Utah, and Mono Lake, California, during October, 1997-2012, and the % difference from the previous year within each staging area when possible.

<table>
<thead>
<tr>
<th>Year</th>
<th>Great Salt Lake</th>
<th>Mono Lake</th>
<th>Total</th>
<th>Great Salt Lake % difference</th>
<th>Mono Lake % difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>1 460 200</td>
<td>1 800 000</td>
<td>3 260 200</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1998</td>
<td>522 300</td>
<td>900 000</td>
<td>1 422 300</td>
<td>-64</td>
<td>-50</td>
</tr>
<tr>
<td>1999</td>
<td>1 008 700</td>
<td>1 300 000</td>
<td>2 308 700</td>
<td>93</td>
<td>44</td>
</tr>
<tr>
<td>2000</td>
<td>1 127 300</td>
<td>1 800 000</td>
<td>2 927 300</td>
<td>12</td>
<td>38</td>
</tr>
<tr>
<td>2001</td>
<td>1 878 000</td>
<td>1 400 000</td>
<td>3 278 000</td>
<td>67</td>
<td>-22</td>
</tr>
<tr>
<td>2002</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2003</td>
<td>930 000</td>
<td>NA</td>
<td>930 000</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2004</td>
<td>233 400</td>
<td>770 000</td>
<td>1 003 400</td>
<td>-75</td>
<td>NA</td>
</tr>
<tr>
<td>2005</td>
<td>1 358 500</td>
<td>1 080 000</td>
<td>2 438 500</td>
<td>482</td>
<td>40</td>
</tr>
<tr>
<td>2006</td>
<td>2 703 400</td>
<td>NA</td>
<td>2 703 400</td>
<td>99</td>
<td>NA</td>
</tr>
<tr>
<td>2007</td>
<td>1 200 600</td>
<td>NA</td>
<td>1 200 600</td>
<td>-56</td>
<td>NA</td>
</tr>
<tr>
<td>2008</td>
<td>1 173 400</td>
<td>226 000</td>
<td>1 399 400</td>
<td>-2</td>
<td>NA</td>
</tr>
<tr>
<td>2009</td>
<td>1 141 800</td>
<td>609 500</td>
<td>1 751 300</td>
<td>-3</td>
<td>170</td>
</tr>
<tr>
<td>2010</td>
<td>895 800</td>
<td>591 100</td>
<td>1 486 900</td>
<td>-22</td>
<td>-3</td>
</tr>
<tr>
<td>2011</td>
<td>2 304 200</td>
<td>1 020 000</td>
<td>3 324 200</td>
<td>157</td>
<td>73</td>
</tr>
<tr>
<td>2012</td>
<td>3 422 400</td>
<td>1 160 000</td>
<td>4 582 400</td>
<td>49</td>
<td>14</td>
</tr>
</tbody>
</table>
Table 4-2. Estimated Eared Grebe population (± SE; in thousands) on the Great Salt Lake, Utah, as derived from monthly stratified aerial survey counts, October–January, 2009–2012.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Oct</td>
<td>1104 ± 493</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>1593 ± 556</td>
</tr>
<tr>
<td></td>
<td>Dec</td>
<td>2219 ± 1183</td>
</tr>
<tr>
<td></td>
<td>Jan</td>
<td>0 ± 0</td>
</tr>
<tr>
<td>2010</td>
<td>Oct</td>
<td>801 ± 404</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>838 ± 503</td>
</tr>
<tr>
<td></td>
<td>Dec</td>
<td>1745 ± 687</td>
</tr>
<tr>
<td></td>
<td>Jan</td>
<td>0 ± 0</td>
</tr>
<tr>
<td>2011</td>
<td>Oct</td>
<td>3432 ± 1501</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>2072 ± 668</td>
</tr>
<tr>
<td></td>
<td>Dec</td>
<td>3838 ± 1228</td>
</tr>
<tr>
<td></td>
<td>Jan</td>
<td>0 ± 0</td>
</tr>
</tbody>
</table>
Table 4-3. Densities of Eared Grebes (#/km$^2$; EAGR), commercial brine shrimp cyst harvest boats (#/km$^2$; Boats) and adult brine shrimp (#/L; Brine shrimp) in aerial survey strata within the Great Salt Lake, Utah during the commercial brine shrimp cyst harvest season, 2009–2011. Commercial harvest is not allowed in the Ogden stratum, so no boat densities were calculated.

| Year | Month | EAGR | Boats | Brine shrimp | EAG R | Boats | Brine shrimp | EAG R | Boats | Brine shrimp | EAG R | Boats | Brine shrimp | EAG R | Boats | Brine shrimp | EAG R | Boats | Brine shrimp | EAG R | Boats | Brine shrimp |
|------|-------|------|-------|-------------|--------|-------|-------------|--------|-------|-------------|--------|-------|-------------|--------|-------|-------------|--------|-------|-------------|--------|-------|-------------|--------|
| 2009 | Oct   | 1    | 0.021 | 0.82        | 415    | 0.012 | 0.77        | 2433   | NA    | 0.89        | 143    | 0.004 | 1.62        | 124    | 0.007 | 1.50        |
|      | Nov   | 264  | 0.019 | 1.41        | 4      | 0.011 | 1.57        | 1222   | NA    | 1.06        | 181    | 0.007 | 2.00        | 3557   | 0.004 | 1.99        |
|      | Dec   | 0    | 0.017 | 0.06        | 408    | 0.004 | 0.39        | 92     | NA    | 0.00        | 3676   | 0.007 | 0.04        | 1073   | 0      | 0.09        |
| 2010 | Oct   | 0    | 0.023 | 0.90        | 139    | 0.005 | 1.09        | 1501   | NA    | 1.41        | 142    | 0.004 | 0.92        | 656    | 0.004 | 1.22        |
|      | Nov   | 0    | 0.045 | 0.27        | 0      | 0.004 | 0.51        | 845    | NA    | 0.77        | 0      | 0      | 0.24        | 0      | 0      | 0.04        |
|      | Dec   | 841  | 0.002 | 0.02        | 252    | 0.007 | 0.04        | 1      | NA    | 0.05        | 1069   | 0.031 | 0.01        | 2579   | 0      | 0.09        |
| 2011 | Oct   | 493  | 0.030 | 0.93        | 686    | 0.011 | 1.04        | 6143   | NA    | 0.78        | 1747   | 0.002 | 1.04        | 154    | 0      | 0.94        |
|      | Nov   | 1059 | 0.023 | 0.47        | 774    | 0.018 | 0.57        | 2454   | NA    | 0.30        | 729    | 0.004 | 0.58        | 98     | 0      | 0.58        |
|      | Dec   | 1171 | 0.032 | 0.08        | 1097   | 0.004 | 0.04        | 0      | NA    | 0.03        | 3876   | 0.004 | 0.09        | 3272   | 0      | 0.09        |
|      | Mean  | 425  | 0.024 | 0.55        | 419    | 0.008 | 0.67        | 1632   | NA    | 0.59        | 1285   | 0.007 | 0.73        | 1279   | 0.002 | 0.78        |
Table 4-4. Competitive (delta AIC < 2) models of change in abundance of Eared Grebes on the Great Salt Lake, Utah, October–December, 2009–2011. Eared Grebe abundance was modeled with density of all brine shrimp life stages (allstages), adult brine shrimp (bsadults), and cysts (cysts), and average salinity over the previous month (salinity), average low temperature during the previous month (prevtemp), and the density of commercial brine shrimp cyst harvest boats (boats).

<table>
<thead>
<tr>
<th>Model</th>
<th>Number of parameters</th>
<th>AIC</th>
<th>Delta AIC</th>
<th>AIC weight</th>
<th>Adj. r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>bsadults+prevtemp</td>
<td>4</td>
<td>657.59</td>
<td>0</td>
<td>0.12</td>
<td>0.102</td>
</tr>
<tr>
<td>allstages+prevtemp</td>
<td>4</td>
<td>657.72</td>
<td>0.14</td>
<td>0.11</td>
<td>0.097</td>
</tr>
<tr>
<td>boats</td>
<td>3</td>
<td>657.89</td>
<td>0.31</td>
<td>0.10</td>
<td>0.008</td>
</tr>
<tr>
<td>bsadults</td>
<td>3</td>
<td>658.13</td>
<td>0.54</td>
<td>0.09</td>
<td>0.001</td>
</tr>
<tr>
<td>bflarvae+prevtemp</td>
<td>4</td>
<td>658.47</td>
<td>0.89</td>
<td>0.08</td>
<td>0.075</td>
</tr>
</tbody>
</table>
Fig. 4-1. Map of Great Salt Lake, Utah and aerial survey strata used to enumerate Eared Grebe population abundance and distribution.
Fig. 4-2. Plot of estimated Eared Grebe populations on Great Salt Lake, Utah and Mono Lake, California. Estimates were calculated from annual October aerial photography surveys conducted since 1997.
CHAPTER 5

EARED GREBE DIET ON GREAT SALT LAKE, UTAH, AND COMPETITION WITH THE COMMERCIAL HARVEST OF BRINE SHRIMP CYSTS

ABSTRACT Interactions between wildlife and commercial harvest industries need to be understood to manage resources for all users. About 1.5 million eared grebes (Podiceps nigricollis), half the North American population, stage on Utah’s Great Salt Lake (GSL) each fall. A $56 million commercial harvest industry also operates during fall when the harvest of brine shrimp (Artemia franciscana) cysts occurs. Eared grebes and commercial harvest both utilize brine shrimp cysts creating a potentially adverse relationship. I assessed the diet of eared grebes to determine the extent to which they are dependent on brine shrimp and their cysts. I collected individual birds to measure diets and examine changes in body condition of staging eared grebes. Cysts were consumed by 40% of collected eared grebes and made up > 75% aggregate biomass of stomach samples. Despite the high occurrence of cysts in stomach samples, cysts were not the primary food item of eared grebes. Passage of cysts through the digestive system is likely slowed in eared grebes stomachs by a mass of feathers, so esophagus samples are a better indicator of diet. Large brine shrimp were the primary food collected from the esophagus from October until December. After cold water temperatures caused a die-off of adult brine shrimp, cysts became more prevalent in the diet of eared grebes. Analysis of mass of cysts removed from the digestive tract suggest eared grebes removed about 10% of the total mass that was removed by the commercial harvest industry. As diets shifted to cysts in December, eared grebe body weights decreased as their diet shifted to brine shrimp
cysts. Current monitoring and management of commercial harvest are sufficient to maintain yearly populations of adult brine shrimp to sustain eared grebes populations.

**INTRODUCTION**

Interactions between avian populations and commercial fisheries have been studied across many avian species including double-crested cormorants (*Phalacrocorax auritus*; Glahn and Brugger 1995) and various seabirds (Tasker et al. 2000). Impacts of fisheries on avian populations can be direct, through killing of individuals from nets or other fishing gear, or indirect, by altering food supplies. These interactions may alter distributions of birds or reduce their survival. Birds can affect fishery industries as well, when large concentrations of aquatic birds feed on either commercially valuable wild stock, or by invading aquaculture facilities and consuming captive stock. To mitigate conflict, it is important to measure the amount of resources used by both birds and industries and the spatial and temporal use of those resources.

A large commercial harvest of brine shrimp (*Artemia franciscana*) cysts (i.e. eggs) takes place on the Great Salt Lake (GSL), Utah, from October through January. Harvested cysts are used around the world in aquaculture facilities where they are hatched and fed to young shrimp and fish. An average of 9.5 million kg of cysts is harvested annually from the GSL, providing an annual economic effect to the region of > $56 million (Bioeconomics 2012). Cysts occur on the GSL in large floating masses, known as streaks, which provide easy access to large amounts of cyst biomass for both commercial harvesters and avian species.
The GSL’s low-gradient bottom, highly variable water levels, and abundant salt-water tolerant invertebrates create productive habitat used by millions of waterbirds each year (Aldrich and Paul 2002). Avian species that utilize the GSL consume adult brine shrimp (Colwell and Jehl 1994, Conover et al. 2009, Vest and Conover 2011) and cysts (Vest and Conover 2011), and harvesting boats operate in pelagic areas where birds congregate. An average of 1.5 million eared grebes (*Podiceps nigricollis*), more than half of the North American population, use the GSL during the fall as a staging area before continuing their migration to wintering areas in the Gulf of California (Aldrich and Paul 2002). After arrival at the GSL, eared grebe’s flight muscles atrophy and digestive organs increase in size to enhance food digestion and building of fat reserves. Eared grebes also go through a prebasic molt and lose the ability to fly while on the GSL. In late November and early December, organ trends reverse, and flight capacity is regained after an increase in flight muscle mass (Jehl 1997). While staging on the GSL, eared grebes may interact with commercial harvesters of brine shrimp cysts through utilization of the same resource (cysts) or through overlapping spatial use.

The objectives of this research were to describe the diet of staging eared grebes on the GSL and describe cyst use and removal by eared grebes and the commercial cyst harvest. I assessed eared grebe diets and body condition spatially and temporally to describe resource use and the physiological condition of eared grebes while on the GSL.
**STUDY AREA**

The GSL is a large, terminal lake in the eastern Great Basin. Open waters of the GSL cover over 440,000 ha when at a lake elevation of 1280 m above sea level (Baskin 2005). Salinity is variable due to concentrated areas of freshwater inflow and anthropogenic alterations of water exchange. The high salinities in the pelagic areas of the GSL support populations of only 3 macroinvertebrate species, brine shrimp and brine flies (*Ephydra* spp.[2 species]). Brine shrimp hatch from overwintered cysts in the spring as water temperature increases, then progress through 3 stages of increasing size; naupuli, juveniles, and adults. Juveniles and adults graze on phytoplankton and reach peak numbers in early summer, before decreasing as they reduce their food source (Stephens and Birdsey 2002). There is a second, smaller peak in adult brine shrimp abundance in late summer after a rebound of phytoplankton in GSL waters. Throughout summer most reproduction is ovoviparity where eggs hatch in the ovisac and young are released into the water. In fall, when water temperatures drop to levels too low for juvenile or adult survival, oviparity, or the production of diapausing cysts, is the primary reproductive mechanism. A portion of cysts on the GSL float and form large concentrations known as streaks that may remain over winter on the water’s surface or may be deposited on beaches and hatch the following spring. Densities of brine shrimp and their cysts vary across the GSL; their numbers are lowest in areas with less saline water, such as Farmington and Bear River bays (Stephens and Birdsey 2002). Brine fly larvae are found primarily along the substrates of the GSL above an anoxic water layer; larvae densities
are ten times higher on calcareous reefs (bioherms) and mud substrates than on sand substrates (Collins 1980, Wurtsbaugh 2007).

METHODS

Field and laboratory methods

I collected eared grebes from October through December from the GSL in 2010 and 2011. Birds were collected using shotguns firing steel shot under authority of federal (MB693616I) and state (1COLL6550) scientific collection permits and protocol approved by Utah State University Institutional Animal Care and Use Committee (approval number 1309). Their wariness and avoidance behavior did not allow us to watch for feeding before collection, so birds were collected opportunistically. I attempted to collect 25-30 birds each month from each of 4 areas of the GSL: the southern portion of Gilbert Bay, the northern point of Antelope Island, Fremont Island, and Carrington Bay on the west side of the GSL (Fig. 5-1). Birds were frozen as quickly as possible after collection. Birds were later thawed, at which time I aged and sexed each bird and recorded several external and internal measurements. Age was assigned by eye color (bright red in adults, brown to pale orange in juveniles; Storer and Jehl 1985) and sex was determined by examination of gonads. External measurements included body and wing length and body weight. Internal measurements were the wet weights of empty stomach, intestines, and one side of breast muscle. I removed the contents of the digestive tract (esophagus through the stomach) for analysis. Eared grebes ingest feathers which are stored in their stomach. Feathers slow the passage of food into the intestine (Jehl 1988) and may result in longer passage time for harder food items. Longer storage times for harder food items may bias food samples
from the stomach so we sorted these food items separately from the esophagus. Food items were sorted by taxa, and wet weights were taken to the nearest 0.01g.

Limnological data and density of invertebrates were collected bi-monthly at 17 sites across Gilbert and Ogden bays by the Utah Division of Wildlife Resources throughout 2010 and 2011. A description of how these data were collected can be found in Belovsky et al. (2011). Cyst harvest statistics were wet weight of harvested material obtained from the Utah Division of Wildlife Resources, Great Salt Lake Ecosystem Program. Reported weight of harvest includes cysts and all other biomass removed by harvesters, so estimates of cyst removal from reported harvest are biased high.

**Statistical Analysis**

I used Program R for all statistical analysis (R Core Team 2012). I considered an alpha value of < 0.05 to be statistically significant. I calculated frequency of occurrence and aggregate wet weight proportion of each food item for each area of the lake, month, and year. Aggregate proportion of food items from individual birds were used as dependent variables in a permutational multivariate analysis of variance (PerMANOVA; Anderson 2001, McArdle and Anderson 2001) with region of the GSL (Antelope Island, Carrington Bay, Fremont Island, and Gilbert Bay), month, year, age, and sex as independent factors. PerMANOVA is a permutation-based ANOVA procedure that uses pseudo $F$-tests on distance matrices to assess the difference between multivariate groups. I used Bray-Curtis method of distance and ran 9999 permutations. Multiple pair-wise comparisons were conducted on significant factors.
Brine shrimp densities were plotted and compared among years using a
generalized linear model. I also plotted eared grebe mass versus brine shrimp densities
and changes in body measurements for comparison with previous findings of Jehl (1997,
2007) and Caudell and Conover (2006a). I used the amount of cysts ingested by eared
grebes during each year and month to estimate the removal of cysts by eared grebes from
the GSL system. To determine how many birds were consuming cysts I used aerial
survey data conducted concurrent to this study (Chapter 4 this document). I multiplied the
average wet weight of cysts removed from the esophagus and stomach of birds with cysts
in their digestive tract during each year/month by 1.5. This assumes a 16 hour retention
time of cysts in bird digestive systems as measured by Proctor and Malone (1965). Grams
of cysts per day per bird were then multiplied by the product of the peak population count
during each year/month and the percent of birds collected with cysts in their esophagus.
This number was multiplied by the total number of days in each month to obtain a total
cyst removal for that time frame. For example, in October of 2010, 74% of collected
eared grebes had cysts in their esophagus and stomach, with an average of 13.4 g per
bird. Seventy-four percent of the population during that time was 590,000 eared grebes
which were consuming 20.7 g (13.4 g * 1.5) cysts/day. Daily consumption by all eared
grebes was over 11.9 million g each day of October. Total cyst consumption by eared
grebes during October of 2010 was over 360,000 kg.
RESULTS

I collected 398 eared grebes from October 2010 through December 2011. Only 69 (17%) had food in their esophagus and 317 (80%) had food in their stomach; my analysis was restricted to eared grebes with food in their esophagus or stomach. Age ratios (adults:juvenile) of birds used in esophagus and stomach analysis were 9:1 and 8:1, respectively. The sex ratio for both esophagus and stomach samples was 2 males:1 female. There was no significant difference among months or years in either age or sex ratio of collected eared grebes. Principle food items were brine shrimp and their cysts and brine fly larvae based on both esophagus and stomach samples. My analysis combined pupae and larvae into one category, brine fly larvae, though pupae represented < 15% of that category observed in diet samples. Other foods found in small amounts were adult brine flies, plant material, wetland plant seeds, and freshwater invertebrates (Table 5-1). Primarily large brine shrimp were the most common food item found in the esophagus, occurring in 81% of specimens that contained food and representing 72% of the aggregate wet weight biomass of food from the esophagus. Food found in the stomach was dominated by brine shrimp cysts, which occurred in 95% of samples with food in the stomach and represented 76% of the aggregate biomass.

Due to low sample sizes for esophageal contents, food items that represented < 5% aggregate biomass were removed from further analysis; this left large brine shrimp, cysts, and brine fly larvae for analysis of esophagus contents. Differences of diet composition in eared grebe age and sex or any interactions with those variables were not significant, so the final PerMANOVA analysis of esophagus contents included GSL
region, month, and year as factors. Significant models included the effects of region ($F_{3,57} = 2.47, P = 0.039$) and month collected ($F_{2,57} = 10.51, P = 0.0003$) on diet (Table 5-2). Pair-wise comparisons showed a regional difference in diet between birds collected at the Antelope Island and Fremont Island ($F_{1,30} = 3.95, P = 0.040$); birds collected in the Fremont Island region consumed more brine fly larvae, 2.6%, as compared to Antelope Island, 0.2%. Eared Grebe diets in October ($F_{1,46} = 7.12, P = 0.004$) and November ($F_{1,33} = 9.03, P = 0.001$) differed from those in December. Birds collected in December had consumed fewer brine shrimp and more cysts than birds collected during the previous two months (Table 5-3). The aggregate wet weight of brine fly larvae in esophagus samples was consistent among months. Of all eared grebes collected, 303 (76%) had brine shrimp cysts in their stomachs, and the average wet weight of brine shrimp cysts removed from these birds was 8.85 g.

Total biomass removed from eared grebe esophagi and stomachs decreased from October to December (Table 5-4). Average wet weight of esophagus contents in October (0.13 g) and November (0.11 g) were higher than December (0.07 g). Similarly, mean stomach content wet weight was higher in October (8.42g) and November (7.44 g) than December (3.10 g). There were no significant differences between years or among regions of the GSL in total esophagus or stomach biomass.

Declines in eared grebe body mass occurred concurrently with declines in adult brine shrimp abundance ($F_{1,17} = 4.64, P = 0.04, \text{ Adj. } r^2 = 0.18; \text{ Fig. 5-2}$). From October through departure from the GSL in December, mean eared grebe stomach weight
decreased from 24.2 g to 13.7 g, and intestine weight decreased from 27.5 g to 8.0 g. Breast muscle weight increased from 13.6 g to 21.3 g (Fig. 5-3).

Estimated monthly cyst consumption by eared grebes ranged from about 81,000 kg to about 477,000 kg over the two year study (Table 5-5). Reported commercial biomass harvest at the end of each of the 2 years of this study was 11,100,000 and 9,100,000 kg. From October through December, when eared grebes overlap with commercial harvest of cysts, eared grebes consume 7-12% of the cysts that the commercial harvest removes.

DISCUSSION

Different conclusions can be made about the diets of eared grebes on the GSL based on esophagus or stomach contents. Brine shrimp accounted for most of the ingested biomass in esophagus samples, but in stomach samples brine shrimp cysts occurred in > 95% of birds and represented > 75% of the aggregate biomass. Brine fly larvae were also more prevalent in stomach samples compared to esophageal contents. Brine shrimp cysts and brine fly larvae may be detected in the stomach for longer periods of time than brine shrimp due to their lower digestibility (Caudell and Conover 2006b). Hence, assessment of diet among eared grebes will be biased when based strictly on stomach samples.

Previous studies on the GSL have shown adult brine shrimp are the primary food item of eared grebes staging during the fall. Eared grebes collected during September on GSL’s Gilbert Bay consumed both brine shrimp and brine fly adults (Paul 1996, Conover and Vest 2009); by late November, birds ate exclusively brine shrimp (Conover and Vest 2009). Eared grebes collected in the GSL’s less saline areas during the fall had consumed
more freshwater invertebrates (Paul 1996). I found that brine shrimp represented > 80% aggregate biomass in eared grebes collected in October and November. In contrast, eared grebes collected in December, a period of time not previously studied, contained nearly equal parts brine shrimp and cysts. Consumption of brine shrimp by eared grebes at Mono Lake, California, was thought to account for 80% of the fall reduction in brine shrimp numbers (Cooper et al. 1984). The GSL (780,000 ha) is much larger than Mono Lake (18,260 ha) and it is not thought that eared grebes contribute to the decline of brine shrimp in the fall, rather declines occur when temperatures are too low for brine shrimp survival (Belovsky et al. 2011).

Mono Lake is the other primary fall staging area for eared grebes in North America. Avian research has been more intense on this lake, but diet results during fall staging are similar to GSL. Eared grebes diets on Mono Lake were principally adult brine shrimp and brine fly larvae (Winkler and Cooper 1986). In our study, brine fly larvae made up 10% and 15% aggregate wet weight biomass in the esophagus and stomach, respectively. Jehl (1988) used only stomach contents for diet analysis of Mono Lake birds, and diets were comprised of > 90% adult brine shrimp during October through December. Brine shrimp cysts are less accessible to eared grebes on Mono Lake as cysts do not float or form the large, centralized streaks that are found on the GSL (Dana and Lenz 1986).

Jehl (1988) noted an age difference among eared grebes in type of food eaten, as adult eared grebes on Mono Lake consumed more brine shrimp adults and juvenile eared grebes consumed more brine fly adults. This age difference in diet was particularly
evident late in the year when adult brine shrimp densities decreased. In contrast, I found no age or sex difference in diet among eared grebes on the GSL. On Mono Lake there is spatial separation of age groups among eared grebes that result in diet differences. Juvenile eared grebes are more abundant close to shore and consume a higher proportion of brine flies. Eared grebe adults are found further from shore and consume brine shrimp (Jehl 1988). I found similar age ratios in all 4 regions of the GSL. I also found that spatial differences in eared grebe diet were minimal and did not include differences in cyst consumption. Jehl (1988) found the highest proportion of juveniles within 100 m of shore; I found that on the GSL eared grebe concentrations occurred in open water areas and rarely within 100 m of shore.

I found eared grebe’s body weight decreased with a decrease in adult brine shrimp densities. Eared grebe body weight declined quickly during fall of 2010 and 2011 as brine shrimp densities were reduced due to decreasing water temperatures and lack of recruitment as female brine shrimp convert to cyst production, not live birth. This same pattern was seen on Mono Lake (Jehl 1997) and previously on the GSL (Caudell and Conover 2006a). The reduction in adult brine shrimp populations may have been an indication for birds to start physiological changes that prepare them to migrate away from the GSL. Eared grebes increased consumption of brine shrimp cysts into December, but did not gain weight when feeding on this food source.

Stomach contents of staging eared grebes show they may be directly competing with commercial harvesters for brine shrimp cysts. Eared grebes collected in this study had cysts in their stomachs each of the three months examined. Cysts were most
prominent in diets in December, likely due to the declining numbers of adult brine shrimp and increasing access to cysts as they become concentrated in streaks. Only one other study has reported cyst consumption by Eared Grebes; Paul (1996) found trace amounts in birds collected near Antelope Island Causeway. The presence of cysts in October and November may be explained by incidental consumption of cysts, or from digesting gravid female brine shrimp, though the presence of large quantities of cysts in December in diet samples suggest active foraging for cysts. Increases in biomass of cysts consumed in December, coupled with the lack of gravid females, suggested eared grebes were consuming cysts deliberately, rather than incidentally. It is likely that cysts are only consumed when no other foods are available to maintain weight until departure. I found no increase in eared grebe weight when feeding on cysts increased in December. Energy content of cysts (23.5 kJ/g dry weight) were higher than adult brine shrimp (21.9 kJ/g) and brine fly larvae (18.7 kJ/g) in feeding trials, though digestibility was much lower (51.8% energy concentration compared to 87.4% for adult brine shrimp), indicating eared grebes are not able to use efficiently the energy from cysts to build fat (Caudell and Conover 2006b) but cysts are high in protein and may be good for building breast muscle before migration.

**MANAGEMENT IMPLICATIONS**

Consumption of cysts by eared grebes is about 10% of combined eared grebe and commercial harvest removal of cysts. Unlike commercial harvest, eared grebes likely return large quantities of viable cysts to the ecosystem when consumed cysts are passed through the digestive system and remain viable (Proctor and Malone 1965). Hatching
efficiency of cysts fed and recovered from two species of birds were above 15% (MacDonald 1980) and cyst passage rates would indicate cysts are returned to GSL waters before migration. Currently the Utah Division of Wildlife Resources regulates the commercial harvest and discontinues the season when densities reach 21 cysts/L, which is sufficient to retain enough cysts to repopulate brine shrimp in the GSL the following spring and meet the needs of the eared grebe population (Conover and Caudell 2008, Belovsky et al. 2011). Previous studies have estimated a minimum density of 0.38-5.80 brine shrimps/L is required to support grebe populations. Since these estimates are both lower than the long-term average of brine shrimp in the GSL of 6.97 brine shrimp/L (Belovsky et al. 2011), current management of cyst levels and subsequent summer adult brine shrimp abundances seems to be adequate for current eared grebe population levels. The use of cyst density remaining in the GSL, rather than total amount harvested, allows the Utah Division of Wildlife Resources to control cyst densities by closing the harvest season when needed.

**LITERATURE CITED**


MacDonald, G. H. 1980. The use of Artemia cysts as food by the flamingo


Table 5-1. Diet of eared grebes (percent occurrence and aggregate percent wet weight) collected from the Great Salt Lake, Utah, October-December 2010-2011.

<table>
<thead>
<tr>
<th></th>
<th>Esophagus (n=69)</th>
<th>Stomach (n=317)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Occurrence</td>
<td>Aggregate %</td>
</tr>
<tr>
<td>Brine shrimp cysts</td>
<td>20.3</td>
<td>16.3</td>
</tr>
<tr>
<td>Brine shrimp adults</td>
<td>81.2</td>
<td>72.4</td>
</tr>
<tr>
<td>Brine fly</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Brine fly larvae</td>
<td>20.3</td>
<td>9.9</td>
</tr>
<tr>
<td>Plant material</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Wetland plant seeds</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Wetland invertebrates</td>
<td>2.9</td>
<td>1.4</td>
</tr>
</tbody>
</table>
Table 5-2. Permutational multivariate analysis of variance model results for temporal and spatial factors influencing eared grebe diets on the Great Salt Lake, Utah, October-December 2010-2011. Regions are Antelope Island, Carrington Bay, Fremont Island, and Gilbert Bay.

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>F.Model</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>3</td>
<td>2.471</td>
<td>0.039</td>
</tr>
<tr>
<td>Month</td>
<td>1</td>
<td>10.511</td>
<td>0.001</td>
</tr>
<tr>
<td>Year</td>
<td>1</td>
<td>1.345</td>
<td>0.256</td>
</tr>
<tr>
<td>Region x month</td>
<td>2</td>
<td>1.650</td>
<td>0.173</td>
</tr>
<tr>
<td>Region x year</td>
<td>1</td>
<td>0.136</td>
<td>0.869</td>
</tr>
<tr>
<td>Residuals</td>
<td>57</td>
<td>0.715</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>65</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5-3. Aggregate percent wet weight biomass of the 3 most common food items found in the esophagus of eared grebes collected on the Great Salt Lake, Utah, October through December, 2010 and 2011.

<table>
<thead>
<tr>
<th>Month</th>
<th>n</th>
<th>Brine shrimp cysts</th>
<th>Adult brine shrimp</th>
<th>Brine fly larvae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct</td>
<td>31</td>
<td>8.3</td>
<td>81.3</td>
<td>9.9</td>
</tr>
<tr>
<td>Nov</td>
<td>18</td>
<td>1.0</td>
<td>87.4</td>
<td>9.8</td>
</tr>
<tr>
<td>Dec</td>
<td>17</td>
<td>44.1</td>
<td>47.1</td>
<td>9.9</td>
</tr>
</tbody>
</table>
Table 5-4. Average biomass (g/bird) of food items removed from the esophagi and stomachs of eared grebes collected from the Great Salt Lake, Utah, 2010 and 2011.

<table>
<thead>
<tr>
<th></th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esophagus</td>
<td>2010</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>0.20</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>0.13</td>
<td>0.11</td>
</tr>
<tr>
<td>Stomach</td>
<td>2010</td>
<td>12.01</td>
<td>7.40</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>4.84</td>
<td>7.48</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>8.42</td>
<td>7.44</td>
</tr>
</tbody>
</table>
Table 5-5. Estimated amount of brine shrimp cysts (kg) consumed by eared grebes and reported harvested by the commercial harvest industry during 2 winters on the Great Salt Lake, Utah.

<table>
<thead>
<tr>
<th></th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
<th>% of yearly total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eared grebes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>367,471</td>
<td>195,586</td>
<td>269,125</td>
<td>832,182</td>
<td>7.6</td>
</tr>
<tr>
<td>2011</td>
<td>418,397</td>
<td>477,997</td>
<td>81,673</td>
<td>978,067</td>
<td>12.2</td>
</tr>
<tr>
<td><strong>Commercial harvest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>6,119,180</td>
<td>1,774,069</td>
<td>2,278,363</td>
<td>10,171,613</td>
<td>92.4</td>
</tr>
<tr>
<td>2011</td>
<td>1,877,047</td>
<td>3,856,355</td>
<td>1,323,820</td>
<td>7,057,222</td>
<td>87.8</td>
</tr>
</tbody>
</table>
Figure 5-1. Map of Great Salt Lake, Utah and principle bays and islands mentioned in the text.
Figure 5-2. Mean brine shrimp densities (A) within the Great Salt Lake, Utah and mass of eared grebes collected (B) during the fall, 1 October through 28 December, 2010 and 2011. Short dashed lines are 2010, and long dashed lines are 2011.
Figure 5-3. Mean weight of stomach, one side of breast muscle, and large and small intestines of eared grebes collected from the Great Salt Lake, Utah, October through December 2011.
CAUSES OF EARED GREBE (*Podiceps nigricollis*) MORTALITY DURING A MASS DOWNING

**ABSTRACT.**— A mass downing of migrating Eared Grebes (*Podiceps nigricollis*) occurred 12 December 2011 in and around Cedar City, Utah. During the fall, hundreds of thousands of Eared Grebes stage on the Great Salt Lake, Utah and mortalities due to birds being forced to the ground (downings) during migration occur every few years. I examined body condition, population characteristics, and heavy metal concentrations among downed birds and those that still occupied the Great Salt Lake both pre- and post-downing. Eared Grebes collected pre-downing were heavier (523 g) than deceased birds (433 g). Body weight (g) and subcutaneous fat thickness (mm) were lower in downed birds than pre-downing birds, likely the result of a 400-km flight from the staging area to Cedar City. In addition to total body mass differences, liver, heart, and intestine weights were all greater in both pre- and post-downing GSL birds than downed birds. This may be due to catabolism of tissue during migration or incomplete physiological changes before migration. Adult biased age ratios were observed in all groups but pre-downing (34 adults:5 juvenile) and post-downing (39:2) groups were less biased than the downed group (100:1). Mercury and selenium concentrations in all groups were above the level observed to impact bird species. Mercury concentrations in the liver ranged from 4.4–25.8 ppm and mercury concentrations measured in birds collected pre-downing were lower than downed birds. Despite high levels of mercury and selenium no adverse effects of heavy metal contamination have been noted in studies of Eared Grebes on the Great
Salt Lake. Weather was likely the proximate cause of the downing but impacts of heavy metal toxicity should be examined further to determine their effect on staging Eared Grebes.

**INTRODUCTION**

Mass mortality events when birds are forced down during migration (downings) of many migratory bird species have been documented for more than a century (Newton 2007) and the proximate cause of downings is often low visibility, but the ultimate factors that dictate why some individuals perish while others survive are unknown. A mass downing of Eared Grebes (*Podiceps nigricollis*) occurred in and around Cedar City, Utah during a snowstorm on 12 December 2011. Cedar City is 400 km from the Great Salt Lake (GSL), Utah, the origin of the downed birds. Radar data indicate Eared Grebes left the GSL around 18:00 hr (NOAA 2013) and first reports of downed birds occurred about 22:30 hr, with the downing estimated to be completed by 01:30 hr on 13 December (K. Day, unpublished report). Weather from approximately 17:00 hr on 12 December to 02:00 hr on 13 December was described as snowing, overcast, and foggy (MesoWest 2013). Visibility was 1.1 km and winds were light (maximum 4 km/hr) from the southwest (MesoWest 2013), the direction Eared Grebes were flying. The origin of the flight of Eared Grebes was confirmed by two sources. First, an Eared Grebe I banded earlier that year on the GSL was recovered in Cedar City after the downing. In addition, weather radar data from the night of 12 December 2011 showed a large migrational movement away from the GSL in a south/southwesterly direction, leading towards Cedar City, and utilizing the pathway observed to be taken by migrating Eared Grebes (NOAA
2013). The initial downing report stated over 7,000 Eared Grebes were involved in the downing, including deceased and rescued birds (K. Day, unpublished report). The migration route through central and southern Utah is known to be hazardous, and numerous downings of Eared Grebes have been reported there in the past (Jehl 1996; Jehl et al. 1999). Eared Grebes have low mobility on land and can only take flight from water, so landing in terrestrial areas results in death on impact or from their inability to move to water. Mass mortalities of Eared Grebes during migration have been documented since 1880 with the first mention in the literature by Cottam (1928) and causes are thought to be extreme weather events (i.e. snow storms; Jehl 1996) though other ultimate causes have not been examined, including the impact of heavy metal toxicity.

There are at least five hypotheses for why Eared Grebes went down and perished. 1) Birds that perished may have been in low physiological condition, as measured by body mass, than Eared Grebes still at staging areas. 2) Juvenile Eared Grebes that were less experienced in migration may have become disoriented and unable to continue migration. 3) Deceased Eared Grebes were diseased and were less able to navigate or continue their migration flight. 4) High concentrations of mercury or selenium may have decreased muscle coordination (Eisler 1987, 2000) or caused behavioral changes (Frederick et al. 2004; Hoffman et al. 2011) resulting in higher mortality. 5) There was no difference between individuals that died and those that continued migration rather; some birds were caught in an unpredictable weather event they were unable to maneuver through.
Large, stochastic mortality events are hypothesized to be the principle regulator of Eared Grebe populations (Jehl 1996; Jehl et al. 2002); descriptions of the size, intensity, and cause of these events will help managers explain population fluctuations. My objective was to examine differences between the group of Eared Grebes that went down in Cedar City, Utah and birds that still occupied the staging area. I was not able to collect Eared Grebes that left the GSL on 12 December 2011 but did not go down during the downing, so I used Eared Grebes collected on the GSL immediately before and after the downing as surrogates for birds that were able to continue migration. I hypothesized downed Eared Grebes were in poorer body condition than Eared Grebes still at the GSL.

METHODS

The downing of Eared Grebes in Cedar City, Utah occurred during my concurrent work on the fall staging ecology of Eared Grebes on the GSL. I collected birds each month from across the GSL, including within 10 days prior to and following the downing. I collected Eared Grebes opportunistically using shotguns shooting steel shot under authority of federal (MB693616I) and state (1COLL6550) scientific collection permits and protocol approved by Utah State University Institutional Animal Care and Use Committee (approval number 1309). Birds were collected from two areas of the GSL pre-downing; the southern portion of Gilbert Bay and west of Fremont Island, and from the southern portion of Gilbert Bay post-downing. Birds were frozen after collection and transported to the lab for analysis. All Eared Grebes that went down in Cedar City were recovered by Utah Division of Wildlife Resources personnel and volunteers. Live birds
were placed on large ponds and rivers (K. Day, unpublished report). Deceased birds were
disposed of or frozen and delivered to Utah State University.

To obtain individual characteristics, each bird was removed from the freezer and
thawed at room temperature prior to taking measurements. Body mass was obtained prior
to dissection and measured to the nearest 0.5 g. Sex was determined by examining
gonads, and age class (juvenile or adult) was determined by eye and plumage coloration
(Storer and Jehl 1985). Each bird was inspected for external parasites and obvious signs
of disease.

During dissection, each bird was examined again for signs of disease (e.g. avian
cholera and botulism) as described in Friend and Franson (1999). The thickness of each
bird’s subcutaneous fat over the keel of the sternum was measured to the nearest 1.0 mm,
as an index of body fat (Winkler and Cooper 2008). The left pectoral muscle and the
muscles of one leg from the hip to the intertarsal joint were removed and weighed
separately to the nearest 0.1 g. The heart, liver, empty stomach, and intestines were
cleared of surface fat and weighed to the nearest 0.1 g. The contents of the digestive
system were examined for food items and parasites. The liver was placed in a whirl pack
bag, frozen, and sent to the Utah Veterinary Diagnostics Lab for analysis of mercury and
selenium concentrations (ppm wet weight) for 15 individual Eared Grebes from each
group.

For each Eared Grebe, the liver selenium and mercury concentrations were
divided by their atomic weight (78.96 and 200.59 respectively) to obtain molar
concentrations (nmol/g wet weight; Burger et al. 2013). Molar concentrations were used
to determine the molar ratio of selenium to mercury. Mercury and selenium are known to ameliorate or decrease the toxic effect of the other (Falnoga et al. 2006), and research has suggested the molar ratio of selenium to mercury may be an indicator of the protective effect of selenium on mercury, with a selenium:mercury ratio somewhere above 1:1 as protective (Ralston et al. 2008; Ralston 2009).

I used ANOVA to test for differences in body mass, organ and muscle mass, and mercury and selenium concentrations, among pre-downing, downing, and post-downing groups along with interactions among groups with age and sex. Tukey HSD tests of pairwise differences were used for significant differences (Zar 1999). I used chi-squared tests for differences in age and sex ratios between pre-downing, downing, and post-downing groups. All analysis was done in Program R (R Core Team 2012), and I considered an alpha value of ≤ 0.05 to be statistically significant.

RESULTS

I collected 45 Eared Grebes within 1 week pre-downing, 4–9 December, and 50 Eared Grebes post-downing, 19 December 2011. Biologists recovered and delivered to me 101 Eared Grebes that went down in Cedar City immediately after the downing on 13 December. Aerial surveys conducted concurrent to this study showed all Eared Grebes had left the GSL by 3 January 2012 (Chapter 4 this document). There were no significant differences in the group by age or group by sex interactions, so all reported results are among groups only. There were differences among groups in total body weight ($F_{2,180} = 71.7, P < 0.001$), and mass of stomach ($F_{2,181} = 127.4, P < 0.001$), liver ($F_{2,181} = 77.3, P < 0.001$), heart ($F_{2,175} = 3.6, P = 0.03$), intestine ($F_{2,175} = 77.5, P < 0.001$), and leg muscle
Total, stomach, liver, intestines, and leg muscle weights were all heavier in birds collected pre-downing than those collected during the downing (Table 6-1). Eared Grebes collected post-downing had heavier liver, heart, intestines, and leg muscle weights than downed birds (Table 6-1). Subcutaneous fat thickness was higher pre- (7.6 mm) and post-downing (7.1 mm) than measured in downed birds (3.9 mm; $F_{2,170} = 73.3$, $P < 0.001$).

Most Eared Grebes in the downed group were adults. All groups had an adult-biased age ratio though the pre-downing group (34 adults:5 juveniles) was less biased than the downed group (100:1; $\chi^2_1 = 6.93$, $P = 0.008$). Age ratio of the post-downing group (39:2) was similar to the pre-downing group. Male to female sex ratio was highest in pre-downing group (33 males:11 females; $\chi^2_2 = 17.24$, $P < 0.001$) followed by the post-downing (24:20) and downed (35:63) groups.

Signs of disease were present in a similar number of Eared Grebes among groups; five were observed in each of the pre- and post-downing groups and four were observed in the downed birds. Proportion of disease was 0.11 in the pre-downing group, 0.10 in the post-downing group, and 0.04 in the downed group. All but one of the indicators of disease was internal parasites which are common in Eared Grebes (Storer 2000); the exception was a single Eared Grebe collected pre-downing with a liver showing signs of disease.

Mercury concentrations in Eared Grebe livers ranged from 4.4–25.8 ppm, and selenium concentrations were 1.8–7.2 ppm (Table 6-2). There were no significant differences in the group by age or group by sex interactions among mercury or selenium.
concentrations. Mean mercury concentrations measured in bird livers were different by group ($F_{2,34} = 4.9, P = 0.01$). Eared Grebes collected pre-downing ($P = 0.02$) and post-downing ($P = 0.03$) had mercury concentrations approximately 24% lower than downed birds. There were no significant differences among groups in selenium concentrations measured ($F_{2,34} = 1.2, P = 0.30$). All selenium:mercury molar ratios were below 1:1.

**DISCUSSION**

I examined five hypotheses for why some Eared Grebes were caught in this downing and perished; Eared Grebes that perished had lower physiological condition than birds still at staging areas, juvenile Eared Grebes were less experienced in migration and become disoriented, deceased Eared Grebes were diseased, mercury or selenium toxicity decreased muscle coordination, and no difference among groups, rather birds were caught in an unpredictable weather event. Many of the changes in body condition characteristics seen in this analysis can be attributed to the rigors of the 400-km flight from the GSL to the Cedar City area. Differences in total body mass are likely due to catabolism of fat throughout the body, and I observed a large difference in subcutaneous fat thickness between Eared Grebes on the GSL and those that died in the downing.

Though body mass differences may be strictly due to the 400-km flight, I estimated how much weight Eared Grebes should lose during their flight to the average difference I observed among deceased birds and birds still at the GSL. I estimated mass lost per hour by Eared Grebes in flight using the basal metabolic rate (BMR) of Eared Grebes estimated previously (0.23 kJ/g/hr; Conover and Caudell 2008) and by converting energy used to mass lost using a fat loss conversion of 0.03 grams/kJ (Robbins 1993).
This conversion resulted in 0.71 grams lost per hour at Eared Grebe’s BMR. Forward flight is estimated to expend up to 14 times the energy of BMR (Robbins 1993; Jehl 1994), resulting in a flight energy cost estimate of near 10 g/hr. Conversion from energy used to mass lost involves many variables but this method provides a baseline of expected mass loss. In addition, metabolic rate during flight may be lower than 14 times BMR, but Eared Grebes are inefficient flyers so it is likely they reach the upper limit of the metabolic rate of birds in flight. My estimate of 10 g/hr is higher than previous estimates of 3.24–7.60 g/hr (Jehl 1993; Jehl 1994) calculated using average difference in departure and downed Eared Grebes mass in Utah for an estimate. I estimated total mass loss caused by the energy demands of flight should be 50–80 g for the 5–8 hour flight from the GSL to Cedar City and I found a 77 g difference between birds still at the GSL (mean of pre- and post-downing; 510 g) and downed birds (433 g). This difference falls in the estimated range of mass lost during the migration flight and does not support the hypothesis that Eared Grebes that perished were lighter than birds still at staging areas.

Body mass of Eared Grebes still at the GSL indicated the average bird was prepared for the migration flight to the Salton Sea, California, or the Gulf of California; the two primary destinations of Eared Grebes migrating from the GSL. I found an average body mass of pre-departure birds of 523 g, well above the estimated minimum mass (298 g) needed at departure for a non-stop flight to wintering sites (Jehl 1993). The range of body mass found in all groups in this study (320–520 g) was within and exceeded the range seen in downings at two locations in 1991 (285–464 g; Jehl 1993) and in downings at four locations in 1996-1997 (367–446 g; Jehl 1999), indicating similar
departure weights of Eared Grebes each year. Brine shrimp (Artemia franciscana), the primary food of staging Eared Grebes, densities on the GSL were similar between two years of downings with data; mean adult brine shrimp densities from August through October were 0.81 and 0.89 shrimp/L in 1996 and 2011, respectively. These values were lower than the average 2003–2010 August through October adult brine shrimp density of 1.43/L, though no among–year differences in adult brine shrimp density were detected.

The die-off of adult brine shrimp is likely a signal for Eared Grebes to initiate physiological changes and depart staging areas (Jehl 2007).

Digestive organ mass of Eared Grebes in this study was lower than those measured in a previous downing. After a downing north of Cedar City in 1991, mean mass of the intestines (15.5 g), liver (9.4 g), and stomach (14.2 g; Jehl 1997) were higher than downed birds in this study, and closer to the mass of those organs measured from Eared Grebes still on the GSL in my study. Eared Grebes examined after downing in 1991 were collected 65 km north of Cedar City and therefore had travelled a shorter distance than birds I examined. If those organs were catabolized for energy then shorter flight distance may have been the reason for differences. Alternatively, Jehl (1997) found similar mean heart (3.9 g) and leg muscle (14.8 g) mass as I measured. I did not find a difference in breast muscle size among groups in this study, indicating all Eared Grebes on the GSL during this time had flight muscles of sufficient size to migrate. I found an average breast muscle mass of 20.9 g, and in all groups, the breast muscle weight exceeded 20 g, the breast muscle mass hypothesized for Eared Grebes to be able to fly at departure weights (Jehl 1988, 1993), indicating Eared Grebes that perished had similar
migration condition to Eared Grebes still at the staging area and those examined in previous years.

I did not find a high proportion of juveniles in the downed Eared Grebes: in contrast 99% of the downed birds were adults. This indicates disoriented juveniles were not the cause of this group of birds going down. Jehl (1993, 1997) noted juvenile Eared Grebes migrated from the GSL earlier in the fall than adults. This was thought to be due to lower initial weight on arrival at staging areas, and earlier depletion of fat deposits after adult brine shrimp die off, forcing earlier migration dates. I also found adult–biased age ratios in all groups but the age ratio had not changed from October (56 adults:2 juveniles) and November (32:4) of the same year (Chapter 5 this document) indicated juveniles were still present directly before migration at a similar ratio to the early fall population. In addition, all but one of the deceased birds I analyzed was an adult indicating this migration event consisted mostly of adults. The age ratio was more adult–biased post-downing compared to pre-downing so it is possible large groups of juveniles migrated away from the GSL in a different departure event. Radar data show only one small group of birds left the GSL between the downing and my post-downing collection (NOAA 2013), so no large change in age ratio would be expected. Jehl (1993) found similar age ratios at downings as my results. Four downings in December 1996 and January 1997 all had highly biased age ratios with adults representing 75-97% of downed birds (Jehl et al. 1999). Neither Jehl (1993) or Jehl et al. (1999) examined the birds on the GSL pre- or post-downing to compare age ratios to other times of the year to support earlier juvenile departure dates.
Outbreaks of *Streptococcus zooepidemicus* (Jensen 1979) and avian cholera (L. Glaser personal communication) have been associated with numerous die-offs of Eared Grebes at the GSL, usually in late fall. Avian cholera outbreaks in particular occur regularly on the GSL. Cholera impacts occur quickly and may result in birds falling out of the sky with no signs of disease (Friend and Franson 1999). Symptoms of cholera include lesions on the heart, liver, stomach, and intestines, including liver discoloration that appears as white or yellow spots (Friend and Franson 1999), but I did not observe diseased organs in any dead Eared Grebes from the downing. No body condition indicators provided evidence of disease but I did not test for either cholera or *Streptococcus zooepidemicus* so cannot confirm or refute Eared Grebes that died were sick. In addition, no large outbreaks of disease were seen in Eared Grebes on the GSL in fall of 2011, indicating the disease was not prevalent that year. Hence I found no evidence that disease or parasites were responsible for some birds going down in Cedar City.

Mercury levels can cause harmful effects to birds at concentrations starting at 0.2–0.5 ppm (Eisler 1987; Yeardley *et al.* 1998), well below concentrations observed in Eared Grebes in my study and throughout Eared Grebe’s measured range (Burger *et al.* 2013). Selenium is an essential trace element but at toxic levels can cause embryo deformities, lower hatching rates, and increased infertile eggs in birds but these adverse effects have little to do with the ability to migrate (Eisler 2000). Selenium and mercury interactions may reduce the bioavailability or toxicity of the other (Belzile *et al.* 2005; Ralston *et al.* 2008), so increased concentrations do not necessarily result in harmful
effects. Burger et al. (2013) measured selenium, mercury, and the selenium:mercury molar ratio of birds from the same downing as this study as well as from Eared Grebes on the GSL one week prior to the downing. They found lower mercury concentrations, similar selenium concentrations, and higher selenium:mercury molar ratios than measured in my study in both the pre-downing and downed group. Mercury and selenium concentrations in my study were similar to previous measurements on the GSL (Conover and Vest 2009; Darnall and Miles 2009). Mercury levels in livers of Eared Grebes on the GSL have been shown to increase since time of the birds’ arrival in the fall, from October through December (Conover and Vest 2009; Darnall and Miles 2009). If selenium provides some protection from mercury toxicity, then Eared Grebes with low selenium:mercury molar ratio should experience the greatest adverse effects, particularly ratios below 1:1 as seen here. Low mercury levels are critical as Eared Grebes approach the time for migration flights to wintering grounds as neurological links to muscles and muscle coordination are vital to a successful flight. Both muscle function and coordination can be impacted by high mercury concentrations (Eisler 1987, 2000).

Despite the low selenium to mercury ratios seen in my study and previous research, no studies of staging or migrating Eared Grebes have shown adverse effects due to mercury or selenium toxicity (Jehl 1988; Conover and Vest 2009; Burger et al. 2013), but my data suggest toxic effects of mercury may have been a factor in this downing. Alternatively, concentrations may increase in migrating Eared Grebes when liver mass is reduced prior to migration resulting in increased concentration of mercury and selenium. Rattner and Jehl (1997) showed an increase in mercury concentration from staging to
post-migration of Eared Grebes from Mono Lake, California in conjunction with a decrease in liver mass. If high mercury concentrations impacted muscle coordination during flight than toxicity would impact diving for food and other movements. No other large scale die-offs at staging areas have been linked to heavy metal concentrations so it is possible that high selenium and mercury concentrations are offset by each other or impact Eared Grebes staging at saline lakes differently than other birds.

Weather during this downing was similar to that reported in other downings. Consistent weather patterns observed during Eared Grebe downings are low visibility, precipitation, and light winds. In the downing I discuss here, winds were \( \leq 4 \) km/hr from the southwest, similar to the 0–3 km/hr southwest winds observed in a 1991 downing in Cedar City (Jehl 1993). The most important weather factor was likely reduced visibility due to snow; over 60 mm of snow fell in the Cedar City area between 18:00 on 12 December and 03:00 on 13 December and visibility was as low as 1.1 km (MesoWest 2013). Cases of poor navigation and downings during migration for other nocturnal migrants are associated with a low cloud ceiling, precipitation, or fog (Martin 1990). The set of cues used by Eared Grebes for navigation during migration is unknown, but most nocturnal migrants have been shown to use magnetic cues or visual cues of stars or topographical landmarks (Berthold 2001). Navigation using topographical landmarks would be difficult due to the low visibility during the downing. Topography cues during migration are commonly used by both diurnal and nocturnal migrants and the Wasatch Mountain Range along Eared Grebe’s migration route may provide guidance through most of the journey (Bingman et al. 1982). If the mountains were obscured, the Eared
Grebes may have sought a landing area to wait out the storm and been attracted to light sources resembling open water. In addition, many nocturnal migrants become disoriented when both the ground and stars are not visible to them, or when artificial lights from the ground are obscured by fog or precipitation (Martin 1990), conditions that Eared Grebes experienced the night of 12 December 2011.

Of the five hypotheses considered above, my data show some support for one; increased heavy metal concentrations. No toxicity effects have been seen in past studies of Eared Grebes staging on the GSL, though my data represent evidence for potential toxicity effects during migration. Weather patterns seen during this downing were similar to that described in previous Eared Grebe downings and were consistent with downing conditions in other nocturnal migrants. Eared Grebes still at the GSL may have still been undergoing physiological changes and were not prepared to migrate while birds that died were likely in the wrong place at the wrong time.

LITERATURE CITED


Frederick, P. C., B. Hylton, J. A. Heath and M. G. Spalding. 2004. A historical record of
mercury contamination in southern Florida (USA) as inferred from avian feather tissue. Environmental Toxicology and Chemistry 23: 1474-1478.


Table 6-1. Mean (SD) of total and organ group weights (grams wet weight) from Eared Grebes collected before, during, and after a downing event in Cedar City, Utah. Different letters within each row signify statistical differences (p < 0.05).

<table>
<thead>
<tr>
<th>Weights (g)</th>
<th>Pre-downing (n=45)</th>
<th>Downing (n=101)</th>
<th>Post-downing (n=50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>523.6(64.2)</td>
<td>432.7(45.0)</td>
<td>495.9(59.9)</td>
</tr>
<tr>
<td>Stomach</td>
<td>16.8 (4.6)</td>
<td>9.5 (2.2)</td>
<td>13.7 (3.1)</td>
</tr>
<tr>
<td>Liver</td>
<td>12.8 (4.0)</td>
<td>7.5 (1.5)</td>
<td>11.1 (3.3)</td>
</tr>
<tr>
<td>Heart</td>
<td>4.3 (0.6)</td>
<td>4.1 (0.6)</td>
<td>4.4 (0.7)</td>
</tr>
<tr>
<td>Intestines</td>
<td>17.5 (4.9)</td>
<td>9.6 (3.5)</td>
<td>13.8 (3.5)</td>
</tr>
<tr>
<td>Leg muscle</td>
<td>15.4 (2.3)</td>
<td>13.7 (1.8)</td>
<td>14.9 (2.2)</td>
</tr>
<tr>
<td>Breast muscle</td>
<td>20.5 (2.9)</td>
<td>21.1 (2.5)</td>
<td>21.2 (2.8)</td>
</tr>
</tbody>
</table>
Table 6-2. Mean (SD) of wet weight mercury (Hg; ppm) and selenium (Se; ppm), and the molar ratio (Se:Hg), measured in Eared Grebe livers collected before, during, and after a downing event in Cedar City, Utah (n = 15 for all groups).

<table>
<thead>
<tr>
<th></th>
<th>Se</th>
<th>Hg</th>
<th>Se:Hg molar ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-downing</td>
<td>4.0(1.3)</td>
<td>13.1(3.6)</td>
<td>0.8(0.1)</td>
</tr>
<tr>
<td>Downing</td>
<td>4.4(0.8)</td>
<td>17.1(4.0)</td>
<td>0.7(0.1)</td>
</tr>
<tr>
<td>Post-downing</td>
<td>3.8(0.9)</td>
<td>13.2(4.4)</td>
<td>0.8(0.3)</td>
</tr>
</tbody>
</table>
CHAPTER 7

MIGRATION PATTERNS AND NATAL ORIGINS OF NORTHERN SHOVELERS
DERIVED FROM BANDING RECORDS AND STABLE ISOTOPES

ABSTRACT

The natal origin of wintering birds and their migration strategy is important to understand the impact of population changes throughout the annual cycle and to identify management actions to reverse population declines. In addition, identifying important point sources of nutrients used throughout the annual cycle can assist managers in providing food resources in appropriate areas. I used banding data and stable hydrogen isotope ratios to describe the migration strategy and natal origin of Northern Shovelers (*Anas clypeata*; henceforth shoveler) wintering at the Great Salt Lake (GSL), Utah. I used likelihood-based assignment models to predict the breeding locations of these birds.

Shovelers recovered at the GSL (*n* = 22) had been banded during the summer in southern Alberta and Saskatchewan and northern Montana. Stable-isotope likelihood-based assignment placed the largest number of shovelers collected on the GSL as breeding in the western US and southern Canada, similar to banding records. The distance travelled by shovelers wintering on the GSL was significantly shorter than birds recovered in wintering areas in the Central and Pacific flyways supporting a hypothesis that some birds stop short of the remainder of the population during fall migration, rather than all shovelers migrating similar distances. Increased energy used to thermoregulate and osmoregulate during winter on the GSL may be offset by decreased energy used during spring migration. High concentrations of mercury found in breast tissue of shovelers on
the GSL were likely obtained while on the GSL though researchers should look in southern Canada for possible exogenous sources of heavy metal contamination.

INTRODUCTION

Migration is an energetically demanding activity for waterfowl and can reduce survival, so the availability of open water and food in close proximity to breeding sites would shorten migration distance and decrease hazards associated with long-distance movements. The ability of many bird species to winter at more northern latitude sites is likely limited by thermoregulatory capacity and food availability. Shorter migration distance to breeding grounds in the spring, however, involves less energetic demands and results in higher nutrients reserves for breeding and would allow for earlier spring arrival and first choice of the best breeding locations. Knowledge of breeding origin of wintering birds is thus important for understanding life history trade-offs that affect population fluctuations, and to identify management actions that can help birds optimize these trade-offs. The source of wintering birds is also important in evaluating the origin of contaminant acquisition. Toxicity cannot be mitigated without accurate knowledge of where heavy metals were ingested.

The Great Salt Lake (GSL), Utah, is near the northern extent of the wintering range of North American dabbling ducks (Anas spp.) and provides an abundant food supply throughout winter in the form of salt-tolerant invertebrates. The GSL also has abundant open water and experiences minimal loss of habitat availability during winter because its hypersaline water prevents ice formation. Waterfowl that winter on the GSL endure colder temperatures than birds wintering at more heavily used wintering areas
further south, and they must cope with hypersaline water. The challenges of wintering on
the GSL raise questions as to the life-history implications of enduring low temperatures
and high salinities. In addition, ducks and other waterbirds on the GSL have been shown
to have high levels of mercury and selenium in their tissues. In 2005, Utah was one of the
first states to issue a waterfowl consumption advisory due to mercury levels in waterfowl
breast muscle being above safe human consumption levels (Utah Division of Wildlife
Resources 2005, Vest et al. 2009). Species found to be high in mercury were Northern
Shoveler (*Anas clypeata*; henceforth shoveler), Common Goldeneye (*Bucephala
clangula*), and Cinnamon Teal (*Anas cyanoptera*); the GSL provides wintering habitat for
the former two species and nesting habitat for Cinnamon Teal. Mercury concentrations
increased over the time that ducks occupied the GSL, supporting the hypothesis that
ducks were ingesting mercury at the GSL, but it is important to consider other sources of
contamination.

Banding data has been an invaluable tool to assist managers in describing
migratory connectivity, migration flyways, and migration corridors (Lincoln 1935,
Bellrose 1972). Long-term banding records are particularly useful in studies of waterfowl
because band return rates are higher than other avian species due to hunter harvest.
Records of shoveler band recoveries from the GSL are sparse so banding data does not
provide a complete description of natal origins in this ecosystem, thus another method
was needed for this research. Naturally occurring stable isotopes of hydrogen, nitrogen,
and carbon have been used to describe natal origins of many avian species (Herbert and
Wassenaar 2005). Stable hydrogen isotope ratios in tissues show latitudinal differences

My objectives for this research were to describe the migration strategy and breeding origin of shovellers wintering on the GSL. Energetic costs of wintering further north than conspecifics in a hypersaline environment may impact populations through changes in overwinter survival or subsequent breeding success. Testing assumptions of natal origins is the first step in examining life-history impacts of GSL conditions on wintering birds. The ecological implications of why some shovellers winter further north than others were of interest and important to management and monitoring of wintering waterfowl on the GSL. Additionally, high mercury concentrations in shoveller tissues from the GSL make them a concern for the state of Utah, and knowledge of the source of contaminants is important for mitigation. I used both banding data and stable isotope ratios in consideration of four hypotheses for the origin and migration strategy of shovellers wintering on the GSL: 1) shovellers wintering on the GSL breed in the Prairie Pothole Region and stop short of the remainder of the population during fall migration, 2) shovellers wintering on the GSL nest or were hatched locally, 3) shovellers nesting the furthest north, such as northern Canada and Alaska, also winter the furthest north, such as on the GSL, and 4) mixed migration occurs and shovellers from all breeding areas winter on the GSL.

I examined shovellers wintering at a northern latitude wintering site, the GSL, for this research. Within North America, shovellers are present in large numbers at all major
waterfowl wintering grounds, they are the most numerous winter resident on the GSL, and they are one of only two common dabbling duck species present during winter on the GSL. Shoveler breeding density is highest in the Prairie Pothole Region so one would expect by default that birds wintering on the GSL are closer to breeding grounds than those wintering further south. Alternatively, shovelers that breed in northern Canada and Alaska may represent the wintering population on the GSL while shovelers breeding in the Prairie Pothole Region winter further south resulting in all birds migrating a similar distance.

METHODS

STUDY AREA

The GSL is a large, terminal lake in northern Utah. The entire GSL ecosystem covers nearly 780 000 ha when at a lake elevation of 1280 m above sea level and consists of saline open water, brackish and freshwater wetlands, and upland areas (Aldrich and Paul 2002). The high salinities of the GSL support populations of only two invertebrates, brine shrimp (Artemia franciscana) and brine flies (Ephydra spp.), and large concentrations of avian species utilize the GSL throughout the year (Aldrich and Paul 2002). The most abundant waterfowl species during winter are shoveler and Common Goldeneye; my analysis focused on the former species. Other duck species on the GSL during late fall and winter include Mallard (Anas platyrhynchos), Gadwall (Anas strepera), Northern Pintail (Anas acuta), and Green-winged Teal (Anas crecca). Previous research (Vest and Conover 2011) and ongoing studies have demonstrated shovelers feed
on GSL foods and don’t use the GSL strictly as a resting area away from predators and
hunters.

FIELD AND LABORATORY METHODS

The stable isotope ratio of $^2$H to $^1$H ($\delta^2$H) in precipitation varies by latitude as
heavier $^2$H molecules fall as precipitation at higher rates at lower latitudes. The $\delta^2$H in
precipitation is incorporated into plants and animals and can be integrated up the food
chain. Birds do not continuously grow feathers, rather they molt once or twice a year and
incorporate nutrients and isotopes from the molt time period. The ratio in feathers grown
at a known time period can be used to examine the latitude at which those feathers were
grown. Stable isotope analysis of $\delta^2$H has been used for many avian species and the
relationship between $\delta^2$H in precipitation and $\delta^2$H in feathers has been shown for some
species, including waterfowl (Herbert and Wassenaar 2005). Carbon ($^{12}$C and $^{13}$C) and
nitrogen ($^{14}$N and $^{15}$N) ratios have also been used to infer marine versus freshwater
origins, or agricultural versus native wetland origin of feather growth respectively.

I collected shovelers from 15 December through 28 February during the winters
ensure shovelers were winter residents and not continuing their migration to more
southern locations. Birds were collected using steel shot over decoys or by jump
shooting. Shovelers were collected under authority of federal (MB693616I) and state
(1COLL6550) scientific collection permits and protocol approved by Utah State
University Institutional Animal Care and Use Committee (approval number 1309). I
determined age and sex of shovelers by plumage characteristics and assigned age as hatch
year or after hatch year. Waterfowl females exhibit higher philopatry to breeding areas than males (Rohwer and Anderson 1988, Clarke et al. 1997) so I used only after hatch year females for stable isotope analysis to try and meet the assumption that birds wintering on the GSL would return to the same breeding area in the spring. This assumption is important to accurately describe the spring migration distance of the remainder of the GSL wintering population. In addition, some waterfowl species, particularly males, undertake molt migration and hence do not regrow feathers at breeding sites. Females with broods molt and regrow feathers on breeding grounds, so analysis of females would be more likely to include measurements from where those individuals bred. Adult shoveler typically molt at breeding areas (DuBowy 1980) so it is likely that flight feathers of wintering birds were grown on breeding areas.

I selected two middle primary feathers from one wing of randomly selected individuals for stable isotope analysis. Initial examination of banding data showed all recoveries from the GSL had been banded locally or in the western US and Canada, indicating shorter migration distance than conspecifics. The banding locations also had high densities of saline wetlands (Last and Slezak 1988), so I analyzed carbon isotope ratios in feathers to determine if individuals were using saline ecosystems throughout their annual cycle. Feather isotope samples were analyzed at the Stable Isotope Research Facility for Environmental Research at the University of Utah, Salt Lake City, Utah, USA. Feather samples were washed in solvent, allowed to equilibrate to lab exchangeable hydrogen levels, weighed, and ground. Standard continuous-flow isotope ratio mass spectrometry was used to analyze stable carbon isotope ratios ($\delta^{13}$C) in feathers. I report
measurements of $\delta^{13}$C in standard $\delta$-notation relative to the Vienna PeeDee Belemnite for carbon (Bond and Hobson 2012). Stable hydrogen isotope feather ratio ($\delta^{2}$H$_{f}$) measurements were conducted on non-exchangeable hydrogen using continuous-flow isotope ratio mass spectrometry as described by Wassenaar and Hobson (2003). I report measurements in standard $\delta$-notation relative to the Vienna Standard Mean Ocean Water for hydrogen, with a sample reproducibility of $\pm 2$ ‰ (Bond and Hobson 2012).

STATISTICAL ANALYSIS

I converted $\delta^{2}$H$_{f}$ ratios to mean growing-season stable hydrogen isotope ratios in precipitation ($\delta^{2}$H$_{p}$) using the relationship of $\delta^{2}$H$_{f}$ to $\delta^{2}$H$_{p}$ derived by Herbert and Wassenaar (2005) for Mallards and Northern Pintails of known origin in western North America ($\delta^{2}$H$_{f}$ = -57 + 0.83 / $\delta^{2}$H$_{p}$; $P < 0.001$). I associated $\delta^{2}$H$_{f}$ with $\delta^{2}$H$_{p}$ obtained from an elevation-corrected Geographic Information System isoscape provided by Meehan et al. (2004). I assigned feather $\delta^{13}$C as grown in freshwater ($< -20$ ‰) or saline ($> -20$ ‰) habitats (Fry and Sherr 1989, Hobson and Sealy 1991, Yerkes et al. 2007). There were no differences in $\delta^{2}$H$_{f}$ and feather $\delta^{13}$C among years so I combined all data in further analysis.

I obtained band recovery data from the United States Geological Survey, Patuxent Wildlife Research Center Bird Banding Laboratory, and all data were current to 15 January 2013. I restricted analysis to shovelers banded during the summer breeding season (15 May – 31 July) and recovered during winter (1 December – 28 February). Shovelers migrating through the GSL winter in both the Central and Pacific flyways in the US and Mexico (Bellrose 1980) so I analyzed migration distances and natal origins of
shovelers recovered within those regions. All recovered shovelers from all years (1926–2012) were used in band recovery analysis. Sample size of recovered shovelers during winter on the GSL was small \( (n = 22) \) and only three recovered birds were female, so all age and sex classes were used rather than strictly after hatch year females as in stable isotope analysis. I calculated the distance between banding and recovery locations to examine how far birds travelled between breeding and wintering grounds. I summarized these data across recoveries in the Central and Pacific flyways in the US and Mexico. Utah recoveries were separated from the remainder of the Pacific Flyway for comparison in this study. I tested the difference in migration distance among flyways and between sexes using an ANOVA with Tukey’s HSD test and t-test respectively (Zar 1999).

I used likelihood-based assignment models including estimates of uncertainty to assign breeding location of shovelers wintering on the GSL. I restricted assignment of shovelers breeding range to the Pacific and Central flyways as analysis of all shoveler band recovery data showed no movement of breeding shovelers from the Atlantic or Mississippi flyways to the Pacific Flyway. I chose not to use banding data as prior probabilities in stable hydrogen isotope likelihood-based assignment models. Previous research has used band recovery data as prior probabilities of breeding locations (Hobson et al. 2009), or to delineate breeding range of birds (Mazerolle et al. 2005), but due to the small sample size of recoveries from the GSL, I felt banding data did not provide a complete picture of breeding distribution.

For each bird, I assessed the probability that any given cell in the \( \delta^2H_p \) isoscape represented the origin of an individual by using the normal probability density function:
\[ f(y^* | \mu_c, \sigma_c) = \frac{1}{\sqrt{2\pi \sigma_f}} \exp \left[ -\frac{1}{2\pi} \sigma_f^2 (y^* - \mu_c)^2 \right] \]

Where \( f(y^* | \mu_c, \sigma_c) \) is the probability a cell (c) within the isoscape represents a potential origin of an individual of unknown origin (y*), given the mean \( \delta^2 H_p \) for the cell (\( \mu_c \)) and the error in \( \delta^2 H_f \) measurement (\( \sigma_f \); Van Wilgenburg and Hobson 2011). For each bird, this resulted in a surface of spatially explicit probability densities which were then standardized to the highest value in the surface. I then reclassified the surface based on 3:1 odds that the assignment origin was correct relative to being incorrect (Van Wilgenburg and Hobson 2011) and coded the upper 75% of cells as 1 and all others as 0. This resulted in one binary map per shoveler which I then summed over all individuals. I used a 75% chance of correctly assigning an individual to compromise between the risk of being incorrect and reduced geographic extent of assignment with a lack of prior information (Van Wilgenburg and Hobson 2011). Analysis of probability surfaces was done using the RASTER package in Program R (R Core Team 2012).

**RESULTS**

Banding locations of the 22 shovelers recovered on the GSL showed one wintering bird was banded in central Alaska, one in Utah, and the remainder in the northwestern US (Montana) and Canada (Fig. 7-1). Banding location of shovelers recovered in two other wintering areas in the Central and Pacific flyways, California’s Central Valley and the Texas Gulf Coast, were distributed throughout shovelers breeding latitudes (Fig. 7-2). There was some west to east symmetry where shovelers that originated in the West wintered in California while those that originated in the East wintered along the Gulf Coast, though there was much overlap.
Shovelers recovered in Utah had travelled a significantly shorter distance (945 km; $F_{3, 247} = 43.09, P < 0.001$) than birds recovered in both flyways and Mexico (Table 7-1). The average distance travelled was higher among shovelers recovered in the Central Flyway (2260 km) than the Pacific Flyway (1781 km; difference = 298 km, $P < 0.001$). There was no difference ($t_{249} = 3.06, P = 0.62$) in migration distance between males (1939 km) and females (2394 km).

I obtained primary feather samples for stable hydrogen isotope analysis from 113 shovelers wintering on the GSL; 62 from the winter of 2009–2010, 26 from 2010–2011, and 25 from 2011-2012. Analysis of feather $\delta^{13}$C from shovelers wintering on the GSL found all ratios $<-20 \%$ (Fig. 7-3) suggesting all sampled birds had molted in freshwater habitats. There were no among-year differences in $\delta^{2}$H$_f$ so I combined all years for likelihood analysis. Likelihood-based assignment of stable isotope values placed the largest number of shovelers collected on the GSL as breeding in the western US and southern Canada (Fig. 7-1). Southwestern Alaska was highly represented as well, as this area has similar $\delta^{2}$H$_p$ values as the western US and southern Alberta and Saskatchewan.

**DISCUSSION**

Shovelers recovered on the GSL had shorter migration distances compared to the average shoveler wintering in the Central and Pacific flyways, supporting the hypothesis that shovelers wintering on the GSL stop short of the remainder of the population during fall migration. In addition, banding and $\delta^{2}$H$_f$ data showed that several shovelers wintering on the GSL had bred in the Prairie Pothole Region, though birds from across shoveler’s breeding range were represented on the GSL.
There are at least three explanations for why some birds stop short during migration and travel shorter distances than the remainder of the population (Cristol et al. 1999). First, birds that have only short distances to migrate in the fall get to the northern wintering grounds first and utilize available resources, while later migrants are forced through competition to migrate further south (Alerstam 1990). I do not have data on timing of passage through the GSL or other wintering areas so I am unable to confirm or refute this explanation. However, food resources during winter on the GSL seem to be able to support larger wintering duck populations then what are currently estimated (Chapter 3 this document). Second, larger individuals are more cold tolerant than smaller individuals and thus are able to cope with lower winter temperatures and winter at northern latitudes. Body size has been implicated as the primary mechanism for differential migration in waterfowl (Cristol et al. 1999), though no differences were seen in late winter body mass among shovelers on the GSL and the Texas Gulf Coast (Chapter 3 this document). Finally, some individual shovelers endure immediate costs of wintering in colder areas to benefit from arriving early or in better condition to the breeding grounds in the spring, generally to establish a territory (Myers 1981). Shoveler biology supports this hypothesis as shovelers have high breeding site territoriality (Afton 1979, DuBowy 1980) making it important to reach breeding areas earlier in the spring to secure the best sites.

Decreases in energetic costs of spring migration due to shorter migration distance may result in increased fitness. Late winter and spring body condition are positively associated with breeding success and subsequent recruitment in multiple waterfowl
species (Devries et al. 2008, Guillemain et al. 2008) and lower body condition, as measured by lipid levels, upon arrival limited egg production in shovellers nesting in southern Manitoba (Ankney and Afton 1988). All other factors being equal, shovellers that have shorter migration distances should arrive at the breeding grounds with higher lipid levels than shovellers with longer migration distances. Alternatively, the energetic costs of wintering further north result in lower energy reserves for spring migration and preclude migrating longer distances to more northern breeding grounds. Shovellers wintering on the GSL had similar food consumption and body mass measurements as shovellers on other wintering areas (Chapter 3 this document) indicating the GSL is a suitable substitute for more southern wintering areas, despite the challenges of low temperatures and high salinities.

The hypothesis that all shovellers that winter on the GSL bred or were hatched locally is not supported, though one shoveller banded in Utah was recovered in winter on the GSL and \( \delta^2H \) data suggest at least a few wintering shovellers molted in the Great Basin of the western US. Utah had an estimated 1300 breeding shovellers annually from 2001–2012 (Olson and Trost 2012), well below the wintering population on the GSL (Chapter 2 this document). It is possible all shovellers that bred in Utah wintered on the GSL, though this would not comprise the entire wintering population. Banding data show some shovellers banded in Utah were recovered in California’s Central Valley and on the Gulf Coast, so it is unlikely all shovellers that breed in Utah also winter on the GSL. Local breeders may have an advantage during winter in that they are familiar with the landscape and locate food and freshwater sources with minimal search effort. Local
breeders can also quickly return to familiar, nearby, breeding grounds in the spring. Freshwater marshes are limited within the western US so knowledge of high quality nesting and brood rearing locations may increase reproductive success. Waterfowl that have increased breeding success due to their choice of wintering site may show increased winter site fidelity than conspecifics. Winter site fidelity of shovelers has not been documented (Robertson and Cooke 1999), but Northern Pintails wintering in and around the GSL had some of the highest fidelity to wintering sites compared to conspecifics in other wintering areas (Hestbeck 1993).

Banding data suggest shovelers from the same wintering areas utilize a variety of latitudes as breeding areas, and there is no distinct separation among shovelers from different breeding sites at wintering sites at the scale examined here. This refutes the hypothesis that shovelers migrate similar distances from their breeding grounds to wintering grounds. In addition, only one bird recovered on the GSL was banded in northern Canada or Alaska, the furthest breeding sites of shovelers. Shovelers recovered in the Central and Pacific flyways had travelled over twice the distance as shovelers wintering on the GSL. The difference in average distance travelled between birds recovered on the GSL and those recovered in California’s Central Valley (836 km) or the Texas Gulf Coast (1948 km) is similar to the straight-line distance between the GSL and those areas. The difference in minimum and maximum distance traveled for shovelers recovered in the Pacific Flyway suggest they bred and were banded at a variety of latitudes. In contrast, shovelers recovered on the GSL had a much smaller migration
distance distribution, and potentially a smaller natal origin area, though these results are likely confounded by a small sample size of banded birds recovered on the GSL.

Shovelers wintering on the GSL were assigned to breeding areas locally, in the Prairie Pothole Region, and across their breeding range, supporting the hypothesis of a mixed flock during winter. Band recoveries in California’s Central Valley show the same pattern of wintering birds that were banded locally and across much of shovelers breeding range. Shovelers recovered on the Texas Gulf Coast also exhibited the same pattern, though banding locations covered the entire core area of the Prairie Pothole Region and not the less densely populated areas beyond the Prairie Pothole Region. Individuals from across shoveler’s breeding range that migrate from a northerly wintering area such as the GSL may arrive at breeding sites before conspecifics wintering further south.

There is a northerly shift from historic wintering grounds in some waterfowl populations due to increased water availability in reservoirs and canals (Buller 1975, Hobaugh and Teer 1981) and increased food availability in the form of agricultural waste grain (Jorde et al. 1983) which may result in altered demographics at the population level. Wintering further north often results in crowding into suitable open water sites with adequate food. High concentrations of wintering birds increases vulnerability to disease and predation and may decrease survival (Jorde et al. 1983). Further survival or population decreases may result from increased thermoregulatory demands and in turn a decrease in spring body condition. Though exploitation of anthropogenic water sources and waste grain is a relatively new phenomenon, the GSL has been available to wintering
ducks for thousands of years. Shovelers wintering on the GSL may be a case study in population level impacts of wintering at northern latitudes.

Many avian species have shown an increase in mercury concentrations after arrival on the GSL. Mercury concentrations in shovelers (Vest et al. 2009), Common Goldeneye (Vest et al. 2009), and Eared Grebes (*Podiceps nigricollis*; Conover and Vest 2009) increased from arrival in fall through late winter or migration. These data suggest these contaminants were ingested while on the GSL, and bioaccumulation of mercury has been demonstrated within the ecosystem (Naftz et al. 2008). Some individual birds have shown high levels of mercury early in the fall, soon after populations start arriving to the GSL (Vest et al. 2009), indicating birds may quickly accumulate mercury after arrival, or there is contaminant buildup elsewhere in the annual cycle or in the lifetime of the bird.

Mercury levels in water (0.02–4 ng L\(^{-1}\)) and waterfowl (0–435 ng g\(^{-1}\)) in southern Saskatchewan lakes exhibited a large range, but all measurements of waterfowl mercury levels were below human health recommendations for fish (Hall et al. 2009). High mercury concentrations in the water, and the bioaccumulation of mercury in the ecosystem, suggest there is potential for waterfowl in Saskatchewan to accumulate high mercury concentrations, particularly for species that feed primarily on animal matter, such as shovelers. In this study, I found the highest occurrence of shovelers wintering on the GSL came from southern Canada, including Saskatchewan. The exogenous source of mercury in ducks harvested from the GSL is unknown but researchers should start their search in southern Canada.
Banding data and $\delta^{2}H_f$ analysis suggests shovelers wintering on the GSL bred locally or in the southern portion of their breeding range. These results show support for hypotheses 1 and 4 that I considered for the origin and migration strategy of shovelers wintering on the GSL. First, a portion of the shoveler population wintering on the GSL originated in the Prairie Pothole Region and stopped short of the remainder of the population. Second, some birds from across shoveler’s breeding range wintered on the GSL, indicating mixed migration. The hypothesis that shovelers all migrated similar distances and birds that wintered the furthest north on the GSL also bred the furthest north is not supported. Finally, though some shovelers wintering on the GSL were assigned to local populations, many more had stable isotope likelihood assignments outside the western US, so a hypothesis that GSL wintering birds were local breeders is not supported by these data.

**LITERATURE CITED**


Bellrose, F. C. 1972. Mallard migration corridors as revealed by population distribution,


Table 7-1. Straight–line distance (km) between initial banding and final recovery sites for all recovered Northern Shovelers banded 15 May through 31 July and recovered 1 Dec through 28 February, 1926–2012, in the Central and Pacific flyways of the US and Mexico.

<table>
<thead>
<tr>
<th></th>
<th>Female</th>
<th>Male</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Central Flyway</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>39</td>
<td>47</td>
<td>86</td>
</tr>
<tr>
<td>Average</td>
<td>2281</td>
<td>2240</td>
<td>2260</td>
</tr>
<tr>
<td>Maximum</td>
<td>3097</td>
<td>3001</td>
<td>3097</td>
</tr>
<tr>
<td>Minimum</td>
<td>1464</td>
<td>667</td>
<td>667</td>
</tr>
<tr>
<td><strong>Mexico</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>33</td>
<td>48</td>
<td>81</td>
</tr>
<tr>
<td>Average</td>
<td>3026</td>
<td>3094</td>
<td>3060</td>
</tr>
<tr>
<td>Maximum</td>
<td>3835</td>
<td>5874</td>
<td>5874</td>
</tr>
<tr>
<td>Minimum</td>
<td>1405</td>
<td>1097</td>
<td>1097</td>
</tr>
<tr>
<td><strong>Pacific Flyway</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>178</td>
<td>310</td>
<td>488</td>
</tr>
<tr>
<td>Average</td>
<td>1722</td>
<td>1840</td>
<td>1781</td>
</tr>
<tr>
<td>Maximum</td>
<td>4334</td>
<td>4290</td>
<td>4334</td>
</tr>
<tr>
<td>Minimum</td>
<td>15</td>
<td>47</td>
<td>15</td>
</tr>
<tr>
<td><strong>Utah</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>3</td>
<td>18</td>
<td>21</td>
</tr>
<tr>
<td>Average</td>
<td>736</td>
<td>1154</td>
<td>945</td>
</tr>
<tr>
<td>Maximum</td>
<td>1130</td>
<td>3482</td>
<td>3482</td>
</tr>
<tr>
<td>Minimum</td>
<td>222</td>
<td>685</td>
<td>222</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>253</td>
<td>423</td>
<td>676</td>
</tr>
<tr>
<td>Average</td>
<td>1941</td>
<td>2082</td>
<td>2012</td>
</tr>
<tr>
<td>Maximum</td>
<td>4334</td>
<td>5874</td>
<td>5874</td>
</tr>
<tr>
<td>Minimum</td>
<td>15</td>
<td>47</td>
<td>15</td>
</tr>
</tbody>
</table>
Figure 7-1. Distribution of likelihood-based assignment of stable hydrogen isotope flight feather ratios from Northern Shovelers collected from the Great Salt Lake, Utah, USA. Stable hydrogen isotope ratios ($^2$H to $^1$H) measurements were taken...
from one flight feather of Northern Shovelers collected from December–February, 2009–2011 (n = 113). Banding locations (circles; n = 22) of Northern Shovelers recovered on the Great Salt Lake during winter show the pattern of natal origin of Northern Shovelers wintering on the Great Salt Lake.
Figure 7-2. Banding location of Northern Shovelers recovered in California’s Central Valley (green triangles; \( n = 474 \)), and the Texas Gulf Coast (red diamonds; \( n = 88 \)) during winter in relation to the Great Salt Lake, Utah. The distribution of banding locations shows natal origin of Northern Shovelers wintering across the Pacific and Central flyways and indicates birds originated from across their range rather than a specific geographic area.
Figure 7-3. Histogram of stable carbon isotope ratios in flight feathers from Northern Shovelers wintering on the Great Salt Lake, Utah, December–February, 2010–2011. Stable carbon isotope ratios were used to assign molting area where feathers were grown as either a freshwater ($< -20 \%$) or saline ($> -20 \%$) habitat ($n = 25$).
CHAPTER 8

CONCLUSION

CONCLUSIONS

My research focused on the fall staging and wintering ecology of northern shovelers (Anas clypeata), green-winged teal (Anas crecca), common goldeneye (Bucephala clangula), and eared grebes (Podiceps nigricollis) on the Great Salt Lake (GSL), Utah. I addressed six objectives involving avian use of the GSL, particularly in association with the commercial harvest of brine shrimp (Artemia franciscana) cysts: 1) Estimate abundance of wintering waterfowl on GSL and determine what factors impact abundance and distribution while on the GSL. 2) Document food habits of waterfowl utilizing the GSL during fall and winter and indentify overlap of brine shrimp cyst use with the commercial harvest industry. 3) Estimate abundance of eared grebes on the GSL and yearly population fluctuations on the GSL and Mono Lake, California and environmental factors that impact population abundance and distribution. 4) Quantify food habits of eared grebes and measure the removal of brine shrimp cysts by eared grebes from the GSL. 5) Describe differences between deceased migrating eared grebes and eared grebes that still occupied the GSL after a mass downing to determine potential causes of mortality, including the impact of heavy metal toxicity. 6) Examine breeding origin of waterfowl wintering on the GSL to help monitor population changes and evaluate sources of mercury and selenium to ducks from outside of the GSL ecosystem.

I conducted stratified aerial surveys for total ducks, northern shovelers, and goldeneye (common and Barrow’s [Bucephala islandica]) to examine factors that impact
abundance and distribution of ducks on the GSL. North American waterfowl winter throughout a large geographic area and the choice of wintering site has a direct impact on survival and fitness. Climatic and food variables are the most commonly cited factors influencing abundance and distribution of wintering waterfowl. Total ducks and northern shoveler density on the GSL was most correlated with temperature with colder weather resulting in decreased abundance. Goldeneye were more resilient to both higher salinity and colder temperatures than northern shovelers, and food quantity, as represented by brine fly (Ephydra spp.) larvae, was the factor most associated with their density. Distribution of total ducks on the GSL was most correlated with low salinity and immediate access to freshwater, both vital in the ability of birds to osmoregulate and survive in a hypersaline system. My results are consistent with previous findings that ambient temperature is a primary factor in the abundance of wintering waterfowl (Nichols et al. 1983, Schummer et al. 2010). Despite the lack of snow and ice cover on the GSL, both food and weather influenced abundance of wintering ducks. The primary winter food of northern shovelers using the GSL was brine shrimp cysts and abundance of cysts may be impacted by commercial harvest. However, the influence of cyst density on northern shoveler abundance on the GSL was relatively small within the range of cyst densities observed during my study. Goldeneyes are adapted to cold weather and saline habitats found on the GSL, and contrary to northern shovelers my results indicated food abundance was an important variable influencing their population size.

I used October aerial photo surveys on the GSL and Mono Lake and aerial counts on the GSL to describe the distribution of eared grebes staging at their two principle fall
staging areas. At GSL, the large commercial harvest of brine shrimp cysts during the fall and may impact eared grebe population distribution and abundance. Eared grebe populations in North America fluctuated between 1 and 4.5 million birds between 1997 and 2012 according to aerial photo surveys. The long-term (1997-2012) average eared grebe population on the GSL was 1.4 million and on Mono Lake was 1.0 million. Populations changed on GSL and Mono Lake in synchrony, often exhibiting large yearly population fluctuations. Population regulation is likely occurring away from staging areas (Jehl et al. 2002) and acts on both staging populations equally. Locations of eared grebe concentrations on the GSL were influenced by brine shrimp densities and did not overlap with concentrations of commercial harvest boats. Spatial segregation of commercial harvesters and eared grebes reduced negative associations of anthropogenic disturbance on the birds. My results indicated that interactions with commercial harvesters of brine shrimp cysts did not negatively impact eared grebe abundances on the GSL. Knowledge of population changes within and among staging areas will help managers monitor long-term abundances and reduce negative impacts between eared grebes and commercial harvesters.

I collected northern shoveler and green-winged teal during the nonbreeding season to examine diet and body condition of birds using the GSL and to examine the overlap of cyst use by ducks and commercial harvesters. Diets of both duck species changed seasonally. Both duck species consumed wetland plant seeds and invertebrates in higher quantities than other foods during fall and spring; during early and late winter, GSL invertebrates (brine shrimp adults and cysts, brine fly larvae) made up 75–100%
aggregate wet weight mass consumed. Body weight of both northern shoveler and green-winged teal was highest in fall, decreased through winter, and increased again in the spring: a pattern seen in many duck species during the nonbreeding season (Baldassarre and Bolen 2006). There was an overlap of brine shrimp cyst use between commercial harvesters and ducks using the GSL during the nonbreeding season. Brine shrimp cyst removal by northern shoveler and green-winged teal was minimal compared to commercial harvest levels indicating northern shoveler and green-winged teal were not having a negative impact on cyst biomass available for commercial harvest. Furthermore, many cysts that are consumed by ducks pass through the digestive system and remain viable (Proctor 1964, Proctor and Malone 1965, van Leeuwen et al. 2012). Consumption of cysts by northern shoveler and green-winged teal peaked in late winter when harvest ended indicating there was still enough biomass for feeding ducks. The lack of measurable decline in cyst densities due to consumption by birds was supported by my estimate of low cyst removal by ducks compared to commercial harvest.

I assessed the diet of eared grebes to determine the extent to which they are dependent on brine shrimp and their cysts for food. I collected individual birds to measure diets and examine changes in body condition of staging eared grebes. Cysts were consumed by 40% of collected eared grebes and made up > 75% aggregate biomass of stomach samples. Despite the high occurrence of cysts in stomach samples, cysts were not the primary food item of eared grebes. Cysts may be held in the stomach for longer periods by feather mass, so esophagus samples were a better indicator of diet. Adult brine shrimp were the primary food collected from the esophagus from October until
December. After cold water temperatures caused a die-off of adult brine shrimp (Belovsky et al. 2011), cysts became more prevalent in the diet of eared grebes. It is likely that cysts are only consumed when no other foods are available to maintain weight until departure. I found no increase in eared grebe weight when feeding on cysts increased in December, indicating eared grebes were not able to efficiently use the energy from cysts. Consumption of cysts by eared grebes was a fraction of what was removed by harvest. Unlike commercial harvest, eared grebes likely returned large quantities of viable cysts to the ecosystem when consumed cysts are passed through the digestive system and remain viable (Proctor and Malone 1965). Current monitoring and management of commercial harvest are sufficient to maintain yearly populations of adult brine shrimp to sustain eared grebes populations.

I examined body condition, population characteristics, and heavy metal concentrations among eared grebes that died during a downing on 12 December 2011 in and around Cedar City, Utah, and those that still occupied the GSL both pre- and post-downing. Eared grebes collected pre-downing were heavier (523 g) than deceased birds (433 g). Body weight (g) and subcutaneous fat thickness (mm) were lower in downed birds than pre-downing birds, likely the result of a 400-km flight from the staging area to Cedar City. In addition to total body mass differences, liver, heart, and intestine weights were all greater in both pre- and post-downing eared grebes than downed eared grebes. Adult biased age ratios were observed in all groups but pre-downing (34 adults:5 juvenile) and post-downing (39:2) groups were less biased than the downed group (100:1). Mercury and selenium concentrations in all groups were above the level
observed to impact bird species. Mercury concentrations in the liver ranged from 4.4–25.8 ppm and mercury concentrations measured in birds collected pre-downing were lower than downed birds. Despite high levels of mercury and selenium no adverse effects of heavy metal contamination have been noted in previous studies of eared grebes on the GSL (Conover and Vest 2009, Darnall and Miles 2009). Weather was likely the proximate cause of the downing decreased muscle coordination due to mercury toxicity may have been the ultimate reasons why some birds went down in Cedar City while others continued migration.

I used banding data and stable hydrogen isotope ratios to describe the migration strategy and natal origin of northern shovelers wintering at the GSL. The natal origin of wintering birds and their migration strategy is important to understand the impact of population changes throughout the annual cycle and to identify management actions to reverse population declines. I used likelihood-based assignment models (Van Wilgenburg and Hobson 2011) to predict breeding location of northern shovelers wintering on the GSL. Northern shovelers recovered at the GSL (n = 22) had been banded during the summer in southern Alberta and Saskatchewan and northern Montana. The distance travelled by northern shovelers wintering on the GSL was significantly shorter than birds recovered in wintering areas in the Central and Pacific flyways. Stable-isotope likelihood-based assignment placed the largest number of northern shovelers collected on the GSL as breeding in the western US and southern Canada, similar to banding records. High concentrations of mercury found in breast tissue of shovelers on the GSL were likely obtained while on the GSL though researchers should look in southern Canada for
possible exogenous sources of heavy metal contamination. My results suggest northern shovelers wintering on the GSL bred locally or in the southern portion of their breeding range and therefore had shorter migration distances than conspecifics wintering elsewhere.

**FUTURE RESEARCH**

There are still many questions that need to be addressed to fully understand the GSL ecosystem and inform further management decisions. Particularly related to my research are questions about food abundance and availability, and avian species use of the GSL during periods of the annual cycle outside of winter. Brine fly adults and larvae are important to many avian species including goldeneye, phalaropes (Wilson’s [*Phalaropus tricolor*] and red-necked [*P. lobatus*]), and California gulls (*Larus californicus*), but factors influencing brine fly larvae abundance are not well studied on the GSL. Thus, improved understanding of factors influencing brine fly populations is needed to inform GSL management decisions relative to the needs of aquatic birds. In particular, what are the peak emergence dates on the GSL for adult brine flies on the GSL? Are emergence dates synchronized across the entire GSL? What are the best methods to determine the density of brine flies that emerge from the GSL? What factors, such as bottom sediment, account for variation in emergence densities of adult brine flies?

Knowledge of avian diets is fundamental to management of avian populations. For many avian species, particularly California gulls and phalaropes, we cannot assess seasonal or annual changes in their diet while on the GSL. Most importantly, we do not know if avian species can shift their diets if a prey source pulse does not coincide with
species use of the GSL ecosystem. Many different species use the GSL at various times of year and coincide with various food pulses. As food pulses change, so does the density of prey species.

Migratory species are often on the move to find abundant food resources. As climate changes across the globe, avian species are altering the timing and distance of migration to coincide with changing resource availability. Many species are decreasing the distance traveled to wintering grounds, thus altering wintering distribution and resource use (MacLean et al. 2008). Shorebirds and waterfowl in North America have been shown to be migrating south later, north earlier, and utilizing wintering grounds not historically occupied for long periods (see Cox [2010] for review). Consequences of changing migration timing include missing food pulses at stop-over sites, competition with other species for reduced food resources, and increased human-wildlife conflict.

**LITERATURE CITED**


APPENDIX
This is a License Agreement between Anthony Roberts ("You") and John Wiley and Sons ("John Wiley and Sons") provided by Copyright Clearance Center ("CCC"). The license consists of your order details, the terms and conditions provided by John Wiley and Sons, and the payment terms and conditions.

<table>
<thead>
<tr>
<th>License Number</th>
<th>3267170692500</th>
</tr>
</thead>
<tbody>
<tr>
<td>License date</td>
<td>Nov 13, 2013</td>
</tr>
<tr>
<td>Licensed content publisher</td>
<td>John Wiley and Sons</td>
</tr>
<tr>
<td>Licensed content publication</td>
<td>The Journal of Wildlife Management</td>
</tr>
<tr>
<td>Licensed content title</td>
<td>Eared grebe diet on Great Salt Lake, Utah, and competition with the commercial harvest of brine shrimp cysts</td>
</tr>
<tr>
<td>Licensed copyright line</td>
<td>Copyright © The Wildlife Society, 2013</td>
</tr>
<tr>
<td>Licensed content author</td>
<td>Anthony J. Roberts, Michael R. Conover</td>
</tr>
<tr>
<td>Licensed content date</td>
<td>Jul 1, 2013</td>
</tr>
<tr>
<td>Start page</td>
<td>1380</td>
</tr>
<tr>
<td>End page</td>
<td>1385</td>
</tr>
<tr>
<td>Type of use</td>
<td>Dissertation/Thesis</td>
</tr>
<tr>
<td>Requestor type</td>
<td>Author of this Wiley article</td>
</tr>
<tr>
<td>Format</td>
<td>Electronic</td>
</tr>
<tr>
<td>Portion</td>
<td>Full article</td>
</tr>
<tr>
<td>Will you be translating?</td>
<td>No</td>
</tr>
</tbody>
</table>

If you would like to pay for this license now, please remit this license along with your payment made payable to "COPYRIGHT CLEARANCE CENTER" otherwise you will be invoiced within 48 hours of the license date. Payment should be in the form of a check or money order referencing your account number and this invoice number RLNK501158529.

Once you receive your invoice for this order, you may pay your invoice by credit card. Please follow instructions provided at that time.

Make Payment To:
Copyright Clearance Center
P.O. Box 843006
Boston, MA 02284-3006

For suggestions or comments regarding this order, contact RightsLink Customer Support:customercare@copyright.com or +1-877-622-5543 (toll free in the US) or +1-978-646-2777.

Gratis licenses (referencing $0 in the Total field) are free. Please retain this printable license for your reference. No payment is required.
CURRICULUM VITAE

Anthony (Tony) J. Roberts
314 E 200 S, Logan, UT 84321
Phone: (402) 312-3010
Email: tony.roberts@aggiemail.usu.edu

CAREER GOALS:
I seek to conduct management for a respected institution and work with all stakeholders to improve management of wildlife resources. My interests include waterfowl management, interactions among commercial industries and wildlife, the impact of management actions on wildlife populations, and human-wildlife conflicts. I am particularly interested in management and research conducted across ownership and political boundaries. Applying research and management at broad spatial scales is a principle goal of my career.

ACADEMIC BACKGROUND:
PhD, Wildlife Biology August 2009-Present
Utah State University, Logan UT
Dissertation Title: Wintering Waterfowl and Waterbird Populations on the Great Salt Lake, Utah and the Implications of Brine Shrimp Cyst Harvest

MS, Wildlife Science August 2009
Texas Tech University, Lubbock TX
Thesis Title: Avian Community Response to Large-scale Wildfires in the Texas Panhandle

BS, Wildlife Biology and Management May 2005
University of Wyoming, Laramie, WY
Accredited program in Wildlife and Fisheries Biology and Management

PROFESSIONAL EXPERIENCE:
Research Assistant 1 Aug 2009 – Present
Utah State University, Department of Wildland Resources, Logan, UT
Advisor: Dr. Michael Conover (435)797-2436

Work with state and industry personnel to determine the impact of a commercial harvest on wildlife populations. Negotiate with industry for property access and data sharing. Assist with gamebird management at state management areas including prescribed fire and invasive species removal. Design and conduct monthly aerial surveys of gamebirds, including waterfowl, and waterbirds to determine abundance and distribution. Collect waterfowl for diet and body condition analysis. Trap waterbirds, fit them with radio
collars, and monitor movements during fall migration. Analyze data using multiple statistical methods within various statistical programs including Program R and ArcGIS. Manage and coordinate three technicians each of three years in completion of lab work. Write yearly progress reports for funding agency. Present results of data collection to funding agency, scientific advisory groups, and local conservation organizations.

**Wildlife Biologist**

15 April – 15 December 2011

Frontier Environmental Consulting Corporation, Providence, UT

Supervisor: Dennis Wenger (435)757-7022

Performed road-based wintering bird surveys at and around a wind energy facility. Conducted breeding bird point counts at a wind energy facility. Observed behavior of breeding bald eagles and assessed the potential danger of wind energy operations to these birds. Entered survey data and summarized results for reports to clients. Wrote and communicated summary reports for clients to communicate results of surveys and potential risk of operations.

**Graduate Research Assistant**

1 Jan 2007 – 1 Aug 2009

Texas Tech University, Department of Natural Resources, Lubbock, TX

Advisor: Dr. Clint Boal (806)742-2851

Worked with private landowners for property access after a wildfire and communicated my results and management recommendations to them. Coordinated research activities with multiple partners and stakeholder groups including the NRCS and USGS. Planned and performed avian point count surveys on grasslands during the breeding and wintering seasons. Designed and conducted call surveys for resident gamebirds including lesser prairie chicken and bobwhite quail. Searched for and monitored nests of grassland birds. Supervised two technicians during grassland bird work and an additional technician in lab work. Managed an undergraduate research project and supervised the presentation of their results. Analyzed data using a variety of computer programs such as Program R, DISTANCE, and MS Excel.

**Consulting Biologist**

1 Sep – 15 Nov 2007

Tetra Tech, Portland, OR

Supervisor: Amanda Miller

Systematically searched for carcasses at a wind farm in Texas to survey for mortality risks. Participated in searcher efficiency trials to improve survey efficiency. Reported data to project supervisor.

**Waterfowl Biologist**

1 Aug 2006 – 20 Dec 2006

New Jersey Division of Fish and Wildlife, Tuckahoe, NJ

Supervisor: Ted Nichols
Organized a large network of private landowners and volunteers to assist trapping and banding operations. Trapped and banded waterfowl throughout New Jersey using box traps and rocket nets. Obtained avian influenza samples from live waterfowl. Surveyed hunters at check stations to obtain avian influenza samples, physiological measurements, and diet samples. Operated and maintained trap sites and equipment. Surveyed gamebird populations from the ground and performed behavioral observations.

**Game Bird Technician**


Tall Timbers Research Station, Tallahassee, FL

Supervisor: Shane Wellendorf

Worked with private landowners in improving habitat for bobwhite quail. Conducted daily covey call counts for resident gamebirds. Captured, banded, and fixed radio transmitters on adult and young gamebirds. Performed telemetry on gamebirds for habitat use study. Cared for, and maintained enclosures for, captive bobwhite. Entered and analyzed data in Microsoft Access and ArcGIS. Created GIS maps of private properties. Trapped small mammals with Sherman traps and surveyed presence of mesomammals using scent stations. Completed vegetation surveys and timber surveys to assess feasibility of logging operations. Assisted with annual prescribed burning of upland pine. Rode and maintained ATVs and other equipment.

**Field Technician**

15 May - 15 August, 2004 and 2005

Platte River Whooping Crane Maintenance Trust, Wood River, NE

Supervisor: Dan Kim

Performed spot map and point count surveys for grassland birds. Mist netted and banded birds for a monitoring avian production and survival (MAPS) station. Assisted nest searching for prairie songbirds such as bobolinks, Henslow’s sparrows and grasshopper sparrows. Completed vegetation sampling. Collected and identified insects for use and availability study. Entered data in Excel and bird banding programs. Participated in raptor trapping.

**PUBLICATIONS:**


GRANTS:
Utah Agricultural Experiment Station
“Timing and Use of Food Resources by Birds at Great Salt Lake, Utah” – 2012 ($20,000)

Friends of Great Salt Lake Research Grant
“Origin of Waterfowl Wintering on the Great Salt Lake: A Stable Isotope Approach” – 2011 ($1,000)

PRESENTATIONS:

AWARDS:
African Safari Club of Florida Scholarship - 2012
S.J. and Jessie E. Quinney Fellowship – 2009
Houston Safari Club Scholarship – 2008

REVIEWER:
Wildlife Society Bulletin
Human Wildlife Interactions
Journal of Wildlife Management

PROFESSIONAL COURSEWORK:
Introduction to Program MARK. Dr. Brent Bibles, May 2009.
Information Theoretic Approaches to Life Sciences. Dr. David Anderson, March 2009.

RELEVANT SKILLS:
Proficient use of program R for statistical analysis including a variety of packages.
Advanced training in use of geographic information systems, particularly ArcGIS.
Extensive avian trapping and banding experience including species of waterfowl, raptors,
and passerines.

MEMBERSHIPS AND ACTIVITIES:
Member, The Wildlife Society
Member, Ducks Unlimited
Member, American Ornithologists Union
Graduate Student Senator for the College of Natural Resources, Utah State University, 2010-2013
Graduate student representative to the faculty, Texas Tech University, Department of
Natural Resources Management, 2008
President, Lambda Chi Alpha, 2005