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Management and Conservation

Eared Grebe Diet on Great Salt Lake, Utah, and Competition with the Commercial Harvest of Brine Shrimp Cysts

ANTHONY J. ROBERTS,[1] *Department of Wildland Resources, Utah State University, Logan, UT, USA*
MICHAEL R. CONOVER, *Department of Wildland Resources, Utah State University, Logan, UT, USA*

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. We assessed the diet of eared grebes to determine the extent to which they are dependent on brine shrimp and their cysts. We 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% of 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 were 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, cysts became more prevalent in the diet of eared grebes. Concomitantly, 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.

KEY WORDS brine shrimp, eared grebes, fisheries, Great Salt Lake, harvest, saline lakes.

Interactions between avian populations and commercial fisheries have been studied across many avian species including double-crested cormorants (*Phalacrocorax auritu*; Glahn and Brugger 1995) and various seabirds (Tasker et al. 2000). Effects 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 fisheries 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, managers must 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*) eggs (i.e., cysts) takes place throughout 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 are harvested annually from the GSL, providing an annual economic effect to the Salt Lake City area 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.

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[1]*E-mail: tony.roberts@aggiemail.usu.edu*

The GSL's low-gradient bottom, 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 use the GSL consume adult brine shrimp and cysts (Colwell and Jehl 1994, Conover et al. 2009, 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). Upon arrival at the GSL, eared grebe's flight muscles atrophy and digestive organs increase in size to enhance food digestion and build fat reserves. Eared grebes go through a prebasic molt and they 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 interactions between eared grebes and commercial cyst harvest. We 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 ecosystem covers nearly 780,000 ha when at a long-term average lake elevation of 1,280 m and consists of saline pelagic regions and freshwater wetlands along the shore, both of which support large populations of birds throughout the year (Aldrich and Paul 2002). Salinity is variable because of 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 2 invertebrates, brine shrimp and brine flies (*Ephydra* spp.). 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. Adults graze on phytoplankton and reach peak numbers in early summer, before decreasing as they reduce their food source (Stephens and Birdsey 2002). A second, smaller, peak in adult brine shrimp abundance occurs in late summer after a rebound of phytoplankton in GSL waters. Throughout summer, most reproduction is ovoviparous 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. 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; they are least abundant 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 the anoxic water layer; larvae densities are 10 times greater on bioherms and mud substrates than on sand substrates (Collins 1980).

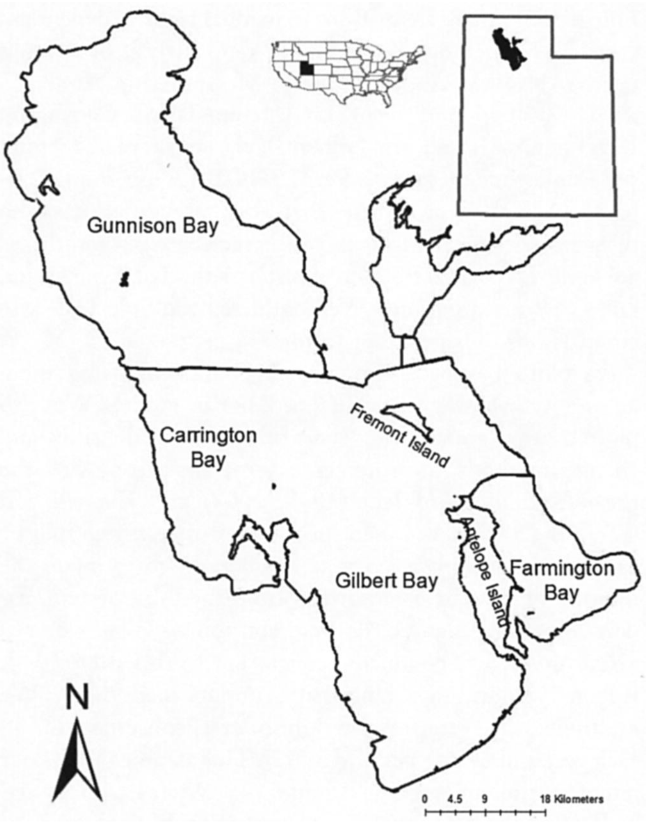

Figure 1. Map of Great Salt Lake, Utah, and principle bays and islands where we investigated diets of eared grebes in 2010 and 2011.

METHODS

Field Methods

We collected eared grebes from October through December from the GSL in 2010 and 2011. We collected birds 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 we collected birds opportunistically. We attempted to collect 25–30 birds each month from each of 4 areas of the GSL: the southern shore of Gilbert Bay, the northern point of Antelope Island, Fremont Island, and Carrington Bay on the west side of the GSL (Fig. 1). We froze birds as quickly as possible after collection. We later thawed birds, at which time we aged and sexed each bird and recorded several external and internal measurements. We assigned age by eye color (bright red in adults, brown to pale orange in juveniles; Storer and Jehl 1985) and determined sex 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 1 side of breast muscle. We 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 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. We sorted food items by species, and measured wet weights to the nearest 0.01 g.

The Utah Division of Wildlife Resources collected limnological data and density of invertebrates bi-monthly at 17 sites across the GSL throughout 2010 and 2011. A description of how these data were collected can be found in Belovsky et al. (2011). We obtained cyst harvest statistics from the Utah Division of Wildlife Resources, Great Salt Lake Ecosystem *Program.*

Statistical Analysis

We used Program R for all statistical analyses (R Core Team 2012). We considered an alpha value of <0.05 to be statistically significant. We calculated frequency of occurrence and aggregate wet weight proportion of each food item for each area of the lake, month, and year. We used aggregate proportion of food items from individual birds 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. We used the Bray–Curtis method of distance and ran 9,999 permutations. We conducted multiple pair-wise comparisons on significant factors.

We plotted brine shrimp densities and compared them among years using a generalized linear model. We also plotted eared grebe mass versus brine shrimp densities and changes in body measurements for comparison with the previous findings of Jehl (1997, 2007) and Caudell and Conover (2006*a*). We 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, we used aerial survey data conducted concurrent to this study (A. J. Roberts, Utah State University, unpublished data). We multiplied the average wet weight of cysts consumed during each year and month per bird by 1.5. This assumes a 16-hour retention time of cysts in bird digestive systems as measured by Proctor and Malone (1965). We then multiplied grams of cysts per day per bird by the product of the peak population count during each year and month and the percent of birds collected with cysts in their esophagus. We multiplied this number 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 an average of 13.4 g of cysts in their esophagus. Seventy-four percent of the population during that time was 590,000 eared grebes, which were consuming 20.7 g cysts/day (13.4×1.5 g). 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

We 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. 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. We found no difference among months or years in either age or sex ratio of collected eared grebes. Principle food items were brine shrimp adults and cysts and brine fly larvae based on both esophagus and stomach samples. Other foods found in small amounts were adult brine flies, plant material, wetland plant seeds, and freshwater invertebrates (Table 1). Adult 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.

Because of low sample sizes for esophageal contents, we removed food items that represented <5% aggregate biomass from further analysis; this left brine shrimp adults, 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 ($F_{2,\,57} = 10.51$, $P \leq 0.001$) on diet (Table 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 adult brine shrimp and more brine shrimp cysts than birds collected during the previous 2 months (Table 3). 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. Average wet weight of esophagus contents in October (0.13 g) and November (0.11 g) were greater than December (0.07 g). Similarly, mean stomach content wet weight was greater in October (8.42 g) and November (7.44 g) than December

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

	Esophagus ($n = 69$)		**Stomach ($n = 317$)**	
	% Occurrence	**Aggregate % biomass**	**% Occurrence**	**Aggregate % biomass**
Brine shrimp cysts	20.3	16.3	95.3	76.1
Brine shrimp adults	81.2	72.4	23.3	7.2
Brine fly	0.0	0.0	0.3	0.4
Brine fly larvae	20.3	9.9	51.4	14.1
Plant material	0.0	0.0	0.9	0.0
Wetland plant seeds	0.0	0.0	9.5	2.4
Wetland invertebrates	2.9	1.4	0.9	0.2

Table 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.

	df	F	P-value
Region	3	2.471	0.039
Month	1	10.511	0.001
Year	1	1.345	0.256
Region × month	2	1.650	0.173
Region × year	1	0.136	0.869
Residuals	57	0.715	
Total	65		

Table 3. Aggregate proportion 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.

Month	n	Brine shrimp cysts	Adult brine shrimp	Brine fly larvae
Oct	31	0.08	0.81	0.09
Nov	18	0.01	0.87	0.09
Dec	17	0.44	0.47	0.09

(3.10 g). We found no 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 (Fig. 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. 3).

Monthly cyst consumption by eared grebes ranged from about 81,000 kg to over 477,000 kg during this study (Table 4). Reported commercial brine shrimp harvest at the end of December each of the 2 years of this study was 10.2 and 7.1 million 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 adults 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 adults because of their lower digestibility (Caudell and Conover 2006*b*). 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

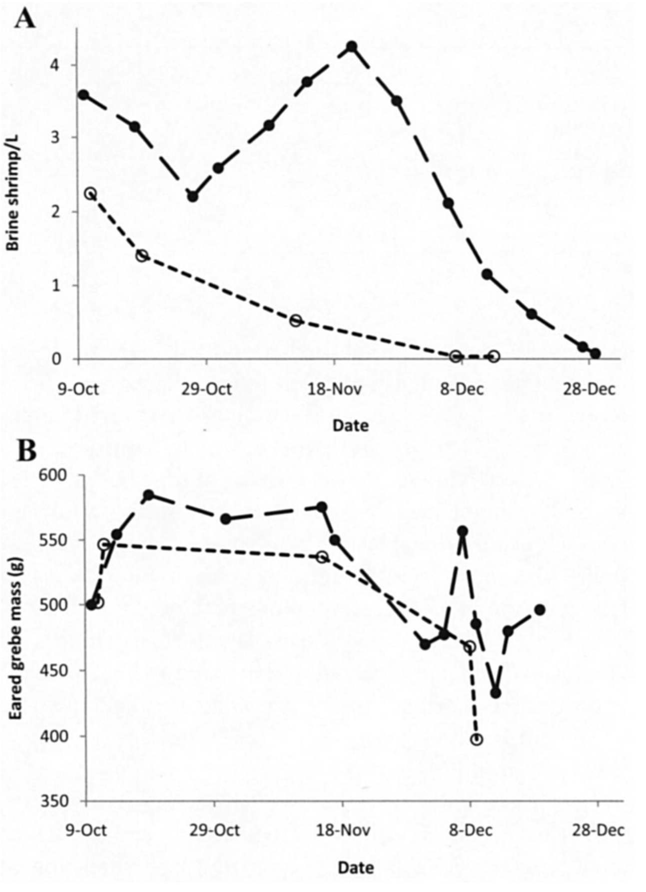

Figure 2. Mean brine shrimp densities (A) within the Great Salt Lake, Utah and mass of eared grebes collected (B) during the fall, 1 October through 28 December 2010 and 2011. Short dashed lines are 2010, and long dashed lines are 2011.

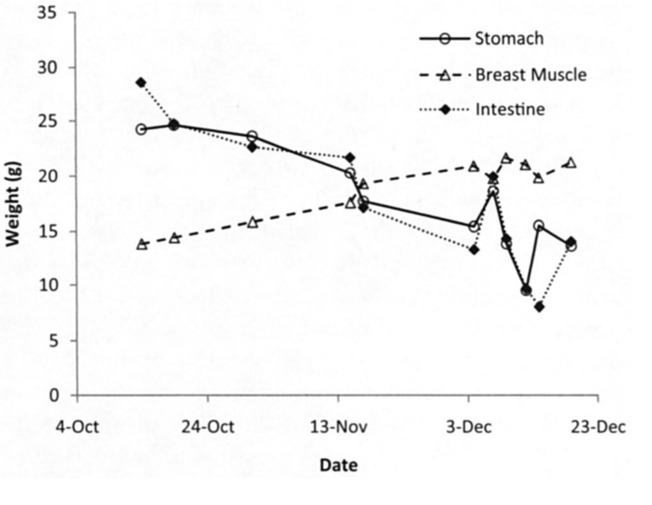

Figure 3. Mean weight of stomach, 1 side of breast muscle, and large and small intestines of eared grebes collected from the Great Salt Lake, Utah, October through December 2011.

Table 4. 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.

	Oct	Nov	Dec	Total	% of yearly total
Eared grebes					
2010	367,471	195,586	269,125	832,182	7.6
2011	418,397	477,997	81,673	978,067	12.2
Commercial harvest					
2010	6,119,180	1,774,069	2,278,363	10,171,613	92.4
2011	1,877,047	3,856,355	1,323,820	7,057,222	87.8

saline areas during the fall had consumed more freshwater invertebrates (Paul 1996). We 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 adults 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 about 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, we found no age or sex difference in diet among eared grebes on the GSL. On Mono Lake, spatial separation of age groups occurs among eared grebes that result in diet differences. Juvenile eared grebes are more abundant close to shore and consume a greater proportion of brine flies. Eared grebe adults are found further from shore and consume brine shrimp (Jehl 1988). We found similar age ratios in all 4 regions of the GSL. We also found that spatial differences in eared grebe diet were minimal and did not include differences in cyst consumption. Jehl (1988) found the greatest proportion of juveniles within 100 m of shore; we found that on the GSL eared grebe concentrations occurred in open water areas and rarely within 100 m of shore.

We found eared grebe body weight was correlated with adult brine shrimp densities. Eared grebe body weight declined quickly during fall of 2010 and 2011 as brine shrimp densities were reduced because of decreasing water temperatures and lack of recruitment as female brine shrimp converted to cyst production, not live birth. This same pattern was seen on Mono Lake (Jehl 1997) and previously on the GSL (Caudell and Conover 2006*a*). Declines in adult brine shrimp, the dominant food source of eared grebes on the GSL, were followed by reduced body mass. 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 and intestinal tract mass declined in late November and December as total food consumption decreased, whereas breast muscle mass increased throughout the study period to regain flight capacity.

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 3 months examined. Cysts were most prominent in diets in December, likely because of the declining numbers of adult brine shrimp and increasing access to cysts as they become concentrated in streaks. Only 1 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 some 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. Cysts are likely only consumed when no other foods are available to maintain weight until departure. We found no increase in eared grebe weight when feeding on cysts increased in December. Energy content of cysts (23.5 kJ/g dry weight) was greater than that of 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 efficiently use the energy from cysts (Caudell and Conover 2006*b*).

MANAGEMENT IMPLICATIONS

Consumption of cysts by eared grebes is a fraction of what is removed by harvest, but nearly 1 million kg of cysts may still be significant to the industry. 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 remaining viable (Proctor and Malone 1965). Hatching efficiency of cysts fed and recovered from 2 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 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 adult brine shrimps/L is required to support grebe populations. Since these estimates are both less than the long-term average of adult brine shrimp in the GSL of 6.20 adult 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.

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LITERATURE CITED

Aldrich, T. W., and D. S. Paul. 2002. Avian ecology of Great Salt Lake. Pages 343–374 *in* J. W. Gwynn, editor. Great Salt Lake: an overview of change. Department of Natural Resources, Salt Lake City, Utah, USA.

Anderson, M. J. 2001. Permutation tests for univariate or multivariate analysis of variance and regression. Canadian Journal of Fisheries and Aquatic Sciences 58:626–639.

Belovsky, G. E., D. Stephens, C. Perschon, P. Birdsey, D. Paul, D. Naftz, R. Baskin, C. Larson, C. Mellison, J. Luft, R. Mosley, H. Mahon, J. Van Leeuwen, and D. V. Allen. 2011. The Great Salt Lake ecosystem (Utah, USA): long term data and a structural equation approach. Ecosphere 2:1–40.

Bioeconomics Inc. 2012. Economic significance of the Great Salt Lake to the State of Utah. Final Report to the Great Salt Lake Advisory, Council, Missoula, Montana, USA.

Caudell, J. N., and M. R. Conover. 2006*a*. Behavioral and physiological responses of eared grebes (*Podiceps nigricollis*) to variations in brine shrimp (*Artemia franciscana*) densities. Western North American Naturalist 66:12–22.

Caudell, J. N., and M. R. Conover. 2006*b*. 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.

Collins, N. 1980. Population ecology of *Ephydra cineria* Jones (Diptera: Ephydridae), the only benthic metazoan of the Great Salt Lake, USA Hydrobiologia 68:99–112.

Colwell, M. A., and J. R. Jehl. Jr. 1994. Wilson's phalarope (*Phalaropus tricolor*). Account 83 *in* A. Poole, editor. The birds of North America. Cornell Lab of Ornithology, Ithaca, New York, USA.

Conover, M. R., and J. N. Caudell. 2008. Energy budgets for eared grebes on the Great Salt Lake and implications for harvest of brine shrimp. Journal of Wildlife Management 73:1134–1139.

Conover, M. R., J. Luft, and C. Perschon. 2009. Concentration and effects of selenium in California gulls breeding on the Great Salt Lake. Final Report to Utah Division of Water, Quality, Salt Lake City, Utah, USA.

Conover, M. R., and J. L. Vest. 2009. Concentrations of selenium and mercury in eared grebes (*Podiceps nigricollis*) from Utah's Great Salt Lake, USA. Environmental Toxicology and Chemistry 28:1319–1323.

Cooper, S. D., D. W. Winkler, and P. H. Lenz. 1984. The effect of grebe predation on a brine shrimp population. Journal of Animal Ecology 53:51–64.

Dana, G. L., and P. H. Lenz. 1986. Effects of increasing salinity on an *Artemia* population from Mono Lake, California. Oecologia 68:428–436.

Glahn, J. F., and K. E. Brugger. 1995. The impact of double-crested cormorants on the Mississippi Delta catfish industry: a bioenergetics model. Colonial Waterbirds 18:168–175.

Great Salt Lake Ecosystem Program. 2012. Brine shrimp harvester information. <http://wildlife.utah.gov/gsl/harvest/information.php>. Accessed 1 Dec 2012.

Jehl, J. R. Jr. 1988. Biology of the eared grebe and Wilson's phalarope in the nonbreeding season: a study of adaptations to saline lakes. Studies in Avian Biology 12.

Jehl, J. R. Jr. 1997. Cyclical changes in body composition in the annual cycle and migration of the eared grebe, *Podiceps nigricollis*. Journal of Avian Biology 28:132–142.

Jehl, J. R. Jr. 2007. Why do eared grebes leave hypersaline lakes in autumn? Waterbirds 30:112–115.

McArdle, B. H., and M. J. Anderson. 2001. Fitting multivariate models to community data: a comment on distance based redundancy analysis. Ecology 82:290–297.

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

Proctor, V. W., and C. R. Malone. 1965. Further evidence of passive dispersal of small aquatic organisms via the intestinal tract of birds. Ecology 46:728–729.

R Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

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 shrimp harvest. Pages 327–336 *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.

Storer, R. W., and J. R. Jehl. Jr. 1985. Moult patterns and moult migration in the black-necked grebe, *Podiceps nigricollis*. Ornis Scandinavica 16:253–260.

Tasker, M. L., C. J. Camphuysen, J. Cooper, S. Garthe, W. A. Montevecchi, and S. J. M. Blaber. 2000. The impacts of fishing on marine birds. Journal of Marine Science 57:531–547.

Vest, J. L., and M. R. Conover. 2011. Food habits of wintering waterfowl on the Great Salt Lake, Utah. Waterbirds 34:40–50.

Winkler, D. W., and S. D. Cooper. 1986. Ecology of migrant black-necked grebes *Podiceps nigricollis* at Mono Lake, California. Ibis 128:483–491.

Associate Editor: Graham Hall.