Behavioral and environmental factors affecting nest-site selection and nest survival in a colonial nesting waterbird

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Authorization to Submit Thesis

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Abstract

Western grebe (*Aechmophorus occidentalis*) populations in North America declined by 90% between 1970 and 2017. Western Grebes nest in breeding colonies and traditional nest monitoring methods cause substantial disturbance to the breeding colony. We explored a non-invasive technique to estimate nest survival and to identify the factors that influence nest survival. We used a small unmanned aerial system (drone) to map and monitor the largest grebe colony in Idaho at Cascade Reservoir. We conducted six flights between 20 June – 11 July 2018 and used the photographs from each flight to create an orthomosaic image that we then digitized and georeferenced. We used the orthomosaic images to assess fine-scale habitat selection for 940 nests as well as recreate nest histories and estimated nest fate for 709 grebe nests. We created a resource selection function using use/non-use data to assess nesting habitat preference. Similarly, we used program MARK to model nest survival. We found that Western Grebes preferred to nest in water between 40-80cm and probability of use increased as distance to open water increased. Our nest survival analysis indicated that when extrapolated to a 30-day nesting cycle, our model estimated that nest success was 51.8%. Probability of nest survival was positively correlated with water depth at the nest and the density of conspecific nests and negatively correlated with distance between the nest to the colony center and distance to deep water habitat (i.e., foraging habitat). The results of this study can be used to inform conservation efforts by identifying the habitat characteristics used for nest-site selection (and hence breeding colony selection) in Western Grebes as well as identifying habitat features related to nest productivity.

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Dedication

To Scott Newbold who taught a jarhead how to love birds.

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Chapter 1: Introduction

An estimated 20% of North American breeding bird species are dependent on freshwater (Sauer et al. 1997). This includes wading birds, waterfowl, waterbirds, and other avian species that are closely associated with wetlands (Leveque et al. 2005). However, wetlands are a quickly diminishing resource with a majority of the United States having lost more than half of their wetlands since the time of European settlement (Dahl 1990). Those wetlands that remain have been increasingly impacted by human development, both agricultural and industrial (Tori et al. 2002).

Species of the family Podicipedidae are one such group of birds that are reliant upon freshwater environments. Commonly known as grebes, they are widely distributed diving birds that inhabit freshwater ponds, lakes, and reservoirs (Gill 1995). While all grebes nest in fresh bodies of water, different species select for different habitat characteristics. Horned Grebes (*Podiceps auritus*) prefer small ponds with open water while Pied-billed Grebes (*Podilymbus podiceps*) choose sites associated with heavy emergent vegetation (Faaborg 1976). Conversely, Silver (*Podiceps occipitales*) and Rolland's Grebes (*Rollandia Rolland*) choose sites that have low mean emergent vegetation density but are close to deep open water (Burger 1974). Low density of emergent vegetation reportedly allows Silver and Rolland's Grebes easier underwater ingress and egress from their nests (Burger 1976) whereas Pied-billed Grebes rely on dense vegetation to provide shelter from high winds which can dislodge and destroy nests (Chabreck 1963).

Like other species of Podicipedidae, Western Grebes (*Aechmophorus occidentalis*) are likely to prefer certain habitat characteristics and these characteristics are likely to affect their nest survival. However, unlike the other grebe species, the Western Grebe has experienced a 90% decline in abundance across their range (Sauer et al. 2017). This decline is reflected in how the Western Grebe is listed in multiple western states and provinces. In Idaho, they are considered a Tier 2 Species of Greatest Conservation Need (Idaho Dept. of Fish and Game 2017) and in Washington they are a candidate species for listing as a sensitive or threatened species (Washington Dept. of Fish and Wildlife 2015). Similarly, they have been assigned to the provincial Red List of species being considered for legal designation as Endangered or Threatened in British Columbia and are listed as a Species of Special Concern in Alberta (Alberta Environ. And Sustainable Resource Development and Alberta Conservation Assoc. 2013). Despite being a large, conspicuous waterbird, the reasons for this decline are currently unknown. Many aspects of their life history and general ecology remain under-studied. Due to their aquatic environment and their aversion to human activities near their nesting colonies, the Western Grebe is particularly challenging to study. Disturbances caused by entering the colony area can lead to the entire colony flushing from their nests simultaneously, leaving them vulnerable to mass nest predation events.

Our goal was to investigate how environmental characteristics influence nest-site selection at the scale of the breeding pair as well as to quantify the effects of environmental and behavioral factors on probability of nest survival. In Chapter 2, we collected fine-scale use/non-use data and created a resource selection function to evaluate habitat preference. In Chapter 3, we used both behavioral and environmental factors as covariates to estimate the probability of nest survival and the factors that affect it. Both chapters employed a novel approach to non-invasively map and monitor Western Grebe breeding colonies.

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Chapter 2: Water depth affects nest placement within breeding colonies of Western Grebes (*Aechmophorus occidentalis*)

Abstract

Habitat selection often operates at multiple hierarchical spatial scales. Colonial nesting species face a unique challenge when selecting a nest site because individuals' choices are influenced by the colony site. The colony site can be a mosaic of high- and low-quality nesting sites and individuals must seek out optimum nesting locations within the constraint of the colony's geographic location. We investigated how water depth and proximity to open water affected fourth-order nest-site selection of Western Grebes (*Aechmophorus occidentalis*), a colonial nesting waterbird that has declined in abundance across its range. We conducted our investigation at a grebe breeding colony located at Cascade Reservoir in Valley County, Idaho. We used drone-collected aerial images of the breeding colony, supplemented by a bathymetric survey to quantify the water depth as well as the distance to open water of 940 grebe nests. We also used the aerial image to generate fine-scale use versus non-use data which we then used to construct resource selection function models. Our top model had an accuracy of 62.9% when predicting between used and non-used areas within the colony footprint. Western grebes preferred to nest in water between 40-80cm and probability of use increased as distance to open water increased. Understanding how individuals make use of available habitat within the colony footprint can help inform conservation efforts, particularly for species that nest in wetland habitats whose water levels are managed for human use.

Key words: *Aechmophorus occidentalis*, drone, habitat selection, resource selection function, Western Grebe.

Introduction

Habitat selection is central to the study of animal ecology (Johnson 1980). Habitat selection differentiates the environmental components that an animal uses from those that they prefer not to use. Habitat selection decisions are thought to occur at four spatial scales (Johnson 1980): selection of physical or geographical ranges (first-order selection), selection that determines the home range of an individual (second-order selection), selection of habitat components within the home range (third-order selection), and selection of space or food items available within a given site (fourth-order selection). This selection hierarchy has proven useful for solitary species, but colonial species may not fit so easily into this hierarchical structure. For example, some birds nest in breeding colonies where many pairs nest in close proximity (Wittenberger and Hunt 1985). Both the colony and the individuals that comprise it may select a geographic range (first-order habitat selection) much the same way that non-colonial animals do, but second-, third- and fourth-order selection may be constrained by tradeoffs associated with colonial behavior. For example, individuals seek out the optimum nesting locations based on what is available within the spatial extent of the colony site and, hence, some individuals may be forced to nest in suboptimal habitat conditions if habitat quality varies throughout the colony. The proximity to conspecifics may provide fitness benefits. Only 5% of western grebes at a site in northern Utah nested singly, and 43.8% of those non-colonial nests failed due to avian predation as opposed to 21.1% for colonial nests (Lindvall and Low 1982).

The Western Grebe (*Aechmophorus occidentalis*) is a migratory waterbird in western North America that nests colonially (LaPorte et al. 2013). The constraints of the colony likely affect their nest-site selection; nest placement of individual grebes is likely constrained by both habitat features and non-habitat social aspects. Water depth and distance to open water are potentially important habitat features that influence nest-site selection because once grebes arrive at their breeding grounds they will not fly again until their winter migration (Piersma 1988), making them entirely reliant upon access to open water for forage, courtship rituals, and nesting. Moreover, their legs are placed at the posterior of their body mass (LaPorte 2013) which makes them excellent swimmers and divers (Lawrence 1950), but awkward on land (LaPorte 2013). The ability to dive off the nest platform is particularly important for escaping potential predators (Lindvall and Low 1982). Hence, grebe nests must be in areas where water depth at the nest allows them to swim up to and climb into nests as well as dive off the nest platform. However, as a colonial nesting species, breeding pairs are not free to select nesting sites that can fulfill these needs. Not only are they constrained to the sites available within or near the colony area, they must also compete with conspecifics for a potentially limited number of optimal nest sites (if quality varies within the colony area). Ultimately, some breeding pairs will be forced into suboptimal nest sites. The heavy reliance upon the water conditions for all their foraging and reproductive needs may mean that the negative effects of fluctuations in water quality, level, and usage will not be evenly distributed throughout the colony.

Prior studies of habitat selection in Western Grebes have quantified habitat characteristics in relation to nest survival, however they have been largely descriptive and no prior studies have used that data to inform hypotheses related to nest-site selection (Nuechterlein 1975, Lindvall and Low 1985). While these studies are helpful, they do not provide a way to predict suitability of different areas. The United States Fish and Wildlife Service developed a Habitat Suitability Index (HSI) for the Western Grebe as a management tool for assessing how well a given area fits the habitat needs of grebes (Short 1984). This HSI model attempted to predict whether or not a particular area was suitable habitat for nesting Western Grebes based on the size of the wetland, fish populations, percent area of the wetland that is covered in emergent vegetation, motorboat activity, quantity of edge between emergent vegetation and open water, water level fluctuations, and wave height within emergent vegetation (Short 1984). This HSI model attempted to assign a value to a given wetland that could inform managers about whether or not the area was suitable as Western Grebe nesting habitat (Short 1984). While this HSI model quantified habitat characteristics, the scale at which they were measured could not offer insight past third-order selection; it could tell us if a particular wetland was suitable for Western Grebes, but not how individual grebes might use that wetland (e.g., where within the wetland the grebes are more likely to nest). More recent studies have used ordered logistic regression to relate Western Grebe abundance to habitat characteristics (Erickson et al. 2017). This type of analysis allowed for greater predictive power than the HSI model, but it examined Western Grebe habitat use largely at the colony level, examining third-order selection. While this study was informative in documenting trends in Western Grebe abundance in relation to a suite of habitat characteristics, it did not have the spatial resolution to explain individual nest-site selection within colonies or to document how nest placement decisions affected fecundity.

Western Grebes have experienced a 90% decline in abundance across their range over the past 40 years (Sauer et al. 2017). The reason(s) for this decline are unknown. Brood production is often alarmingly low at some breeding colonies, suggesting that poor nest survival or chick survival may be at least partially responsible for population declines. Colonial-breeding waterbirds may be particularly sensitive to changes in nest survival because factors that reduce nest survival at one nest are likely to reduce nest survival for the entire breeding colony. Understanding what habitat characteristics individual grebes are selecting can inform conservation and restoration efforts. Similarly, by examining fourth-order habitat selection, managers can ensure that the areas they are protecting or rehabilitating are meeting the needs of all individuals in the population.

In this study, we examined fourth-order habitat selection in Western Grebes to quantify habitat characteristics that affect nest placement within a breeding colony. Contrary to previous studies, we focus on quantifying habitat characteristics at individual nests which provides greater spatial and temporal resolution compared to past studies that examined habitat selection at the scale of the breeding colony. We developed a resource selection function (RSF) for the Western Grebe to assign probability of use based on habitat characteristics. A resource selection function model is effectively a type of HSI model with modern statistical rigor (Boyce et al. 2002). Unlike HSI models, which rely mostly on expert opinion, Resource Selection Functions are estimated directly from data (Boyce et al. 2002). The reliance on empirical data and statistical analyses make Resource Selection Functions a useful tool with a wide array of applications for natural resource management such as providing habitat-based models describing the influence of changing land-use activity on rare species (Boyce et al. 2002). Our use of high spatial resolution use/non-use data allowed us to develop a resource selection function that could elucidate fourth-order habitat selection. Additionally, our study site experiences substantial decreases in water elevation throughout the year which can potentially affect the availability and use of optimal habitat conditions for Western Grebes. An examination of fourth-order selection could demonstrate the effects of such water management practices on nest-site selection. Our objective was to conduct a fine-scale exploration of the influence of water level management on nest placement in Western Grebes.

Methods and Materials

Study site

We conducted our study from 1 June - 15 July 2018 at Cascade Reservoir in Valley County Idaho (N44°36.23' W116°4.43'). Cascade Reservoir is 122km² and lies along the North Fork of the Payette River. Construction of Cascade Reservoir was completed in 1948 and reached full capacity in 1957. This reservoir is a popular recreational destination for boaters and anglers. Cascade Reservoir is home to a breeding colony of Western Grebes with approximately 2500 - 3000 adults based on pre-nesting adult surveys conducted by the Idaho Department of Fish and Game (unpublished Western Grebe Survey, 19 June, 2018). Western Grebes have been nesting at Cascade Reservoir since at least 1983, and possibly earlier (Trost 1985). The water level of Cascade Reservoir is managed for irrigation and, hence, releases from the reservoir create periodic water drawdowns during the summer when grebes are nesting. Water elevation of the reservoir decreases between 1 June and 15 July each year and the extent of the draw down varies annually (avg = 41.5cm, range = -210.67 - 163.37 cm between 2005-2018; 2011 was an anomalous year in which the water elevation began low and then increased dramatically through the nesting period). During the 2018 breeding period, the water elevation decreased by 94.5cm from 1 June to 15 July. The vegetation at the grebe colony is predominantly reed canary grass (*Phalaris arundinacea)*.

Bathymetric survey

We used an aerial image of the 0.028 km^2 colony site from 22 July 2017 to establish 11 parallel 200-meter East-West transects with sampling points every 10m, over what we estimated would be the 2018 colony area. We exported the coordinates for each sampling point from ArcGIS and then uploaded them to a handheld GPS unit (Garmin GPSmap 64, error of ~5m) using Garmin BaseCamp. On 14 June 2018, we walked along each transect and navigated to each sampling point by using a handheld GPS unit and we took a water depth measurement at every sampling point (total of 142 bathymetry points; we were unable to complete all of the points/transects due to their proximity to actively nesting grebes). At each of the 142 points, we measured water depth to the nearest centimeter by submerging a meter stick until the bottom of the stick touched the sediment (when the meter stick met the first point of resistance; we did not push the meter stick into the sediment). The water elevation of Cascade Reservoir during our bathymetric survey was 1471.4 meters (4827.3 feet). We did not conduct subsequent bathymetric surveys of the colony to minimize researcher disturbance on the nesting grebes.

<u>Aerial survey</u>

We used a drone to conduct aerial surveys of the breeding colony on 6 days during the 2018 nesting season (from 20 June to 10 July 2018). We used the aerial survey on 24 June to document the locations of all nests because this flight produced the clearest aerial image that was the closest to the date of our bathymetric survey. The change in water elevation between the bathymetric survey and the 24 June survey was 18.9cm (0.62ft). We operated a 3DR Solo quadcopter equipped with a Ricoh GR II high resolution camera. We used the Tower Drone Control application (3D Robotics 2015) for all of our mission planning. We launched the drone from an unused road (old highway 55) that is approximately 100 meters east of the nearest nesting grebes. The drone crew consisted of one pilot and two visual observers. One visual observer maintained line of sight to the drone during the flight. The second visual observer used binoculars to observe the grebe colony and record any instance of grebes flushing from the colony due to the drone activity. When grebes flush from the colony, they often do so loudly as a large group and they scurry to open, deeper water. Given this behavior, we were confident that we would be able to identify if our drone flights caused females to leave their nests unattended. We conducted some initial testing to determine the optimal altitude to fly the drone to obtain good photo resolution with the camera and no grebes flushed off their nests even when we flew the drone as low as 9.1m above the colony. However, we conducted each flight at an altitude of 45.7m above ground level and at a speed of 14.5 kilometers per hour to obtain optimal camera image quality. We set an intervalometer to take one picture every 2 seconds. These settings ensured 60% overlap and 60% side-lap in each picture which allowed for a more accurate orthomosaic image to be generated. We used principles of photogrammetry to determine our flight speed and altitude based on the pixel size and focal length of our camera (National UAS Project Office 2018). To fly all 11 transects, this flight plan lasted approximately 20 minutes and collected approximately 525 digital images on each of the 6 flights. We used the Agisoft Photoscan software (Agisoft LLC 2018) to stitch the 525 images together into a composite orthomosaic image of the colony and we used the program GlobalMapper 19.1.0 (Blue Marble Geographics 2018) to georeference each orthomosaic image. We set the coordinate system for each image to WGS 1984 UTM Zone 11N and used ArcGIS to digitize each orthomosaic. We were able to identify and mark 940 grebe nests in the orthomosaic image as well as overlay our bathymetry points. We then used the Minimum Convex Polygon tool in ArcGIS to create a 3-hectare polygon around all of the 940 digitized nests and used this polygon as the footprint of the grebe nesting colony.

RSF modeling

We used ArcGIS to generate 940 random non-nest points that were confined to the MCP created above and that were ≥0.5m from any nests or other random non-nest points. We used 0.5m because the minimum nearest neighbor distance for the 940 nests was 0.58m. Western Grebes nests can range in diameter from 53.8cm (Ratti 1977) to 1.2m (Munro 1941). We wanted to ensure that our random non-nest points were locations in which another nest could have feasibly been placed (but was not) and did not overlap with existing nest structures. The nearest neighbor distances between nests at our study site were closer than the 2.0-3.9m distances reported in other studies (La Porte et al. 2013). We created 14 candidate linear models designed to predict the water depth at each nest and each random non-nest point. We used ArcGIS to measure the distance from each of the 142 bathymetric points to three different geographic features at the colony: an abandoned 2-lane paved road (Old Highway 55; ROAD hereafter) that ran north-south to the east of the Colony, a ditch (DITCH) that ran north-south to the west of (and parallel to) the abandoned road, and an irrigation canal (CANAL) that ran east-west (perpendicular to the abandoned road and the ditch). We then selected the top model by comparing AIC scores (Burnham and Anderson 2002). We used the top model to calculate estimated water depth for each nest and each random non-nest point based on their distances from ROAD, DITCH, and CANAL (Fig. 1).

We then measured the distance from each nest and each random non-nest point to deep, open water. Deep, open water was defined as a linear feature that was 50 meters from vegetation on the water side of the colony and where water depth was ≥100 centimeters. The measurements for these two environmental variables were taken as close to colony initiation as possible. This ensured that the values we used were as close to the conditions present during nest-site selection as possible. We created and compared 17 candidate logistic regression models that were designed to differentiate nests from random non-nest points. The suite of potential explanatory variables in the logistic regression models included predicted water depth (based on the previous model described above); distance to deep, open water; 2-way interaction between water depth and distance to deep open water; and quadratic forms of these variables. We investigated quadratic effects of these variables to examine non-linear relationships. We used the R package pROC to calculate Receiver Operating Characteristic (ROC) curves and Area under the curve (AUC). We selected our top model based on the AUC. We used the R package "caret" to create a confusion matrix and calculate the accuracy of our top model. We used a cut point of 0.50 for our ROC analysis. We created partial-effects plots from the top model to assess the relationship between predictor variables and the response variable (probability of nest-site selection).

Results

We collected 142 bathymetric points throughout the grebe colony. The mean water depth at the bathymetric points was 57.9cm (SD = 14.0cm, min = 24.0cm, max = 100.0cm) on 14 June. Our top model for predicting water depth had an R^2 of 0.77 (Table 1). We identified 940 Western Grebes nests from our aerial survey orthomosaic on 24 June. The MCP that encapsulated all nest points was 2.7 hectares. The mean distance of a nest to open water was 185.4m (SD = 34.38m, min = 68.8m, max = 254.2m), and the mean distance of random non-nest points to open water was 171.85m (SD = 37.8m, min = 74.0m, max = 253.1m). The mean estimated water depth differed between nests and random points (Table 2). We calculated AUC and accuracy for our three top-performing Resource Selection Function models (Table 3). The top model (Table 4) included water depth, distance to open water, and the two-way interaction, with probability of use highest between depths of 40cm and 80cm (Fig. 2). The top model had a specificity of 0.70 and a sensitivity of 0.56. We also created a confusion matrix to examine the performance of our top model (Table 5). The probability of a grebe nesting in a specific location decreases as the water depth at the site decreases and increases as distance to open water increases (Fig. 2).

Discussion

Our Resource Selection Function suggests that grebes prefer to build nests in deeper water that is far from the open water-vegetation ecotone. Sites that are close to open water and are located in deeper water have a lower probability of use. That is to say that Western Grebes prefer to nest in areas that contain deep water, but are also far from open water. Water depth at Western Grebe nests at Cascade Reservoir around the time of nest construction were deeper than those reported in other studies (Lindvall and Low 1982, LaPorte et al. 2013). Western Grebes as Cascade Reservoir primarily nested in areas that had water depths between 40cm and 80cm at or around the time of nest construction. Previous studies have reported that grebes generally nest at depths >20cm, but have not reported a maximum value (Lindvall and Low 1982, LaPorte et al 2014). The quadratic relationships and two-way interaction between water depth and distance to open water indicate that there is an optimal median zone in which grebes prefer to nest. This area is neither too deep nor too shallow and neither too far from open water nor too close. Changes in water level can potentially affect this optimal zone in several ways. When water level is higher, there may appear to be more viable nesting habitat than what is actually usable. Decreases in water level as the breeding season progresses may result in less available habitat, leaving late nesters with fewer optimal nesting sites. Similarly, the water level conditions at the time of nest building and initiation are not indicative of what the conditions will be like during hatching. Areas that appear to be viable nesting sites at nest building may be left dry and cut off from open water as water levels decrease. The corollary to this is that when water levels are high early in the season (pre-draw down for agricultural purposes) areas that may become optimal nesting sites later in the season may be too exposed to wave action or cannot support adequate amounts of emergent vegetation due to the deep water.

Water conditions at Cascade Reservoir can change drastically throughout the nesting period. Between the years 2005 and 2018 the average decrease in water level was 41.5cm (usbr.gov/hydromet). During the 2018 nesting season it fell 94.5cm, twice the 14-year average given above (usbr.gov/hydromet). Reductions in water level during the nesting season could have serious consequences for nesting grebes (Nero 1960, Feerer and Garrett 1977), but the extent to which changes in water levels adversely affect nesting grebes is likely specific to each water body and requires explicit quantitative documentation (i.e., via bathymetry) at each colony. The grebes that nest at Cascade Reservoir nested in deeper portions of the area that defined their breeding colony. However, grebes require emergent vegetation at their nests (they will not nest in deep water devoid of vegetation) and most emergent marsh vegetation is more common in shallow water. Deeper water at the nest may mitigate some of the negative effects of falling water levels and allow those grebes to have sufficient depths near their nests when their eggs hatch and they must return to open water.

The Western Grebes that nest on Cascade Reservoir were also more likely to establish nest sites in areas that were far from open water. Points with the highest probability of use (those with ≥60% probability of use) had a mean distance to open water of 203.57m. A preference for areas further from open water corroborates previous studies that have cited exposure to wind-driven waves as a common cause of nest failure in Western Grebes (Allen 2008, LaPorte et al. 2014). Nests that are farther from open water are more likely to be surrounded by denser vegetation. Increased amounts of vegetation between the nest and the open water ecotone helps attenuate waves and increases Western Grebe nest survival (Allen 2008).

Our top model had an accuracy of 62.9%. One issue that undoubtedly limited the predictive ability our model was the spatial scale at which we were attempting to elucidate nest-site selection (i.e., within the grebe colony). That is, we generated random points within the MCP of the colony and many of those random non-nest points could be (and likely were) viable nesting locations, but were merely not chosen by a nesting pair of grebes or were too close to an existing nest and intraspecific aggression prevented grebes from nesting too close. Also, we only examined two variables (water depth and distance to open water); incorporating additional variables (e.g., emergent and aquatic vegetation density) would likely further improve predictive ability of a model at this fine spatial resolution. Due to our desire to avoid disturbing nesting grebes, we also created a predictive model to estimate water depth at both known nests and random non-nest points using the bathymetric measurements we were able to collect. If we were able to collect actual water depth measurements at nests and non-nest points during the time nests were actually selected, water depth likely would have explained even more variation in nest placement.

Cascade Reservoir, like many of the bodies of water that Western Grebes inhabit, undergoes massive water drawdowns for agricultural use. Our results suggest that these drawdowns alter habitat suitability for grebes and these changes occur at a critical time in the grebes' annual cycle. Once grebes select a nest site and begin building a nest bowl and laying eggs, they cannot easily move to a new location in response to unforeseen drawdowns in water level. Hence, water drawdowns can potentially have dire consequences for the reproductive success of this species. Understanding nest-site preference of the Western Grebe can inform management decisions. The factors that were present when a grebe selects a location and builds a nest may not exist by the end of the nesting period (after substantial drawdowns). Identifying the range of acceptable water depths for nesting grebes can help inform water use policy at the reservoirs at which Western Grebes nest.

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Table 2.1 The mean, minimum, maximum, and standard deviation for habitat measurements at Western grebe nests and random non-nest locations within the grebe colony at Cascade Reservoir, Idaho.

		Mean	Min	Max	Standard Deviation
Nest (n = 940)					
	Distance to open water (m)	185.39	68.75	254.22	34.38
	Estimate water depth (cm)	67.88	35.57	94.60	11.42
Random points (n = 940)					
	Distance to open water (m)	171.85	73.95	253.06	37.81
	Estimate water depth (cm)	71.90	36.53	91.26	12.49

Table 2.2 Top-ranked models for predicting water depth (models within a ΔAIC of ≤4). We used the top model to calculate water depth for the resource selection models.

Model	AIC	Delta AIC
ROAD + CANAL + DITCH + $DITCH^2$	953.2468	0
ROAD + $ROAD^2$ + CANAL + DITCH	953.3397	0.0929
ROAD + CANAL + $CANAL^2$ + DITCH + $DITCH^2$	955.0443	1.7975
ROAD + $ROAD^2$ + CANAL + $CANAL^2$ + DITCH	955.1702	1.9234
ROAD + $ROAD^2$ + CANAL + DITCH + $DITCH^2$	955.23	1.9832
ROAD + $ROAD^2$ + CANAL + $CANAL^2$ + DITCH + $DITCH^2$	956.9942	3.7474

Table 2.3 The top-performing resource selection functions ranked by predictive accuracy. Although our top model did not have the lowest AIC value, it was most accurate when predicting whether a given point was a nest or a random point.

Model	AIC	Delta AIC	AUC	Accuracy
Open Water + (Open Water)² + DEPTH + DEPTH² + (Open Water * DEPTH) + DEPTH² * (Water Depth)²	2460.425	2.564	0.6709	0.6293
Open Water + DEPTH + DEPTH² + (Open Water * DEPTH) + (Open Water * DEPTH²)	2470.392	12.531	0.6566	0.6282
Open Water + DEPTH + (Open Water * DEPTH)	2466.867	9.006	0.6577	0.6277
Open Water + (Open Water)² + DEPTH + (Open Water * DEPTH) + ((Open Water)² * DEPTH)	2457.861	0	0.6672	0.6271

Table 2.4 Parameter estimates from our top Resource Selection Function model based on AUC.

Parameter	Estimate	Standard Error	95% Confidence Intervals
Intercept	-3.42E+01	7.06E+01	-1.74E+02, 1.03E+02
Open Water	4.60E-01	6.70E-01	-8.54E-01, 1.79
(Open Water)²	-1.00E-03	1.60E-03	-4.48E-03, 1.84E-03
DEPTH	8.70E-01	1.88E+00	2.78, 4.61
(DEPTH)²	-5.00E-03	1.30E-02	-3.04E-02, 1.93E-02
(Open Water) X (DEPTH)	-1.00E-02	1.80E-02	-4.63E-02, 2.51E-02
(Open Water) X (DEPTH)²	5.00E-05	1.20E-04	-1.92E-04, 2.95E-04
(Open Water)² X (DEPTH)	3.00E-05	4.40E-05	-5.98E-05, 1.13E-04
(Open Water)² X (DEPTH)²	-9.00E-08	3.10E-07	-6.97E-07, 5.07E-07

Table 2.5 The confusion matrix for our top performing resource selection model based on accuracy and AUC.

	Predicted: random	Predicted: Nest
Actual: Random	524	281
Actual: Nest	416	659

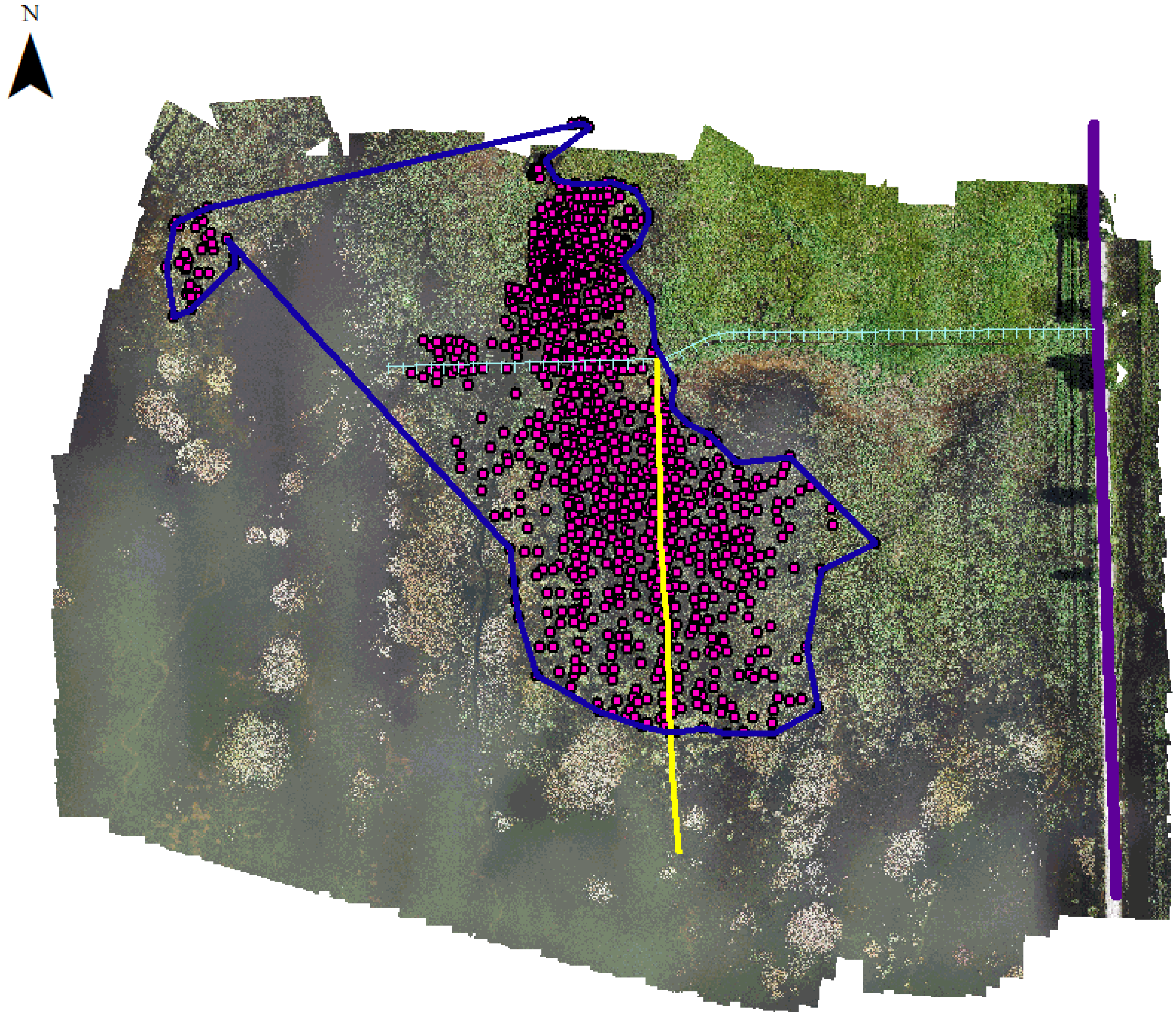

Figure 2.1 A map of the Western Grebe colony area at Cascade Reservoir in Valley County, Idaho. The north-south lines show the location of an old ditch (in yellow) and an abandoned paved road (in purple), and the east-west line shows the location of an old canal (in light green). Grebe nests (in pink) and the boundaries of the colony (in blue) are also depicted. All three features were correlated with water depth in/near the colony.

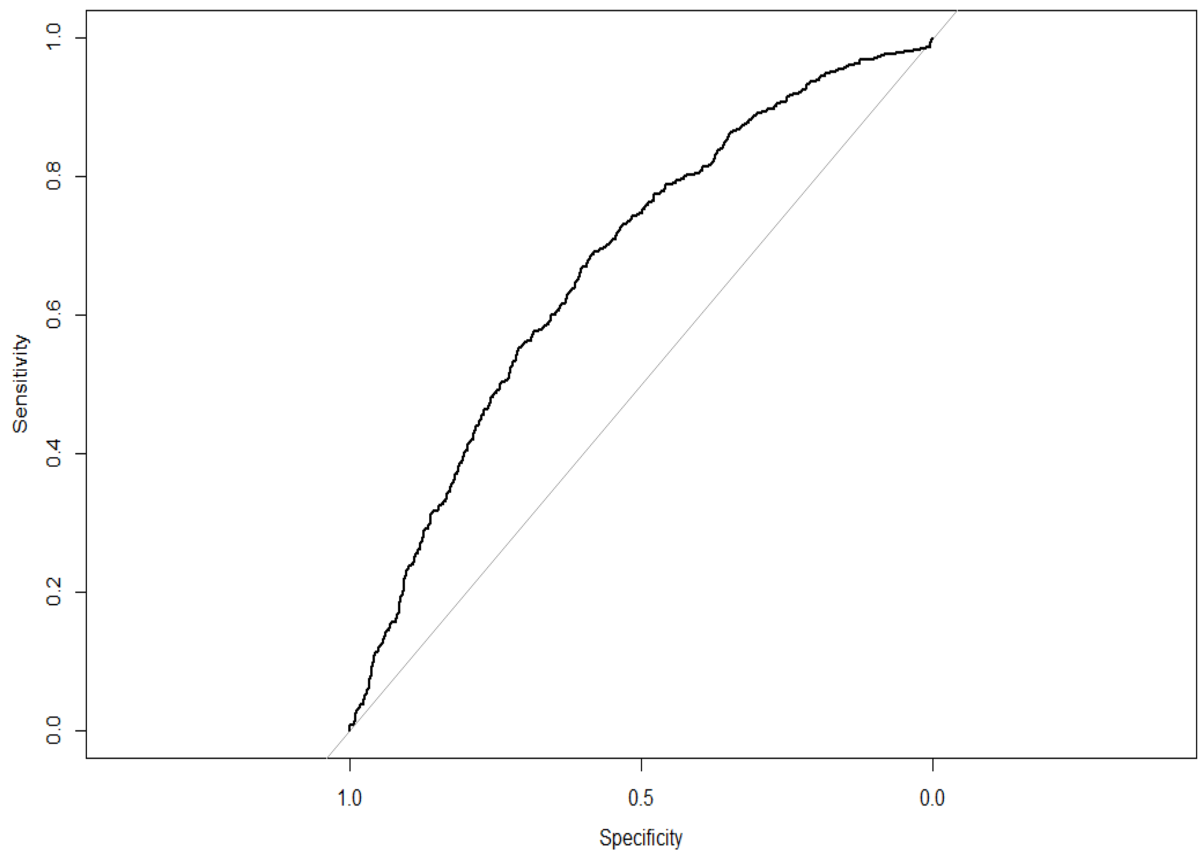

Figure 2.2 Receiver Operating Characteristic (ROC) Curve for the top resource selection model comparing western grebe nest locations and random non-nest locations within the nesting colony. This model had an Area Under the Curve of 0.6709 and an accuracy of 62.9%

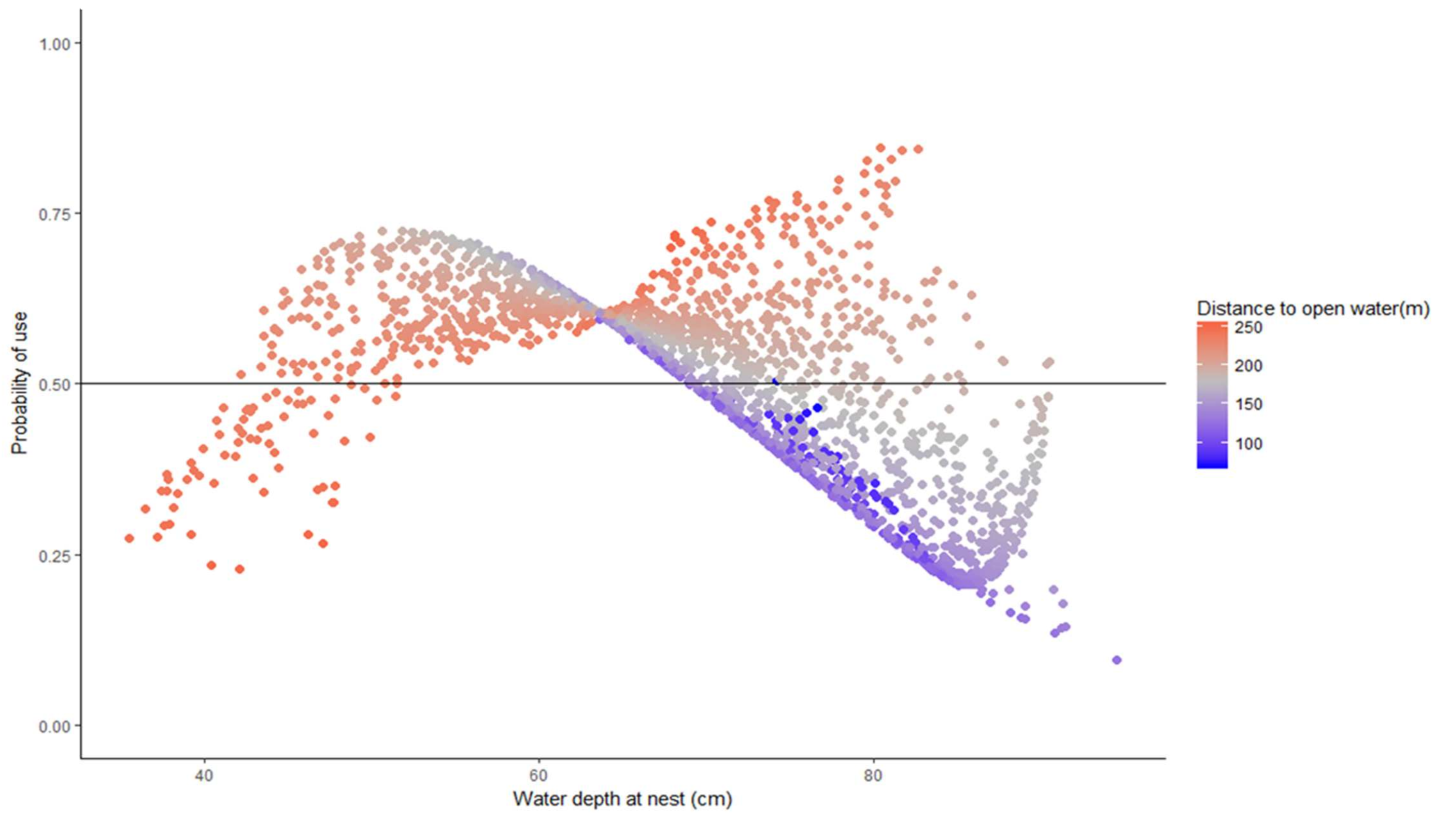

Figure 2.3 Probability of use of a given point in relation to water depth at the point, color-coded by distance to open water. Probability of use was highest for points that were far from open water and at a depth between 40cm and 80cm.

Chapter 3: Factors influencing nest survival of the Western Grebe (*Aechmophorus occidentalis)*

Abstract

Western grebe (*Aechmophorus occidentalis*) populations in North America declined by 90% between 1970 and 2017. Western grebes nest in breeding colonies and traditional nest monitoring methods cause substantial disturbance to the breeding colony. We explored a non-invasive technique to estimate nest survival and to identify the factors that influence nest survival. We used a small unmanned aerial system (drone) to map and monitor the largest grebe colony in Idaho at Cascade Reservoir. We conducted six flights between 20 June – 11 July 2018 and used the photographs from each flight to create an orthomosaic image that we then digitized and georeferenced. The resolution of the images allowed for visualization of the nest, nest contents, and adult grebes. We created nest histories and estimated nest fate for 709 grebe nests. We collected data on the following covariates to assess whether any of them affected nest survival: distance of the nest to the center of the colony; distance of the nest to the edge of the colony; distance of the nest to deep water habitat; water depth at the nest; nearest neighbor distance, and an aggregation index (the mean of the five nearest neighbor distances). We used program MARK to estimate daily nest survival probability and AIC to select among 60 candidate nest survival models. When extrapolated to a 30-day nesting cycle, our model estimated that nest success was 51.8%. Probability of nest survival was positively correlated with water depth at the nest and the aggregation index, and negatively correlated with distance between the nest and the colony center and distance to deep water habitat. The results of this study can be used to inform conservation efforts by identifying areas of western grebe colonies that are most vulnerable and formulating management recommendations to increase nest survival.

Key words: *Aechmophorus occidentalis*, colonial nesting, drone, nest survivorship, Western Grebe.

Introduction

Twenty percent of North American breeding birds are dependent on freshwater (Sauer et al. 1997). However, most states in the U.S. have lost more than half of their wetlands since the time of European settlement (Dahl 1990) and the wetlands that remain have been impacted by agricultural and industrial development (Tori et al. 2002). As a result, many wetland-dependent birds have declined in North America. Western Grebes (*Aechmophorus occidentalis*) have experienced a 90%

decline in abundance across their range (Sauer et al. 2017) and are considered a Tier 2 Species of Greatest Conservation Need in Idaho (Idaho Dept. of Fish and Game 2017). The reasons for this decline are currently unknown but potential causes include pesticides, drainage of lakes for agriculture, entanglement in fishing nets, repeated human disturbance at breeding colonies (e.g., boaters), and food limitation (Storer and Nuechterlein 1992). Heavy metals and other contaminants bioaccumulate in piscivorous birds like the Western Grebe and pesticides were responsible for population declines in California (Herman et al. 1969), but more recent studies in other regions failed to find a relationship between reproductive success and contaminants (Anderson et al. 2008, Ackerman et al. 2015). More studies are needed to examine the effects of contaminants on both reproduction and survival of Western Grebes.

Brood surveys of grebes suggest low recruitment may be the proximate cause of observed population declines in some regions (citations). Low recruitment may reflect high chick mortality or low nest survival. The Western Grebe (*Aechmophorus occidentalis*) is a colonial-nesting waterbird whose distribution spans western North America (LaPorte et al. 2013). They construct nests from aquatic vegetation and form densely packed nesting colonies (LaPorte et al. 2013). Western Grebes are back-brooders; newly-hatched chicks climb onto the back of the adults who then leave the colony and move into open water. This is a process that could potentially be hindered by low water levels, high wave action, or diminished access to open water. Hence, grebes may be particularly vulnerable to fluctuations in water quality, level, and usage. However, few studies have examined the relationship between water depth at the nest and nest survival in grebes. Previous studies of Western Grebe nest survival have examined the effects of wind-driven waves (Allen 2008, LaPorte et al. 2014), avian nest predation (Lindvall and Low 1982), vegetation density (Allen 2008, Erickson et al. 2017), and distance of the colony to either the shore or to open water (Allen 2008, Erickson et al. 2017).

Estimating nest survival and examining the factors that affect nest survival in Western Grebes is challenging because all grebes in a nesting colony typically flush off their nests when humans approach (LaPorte et al. 2013). When adult grebes flush from the colony, they risk kicking eggs into the water and eggs that remain in the nest are exposed to predation, often by gulls and corvids that often co-occur with nesting grebes (Nisbet 2000). Repeat disturbances can lead to grebes completely abandoning the colony (LaPorte 2012). Other researchers have attempted to minimize disturbance by only conducting nest checks once every seven days (Nuechterlein 1975, Allen et al. 2008, LaPorte 2014). This method still causes disturbance and it provides limited temporal resolution of nest survival estimates. Incubation for the Western Grebe lasts 22-24 days (LaPorte et al. 2013). Visiting nests once every seven days limits the investigator's ability to determine nest fate and causes of nest failure.

Documenting the habitat characteristics that affect nest survival can help managers and policy-makers design management and recovery plans for the Western Grebe. Moreover, understanding the behavioral ecology of colonial nesting behavior can inform management actions and facilitate population recovery (Kress 1983, Reed 1999). In other words, documenting the costs and benefits of colonial nesting behavior allow managers to implement appropriate recovery actions for species of management concern that nest colonially.

We tested 3 hypotheses that could potentially explain why Western Grebes have declined in Idaho: 1) hatching failure due to high contaminant levels, 2) high nest predation, and 3) changes in water-level management. To test the first hypothesis, we collected Western Grebe eggs to document contaminant levels. To help test all 3 hypotheses, we used a drone to map and monitor the largest known breeding colony of Western Grebes in Idaho. The drone allowed us to observe grebes and their nests more regularly during the nesting period without the disturbance caused by traditional nest surveys. The drone allowed us to document fate of hundreds of nests within the colony and to link nest fate with water depth and other environmental variables. Our objectives were: 1) to quantify contaminant levels in Western Grebe eggs, 2) to quantify the influence of environmental factors and nest placement behaviors on nest survival of the Western Grebe, and 3) to assess the viability of using a drone to non-invasively monitor a colonial nesting waterbird. We examined whether any of the following four explanatory variables helped explain probability of nest survival: nest initiation date, water depth at the nest, distance of the nest from open water, and the location of the nest within the colony.

Methods and Materials

Study sites

We collected Western Grebe eggs at both Lake Walcott and Cascade Reservoir in July 2017. Lake Walcott and Cascade Reservoir support the 2 largest nesting colonies of Western Grebes in Idaho Lake Lowell at Deer Flat National Wildlife Refuge also supports a large nesting colony and was initially included in our study but we were unable to collect eggs at Lake Lowell. Lake Walcott (N42°37.66' W113°8.97') is located within Minidoka National Wildlife Refuge (NWR) and is a 45-km² impoundment of the Snake River. There is limited recreational use at Lake Walcott and entire sections prohibit motorized boat traffic. Western Grebes have nested at Lake Walcott for over 40 years (Trost 1985). Cascade Reservoir (N44°36.23' W116°4.43') is located in Valley County, Idaho and is a 122-km² impoundment of the North Fork of the Payette River. Construction of Cascade Reservoir was completed in 1948 and it reached full capacity in 1957. Cascade Reservoir is a popular recreational destination for boaters and anglers, and has the largest breeding colony of Western Grebes in Idaho. The average adult population over the past 14 years was 2271 grebes (unpubl. Idaho Dept. of Fish and Game survey data, 2018). Western Grebes have been nesting at Cascade Reservoir since at least 1983 (Trost 1985).

The breeding season began ~1 June and lasted until ~15 July. The water elevation of Cascade Reservoir is measured daily and recorded by the Bureau of Reclamation. All of the water elevation data for this study was taken from the Bureau of Reclamation Hydromet website (www.usbr.gov/pn/hydromet). Cascade Reservoir has routine water drawdowns. The average decrease in water elevation over the past 14 years between 1 June and 15 July has been 41.5cm (www.usbr.gov/pn/hydromet). During the 2018 breeding period, the decrease in water elevation was more than double that 14-year average: it decreased by 94.5cm from 1 June to 15 July 2018. Common Reed (*Phragmites australis*) is the predominant emergent plant within the grebe colony at Cascade Reservoir.

Egg collection and contaminant analysis

We collected Western Grebe eggs on 19 July 2017 from Cascade Reservoir and 11 August from Lake Walcott (Federal Migratory Bird Permit #MB29059C-0, Idaho State Scientific Collection Permit #170320). We walked along a 100-m long, 2-m wide transect through the densest part of the colony and selected a nest at each 10-m interval. We collected 1 egg from each nest and only collected an egg from nests that had ≥3 eggs. At this time, adults grebes had already been observed with young on their backs and nests that we had encountered did not have adults present, nor did we observe flushing behavior. To the best of our knowledge, a majority of the breeding pairs had already hatched their young and vacated the colony. We submitted the eggs to Australian Laboratory Sciences Global, private testing and inspection company headquartered in Brisbane Australia, to document levels for 24 contaminants.

Bathymetric survey

We used an aerial image of the 0.028 km^2 colony site from 2017 to establish 11 parallel 200-meter East-West transects with sampling points every 10m, over what we estimated would be the 2018 colony area. We exported the coordinates for each sampling point from ArcGIS and then uploaded them to a handheld GPS unit (Garmin GPSmap 64, error of ~5m) using Garmin BaseCamp.

On 14 June 2018, we walked along each transect and navigated to each sampling point by using a handheld GPS unit and we took a water depth measurement at every sampling point (total of 142 bathymetry points; we were unable to complete all of the points/transects due to their proximity to nesting grebes). At each of the 142 points, we measured water depth to the nearest centimeter by submerging a meter stick until the bottom of the stick touched the sediment (when the meter stick met the first point of resistance; we did not push the meter stick into the sediment). The water elevation of Cascade Reservoir during our bathymetric survey was 1471.36 meters. We did not conduct subsequent bathymetric surveys of the colony to minimize researcher disturbance on the nesting grebes.

Aerial Drone Survey

We used a drone to conduct six aerial surveys of the breeding colony between 20 June and 11 July of 2019. We operated a 3DR Solo quadcopter equipped with a Ricoh GR II high-resolution digital camera. We used the Tower Drone Control application (3D Robotics 2015) for all of our mission planning. We launched the drone from an unused road (old highway 55) that is approximately 100 meters east of the nearest nesting grebes. The drone crew consisted of one pilot and two visual observers. One visual observer maintained line of sight to the drone during the flight. The second visual observer used binoculars to observe the grebe colony and record any instance of grebes flushing from the colony due to the drone activity. When grebes flush from the colony, they often do so loudly as a large group and they scurry to open, deeper water. Given this behavior, we were confident that we would be able to identify if our drone flights caused females to leave their nests unattended. We conducted some initial testing to determine optimal altitude to fly the drone and grebes did not flush off nests even when we flew the drone at 9.15m above the colony. We did observe that while operating the drone at 9.15m above a focal grebe, that grebe would move out from under the drone but other grebes in the vicinity, but not directly under the drone, did not appear to be disturbed. We did not attempt to fly lower than 9.15m. We conducted each flight at an altitude of 45.72m above ground level and at a speed of 14.5 kilometers per hour because those metrics provided optimal image quality. We set an intervalometer to take one picture every 2 seconds. These settings ensured 60% overlap and 60% side-lap in each picture which allowed for a more accurate orthomosaic image to be generated. We used principles of photogrammetry to determine our flight speed and altitude based on the pixel size and focal length of our camera (National UAS Project Office 2018). Each flight lasted approximately 20 minutes and collected approximately 525 digital images. We used the Agisoft Photoscan software (Agisoft LLC 2018) to stitch images together into a composite orthomosaic image of the colony and we used the program GlobalMapper 19.1.0 (Blue Marble Geographics 2018) to georeference the orthomosaic image. We set the coordinate system for each image to WGS 1984 UTM Zone 11N and used ArcGIS to digitize the orthomosaic. We identified and marked 1059 individual nests in the orthomosaic image and we overlaid our bathymetry points onto the images. We then used the Minimum Convex Polygon (MCP) tool in ArcGIS to create a polygon around all 1059 digitized nests to delineate the perimeter of the nesting colony.

Nest History Reconstruction

We produced six digitized and georeferenced images of the grebe colony, one for each of the six dates that we obtained quality images from drone flights. We used ArcGIS to mark and label each nest in each of the 6 images. For each nest on each survey (i.e., each of the 6 orthomosaic images) we assessed whether the nest structure was present, if an adult grebe was present at the nest, and the contents of the nest if not obstructed by an adult. This produced a data set that included the estimated date a nest was formed (when possible), adult attendance at the nest during each of the 6 visits, and changes in nest contents across the 6 visits. Our aerial images did not capture the exact beginning or end of the grebe breeding period and there was a two-week gap in the middle of the breeding period due to mechanical problems with the drone. These gaps required us to make several assumptions so that we could estimate nest fate for each nest. Our first flight was on 20 June and some clutches were already complete so we know that nests could possibly have been built as early as 11 June and, hence, we assumed that all nests present in the 20 June image were at least nine days old on 20 June because we had no evidence to assume otherwise and this would provide a more conservative estimation of nest failure. Nests were assumed to survive up to the midpoint between the last survey on which it was observed and the first survey on which it was absent. In other words, a nest with an adult present on 24 June, but with an adult absent on 28 June and subsequent surveys was assumed to have survived up to 26 June which is the midpoint between the 24 June and 28 June observation days. We estimated nest initiation date to be the midpoint between the date of the survey that the nest first appeared and the date of the survey immediately prior to that survey. For example, a nest that was present on 28 June but not on 24 June was assumed to have been initiated on 26 June. We used information from the literature to make assumptions regarding the length of the nest construction period (1-3 days; LaPorte et al. 2013), the egg-laying interval (1-2 days; LaPorte et al. 2013), the average clutch size (2.41-4.06 eggs; Ratti 1977, Lindvall and Low 1982), and the incubation period (22-24 days; Lindvall and Low 1982, LaPorte 2013). Hence, we estimated that a nest would require ≥29.5 days to progress from construction to hatching, the sum of the average lengths of the periods described above. This assumes a 2-day nest construction period, a 4.5-day laying period, and a 23-day incubation period. We used these values to provide the most conservative estimate of nest failure. Nests that exhibited a reduction in the number of eggs present, but that had an estimated nest age of <29.5 days were assumed to have failed. If no female was present for three consecutive visits, then the nest was assumed to have failed. This was a valid assumption because we had no records of females absent for 3 consecutive visits at a nest and then present on a subsequent visit. If we could not confidently assume that a nest had failed, we considered its fate to be unknown.

Water depth modeling and nest survival modeling

We used the known depths from our 142 bathymetry points to create 25 candidate linear regression models to predict the water depth at each nest at the time of the bathymetric survey. We used ArcGIS to measure the distance from each of the 142 bathymetric points to three different geographic features present at the colony (Figure 1): Old Highway 55 (ROAD) which lies east of the colony, an irrigation ditch (DITCH) that is to the west of and parallel to Old Highway 55, and a second irrigation ditch (CANAL) that is perpendicular to both Old Highway 55 and the ditch. We then selected the top model by comparing AIC scores (Burnham and Anderson 2002). We used the actual measured water depth for nests that were within 5m of a bathymetric point (n=218). We then used the top model to estimate water depth at each of the remaining 841 grebe nests in the colony based on that nest's distance from ROAD, DITCH, and CANAL.

We used program Mark (White and Burnham 1999) to construct and assess nest survival models based on our reconstructed nest histories with the RMark package (Laake and Rexstad 2014) in R 3.4.2 (R Development Core Team 2014). We used ArcGIS to calculate the following parameters for each nest: nest initiation date, distance of the nest to the geometric center of the colony, distance of the nest to the edge of the colony, the nearest neighbor distance (to the nearest nest), the mean distance to the nearest five nests, the distance of the nest to open water, and the estimated water depth at the nest. The geometric center of the colony is the point that has x and y coordinates that are the mean of all the x and y coordinates of all nests in the colony. The distance of a nest to the edge of the colony was the straight-line distance between a nest and the MCP. We then measured the distance from each nest to open water. We defined 'open water' as a linear feature that was 50 meters from the water-vegetation ecotone on the water side of the colony and had a depth of at least 100 centimeters. This definition of open water was based on the water elevation for 24 June which was 1471.2m (4826.71ft). We predicted water depth at each nest as described above. We also included nest initiation date as described above as a covariate. Within program Mark, we constructed 45 candidate nest survival models (Table 4). Some candidate models included two-way interactions between distance to open water and predicted water depth and between distance to colony center and the nest aggregation index. We also included models with quadratic effects for both distance to open water and predicted water depth. We used Akaike's information criterion (AIC) (Burnham and Anderson 2002) to compare support for each model. We used the parameter estimates from the top model to calculate modeled daily survival probabilities for each nest.

Results

We collected 10 eggs from Cascade Reservoir and 6 eggs from Lake Walcott in 2017. Western Grebes did not form a colony at Lake Walcott in 2017; we were unable to locate more than 2 nests and only 11 chicks were counted. This small number of nests hindered our ability to collect 10 eggs from Lake Walcott. ALS Global tested the eggs (*n*=16) for 24 potential contaminants (Table 1) and all contaminants were within normal levels.

We collected 142 bathymetry points throughout the grebe colony at Cascade Reservoir in 2018 and documented substantial variation in water depth: mean=57.9cm (SD = 14.1cm, min = 24.0cm, max = 100.0cm) (Figure 2). We used the known depths and distances of our bathymetric points to create 25 water depth prediction models and evaluated them using AIC (Table 2). Our top model for predicting water depth had an R^2 of 0.77. We used this model to predict water depth for 491 of the nests that were no within 5m of one of the bathymetric points.

We conducted six drone flights over the grebe colony at Cascade Reservoir during the grebe's breeding season (1 June – 15 July dates). There was an average of 4.2 days between each flight (1 – 11 days). No grebes flushed from the colony during any of our drone flights. We encountered some technical difficulties with the drone which impaired our ability to fly as often as we had planned. The operational range of the stock antennae for the drone handheld controller was not large enough to cover the entire area of the grebe colony so we had to purchase an after-market antennae (Alfa 2.4HGz Wi-Fi antennae) that could expand our range. From the orthomosaic composite photos, we were able to identify 1059 Western Grebe nests. We used a subset of 709 of the 1059 nests to model nest survival. The 709 nests were those that we could accurately follow throughout the six aerial images and estimate their fate. There were some photogrammatic discrepancies between images that resulted in some areas of the image either missing or being warped. The 709 nests had a mean distance to center of 48.87m (SD = 23.24m, min = 0.30m, max = 114.34m), a mean distance to edge of 23.36m (SD = 12.77m, min = 0.00m, max = 53.76m), a mean nearest neighbor distance of 2.17m (SD = 1.16m, min = 0.72m, max = 17.27m), a mean nest aggregation index of 3.413 (SD = 1.68, min = 1.35, max = 25.27), a mean distance to open water of 214.80m (SD = 18.48m, min = 143.20m, max = 255.50m), and a mean predicted water depth of 62.39cm (SD = 11.17cm, min = 36.89cm, max = 85.09cm) (Table 3).

All four of the top models included initiation date, distance to colony center, the nest aggregation index, distance to open water, and predicted water depth at the nest (Table 4). We calculated parameter estimates for all the variables that were represented in our top model (Table 5). We examined the partial-effect plots of each of the four variables in the top models: survival probability was positively correlated with the nest aggregation index and water depth at the nest, and was negatively correlated with initiation date, distance to colony center, and distance to open water (Figure 3). Based on our top model, daily nest survival 97.8% (95% confidence intervals = 97.5%, 98.0%) (Figure 4). We extrapolated the daily nest survival to a 29.5-day nesting period and the probability that a nest survived the duration of the nesting period was 51.8% (95% confidence intervals = 47.1%, 55.4%).

Discussion

Contaminants

Pesticides adversely affect populations of Western Grebes in some regions (Herman et al. 1969), but we were unable to detect any contaminants in grebe eggs from two colonies in Idaho. Heavy metals bioaccumulate in adult Western Grebe muscle tissue and feathers, but fitness consequences from heavy metals has yet to be detected in grebe populations (Anderson et al 2008, Ackerman et al. 2015). Although we did not detect detrimental levels of any of the 24 metals that we tested, we only sampled 16 eggs during a single year at 2 nesting colonies and so further work is needed before we can rule out contaminants as a possible cause of population decline of Western Grebes in Idaho.

Environmental factors and nest placement behaviors

Nest survival of Western Grebes at Cascade Reservoir was 51.8%. Few estimates of nesting survival exist in the U.S. because of the difficulty in estimating nest survival of western grebes without substantial disturbance to the colony. Our estimate of the probability of nest survival is similar to estimates of apparent nest survival for Western Grebes in Canada: 46% - 84% in Manitoba in the 1970's (Nuechterlein 1975) and 43% - 49% in Manitoba from 2009-2010 (LaPorte et al. 2014). The lower nest survival in the 2009-2010 study was attributed to wave action due to an absence of wave-attenuating emergent vegetation and shorter distances of nests to the edge of the colony (LaPorte et al. 2014). In our study, nest survival was indeed positively correlated with distance to the colony edge, but it was also negatively correlated with distance to open water. Nests farther from open water would have more protection from waves, and yet they had lower survival. This contradicts the results from two other studies (Allen 2008, LaPorte et al. 2014). Seasonal water drawdowns at Cascade Reservoir might explain this contradiction; the water level of the reservoir drops as the grebe nesting season progresses and areas farthest from open water are more likely to become too shallow (or dry up completely). The water elevation at Cascade Reservoir decreased by 94.5cm during the nesting period in 2018 (from 10 June to 15 July). Grebes that nest farther from open water may have difficulty getting their newly hatched chicks out to the open water safely.

Grebe nest survival was higher near the colony center so nesting grebes may be forced to build nests in less desirable locations as the colony expands and late arrivals to the colony may be pushed to the less desirable exterior positions. However, building a nest too close to other grebes also has drawbacks; nest survival was positively correlated with distance to the 5 closest nests. Nest placement for grebes may reflect the goldilocks principle whereby nesting in the center of the colony has benefits but being too close to conspecifics can increase competition for resources, increase social agitation, and facilitate the spread of pathogens and ectoparasites (Wittenberger and Hunt 1985). To our knowledge, ours is the first study to examine the consequences of nest placement in a Western Grebe colony of this size, at this scale and with this level of temporal resolution. The colony that we studied consisted of over 1000 nests and we were able to model survival probabilities for more than 700 nests. We coupled our nest surveys with fine-scale bathymetric data that allowed us to quantify the effect of small-scale variation in water depth on nest survival at a greater resolution than previous studies. Similarly, by comparing our bathymetric measurements to daily change in water elevation at the site we were able to infer some potential negative effects of water drawdowns on nest survival, another avenue that has not been examined in Western Grebes. Our non-invasive method of nest monitoring also allowed us to observe nests at a greater frequency than the 7-10 day intervals often cited in other Western Grebe studies (Allen et al. 2008, LaPorte et al. 2014, Nuechterlein 1975). The greater frequency of visits allowed us greater certainty when determining when a nest failed and our method did not cause any disturbance (i.e., did not cause grebes to leave their nests).

The reason that high density sections of the colony located in shallower water have lower survival may be due to the influence of water depth on nest survival. We found a positive relationship between water depth at the nest and nest survival. Western Grebes rely on relatively deep water near the nest to enter and exit the nest as well as to dive off the nest platform to escape predators. Nests in shallower water may not offer the requisite water depth to facilitate their optimal escape behavior. Also, Cascade Reservoir, like many areas that support Western Grebe nesting colonies, undergoes seasonal water drawdowns for agricultural use and such changes are not predictable and may not mimic historical hydrographs that grebes are accustomed to dealing with. Changes in water depth might impact a grebe's ability to maneuver through the colony. This can be particularly harmful if water drawdowns coincide with the hatching of the young. Grebes that build a nest at a location that is suitable or optimal water depth at the time of nest construction may find themselves on dry land by the end of the nesting period. Once the eggs hatch, the chicks must climb onto their parents' backs who then leave the colony for open water. This brief, but critical time period might be a challenge if the grebes do not have suitable water depths around their nest. The water level at Cascade Reservoir decreases by an average of 41.5cm between 1 June and 15 July. The grebe nests with the deepest water may be spared the harmful effects of falling water levels as opposed to those nests built over shallower water. Indeed, nest initiation date was negatively correlated with nest survival. Nests that were initiated later in the study period had lower survival probabilities. Those grebes that initiated nests later were likely to have less options for nest placement due to lower water levels, but also were more likely to have their nest site dried out prior to hatching. Chronic low water levels prevented Western Grebes from nesting in California (Feerer and Garret 1977). Late-nesting grebes at Cascade Reservoir may not be able to find nest sites within the colony with suitable water depths, and those that they do find may not remain viable long enough to produce a brood.

Drone use

The drone allowed us to monitor the nesting habits of the Western Grebe without ever flushing them off their nests and, hence, provided novel data that would be impossible otherwise. We were able to identify 1059 individual nests and monitor 709 of those nests throughout the nesting period. Our drone flights did not cause any nesting grebes to flush from their nests or elicit any responses that suggested the grebes were disturbed. We would not have been able to collect the data that we did while also minimizing disturbance to the grebes if we did not use the drone. Other studies have used drones to produce population counts of birds (Chabot et al. 2015, Barr et al. 2018), but ours is the first, to our knowledge, to monitor nest fate and estimate probability of nest survival for a colonial nesting waterbird via repeated drone flights. This technology has great promise for use with other colonial nesting birds throughout the world.

Conclusion

Nest survival of Western Grebes is influenced by water levels at nest initiation as well as how those water levels change throughout the nesting period. Similarly, survival varies with the position of a nest within the nesting colony. Cascade Reservoir, like many of the water bodies where Western Grebes nest, is subject to human-induced changes in water level which changes both the availability and quality of nesting habitat . Maintaining stable water levels during the nesting period may increase the breeding success of Western Grebes that rely on these man-made reservoirs. Nesting over water presents many challenges especially on water bodies with unpredictable or receding water levels. Future studies should investigate how changes in water level at grebe nesting colonies affect the adults' ability to successfully carry their young from the nest to open water in situations where water depth at the nest drops to zero before hatching.

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Table 3.1 The results of the egg contaminant analyses. We tested 16 eggs (10 from Cascade Reservoir, 6 from Lake Walcott) for 24 possible contaminants. The values shown are the mean, minimum, maximum, and standard error of all 16 eggs.

Contaminant	Mean dry weight (ppm)	Min	Max	Standard Error	Mean wet weight (ppm)	Min	Max	Standard Error
Aluminum	2.00	2.00	2.00	0.00	0.42	0.35	0.48	0.01
Arsenic	0.50	0.50	0.50	0.00	0.11	0.09	0.12	0.00
Boron	2.00	2.00	2.00	0.00	0.42	0.35	0.48	0.01
Barium	0.56	0.17	1.63	0.11	0.12	0.04	0.34	0.02
Beryllim	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00
Calcium	3546	1820	10100	710.26	761	335	2110	157.31
Cadmium	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00
Cobalt	0.04	0.02	0.24	0.01	0.01	0.00	0.06	0.00
Chromium	0.20	0.20	0.20	0.00	0.04	0.04	0.05	0.00
Copper	2.89	1.94	4.53	0.16	0.61	0.38	0.80	0.03
Iron	109	35	168	9.73	23	8	40	2.25
Mercury	0.40	0.20	0.76	0.05	0.08	0.04	0.16	0.00
Methyl Mercury	0.31	0.01	0.68	0.05	0.07	0.00	0.15	0.01
Magnesium	400	326	518	12.82	122	64	669	36.63
Manganese	2.72	0.80	4.48	0.24	0.58	0.17	0.92	0.05
Molybdenum	0.15	0.10	0.28	0.01	0.03	0.02	0.06	0.00
Sodium	8067	7100	9210	153.86	1693	1580	1830	19.38
Nickel	0.20	0.20	0.20	0.00	0.04	0.04	0.05	0.00
Lead	0.02	0.02	0.02	0.00	0.01	0.04	0.04	0.01
Selenium	2.69	1.43	4.11	0.25	0.56	0.27	0.85	0.05
Strontium	4.49	2.19	8.14	0.46	0.96	0.46	1.80	0.11
Thallium	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00
Vanadium	0.20	0.20	0.20	0.00	0.06	0.04	0.40	0.02
Zinc	49	36	68	2.37	10	7	16	0.63

Table 3.2 List of water prediction models and associated AIC values.

Model	AIC	Delta AIC
ROAD + CANAL + DITCH + $DITCH^2$	953.24	0
ROAD + $ROAD^2$ + CANAL + DITCH	953.33	0.09
ROAD + CANAL + $CANAL^2$ + DITCH + $DITCH^2$	955.04	1.79
ROAD + $ROAD^2$ + CANAL + $CANAL^2$ + DITCH	955.17	1.92
ROAD + $ROAD^2$ + CANAL + DITCH + $DITCH^2$	955.23	1.98
ROAD + $ROAD^2$ + CANAL + $CANAL^2$ + DITCH + $DITCH^2$	956.99	3.75

Table 3.3 The mean, standard error, minimum, and maximum values for 6 features that we included in models to explain variation in probability of nest survival for Western Grebes at Cascade Reservoir.

Nest measurements	Mean	Standard Error	Min	Max
Distance to colony center (m)	48.8	0.87	0.3	114.34
Distance to colony edge (m)	23.6	0.48	0	53.76
Distance to nearest neighbor (m)	2.1	0.04	0.72	17.27
Mean distance to five nearest neighbor (m)	3.4	0.06	1.35	25.27
Distance to open water (m)	214.8	0.69	143.2	255.5
Predicted water depth at nest (cm)	62.4	0.42	36.89	85.09

Table 3.4 List of best-performing nest survival models and associated AIC values.

Model	AICc	Delta AICc	AICc Weights
Day + CENTER + AGG + OW + P_DEPTH	1957.74	0	0.63
Day + CENTER + AGG + OW + P_DEPTH + P_DEPTH^2	1959.74	2.00	0.23
Day + NN + EDGE + CENTER + AGG + OW + P_DEPTH	1960.87	3.14	0.13
Null	2050.81	93.07	0

Table 3.5 Parameter estimates from the top performing nest survival model.

	Beta	Standard Error	95% Confidence interval
Intercept	8.632	0.890	6.897, 10.367
Day	-0.101	0.014	-0.129, -0.073
Center	-0.017	0.004	-0.024, -0.009
AGG	-0.074	0.036	0.004, 0.144
OW	-0.020	0.003	-0.027, -0.013
P_Depth	0.015	0.007	-0.008, 0.019

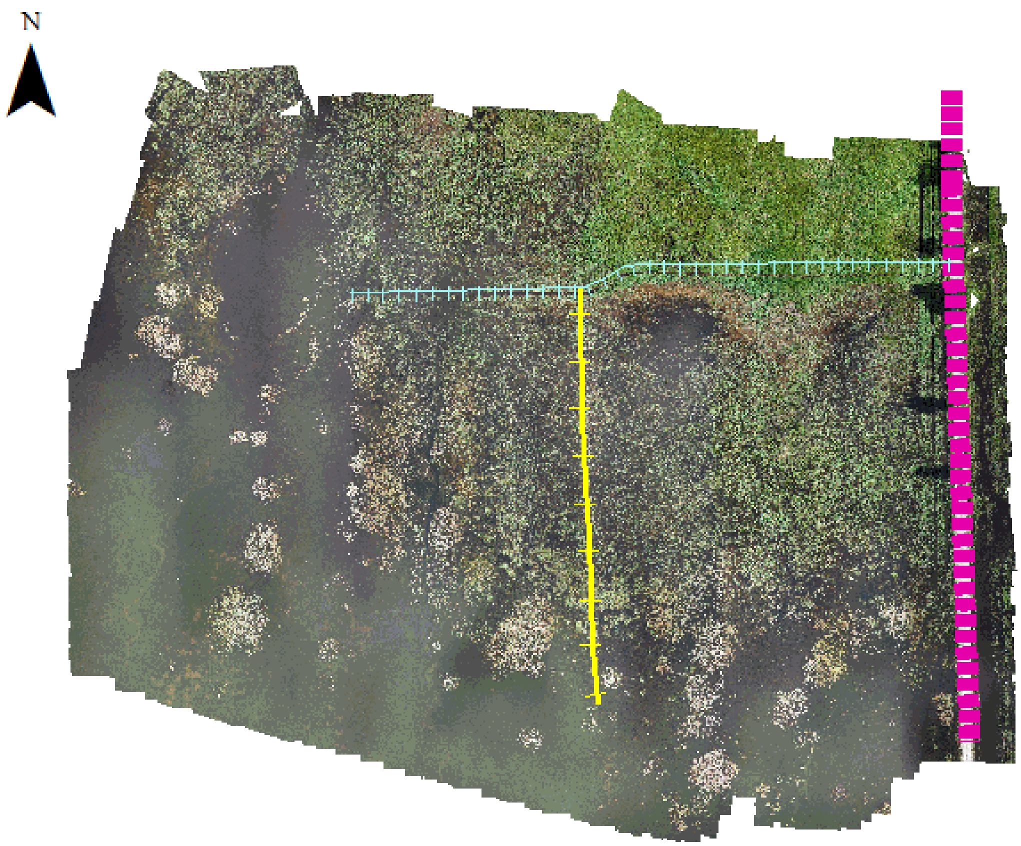


Figure 3.1 Aerial photo of the area at Cascade Reservoir where the Western Grebe colony nested in 2017 and 2018. The North-South lines are DITCH on the left (in yellow) and ROAD on the right (in purple). The WEST-EAST line is CANAL (in light green).

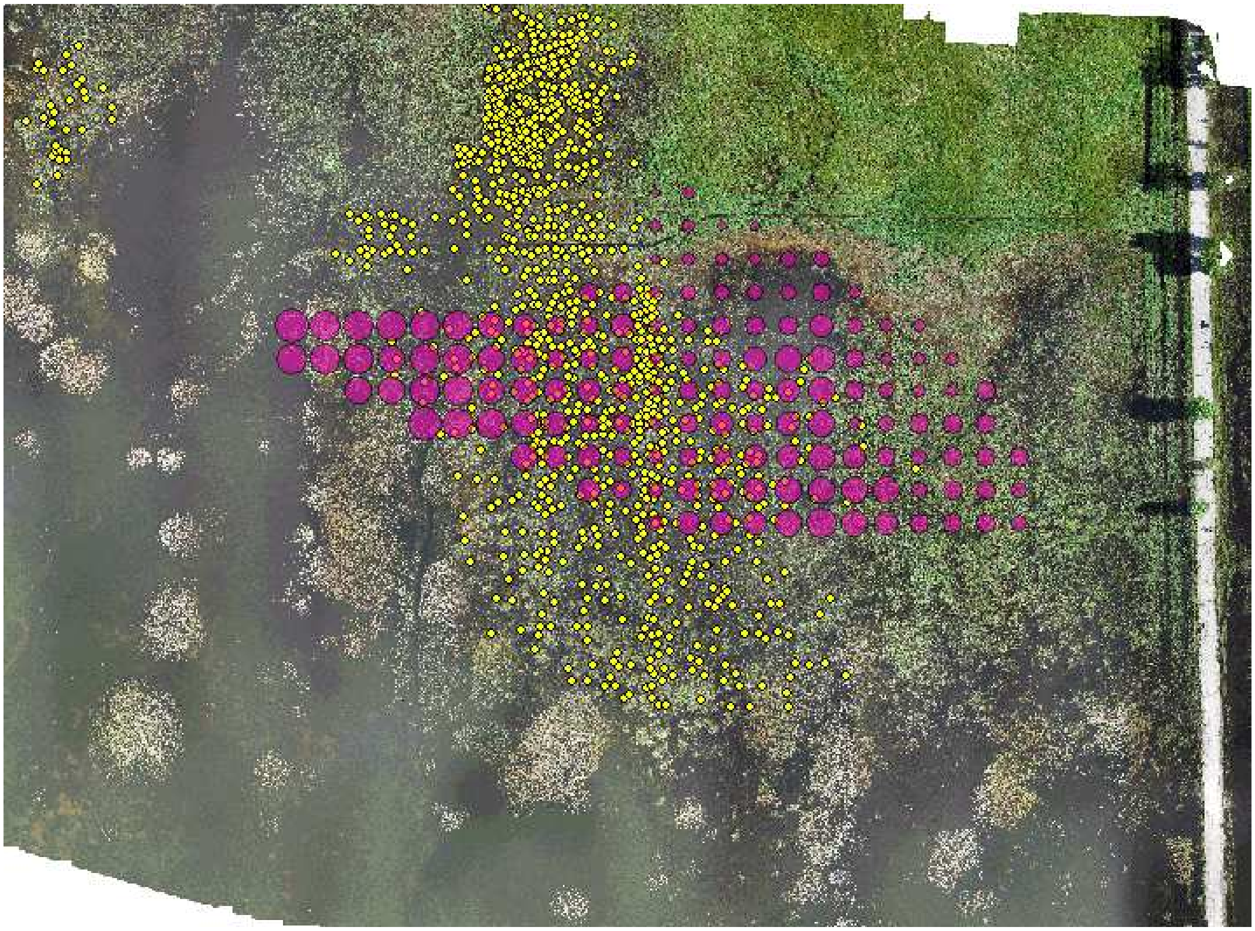
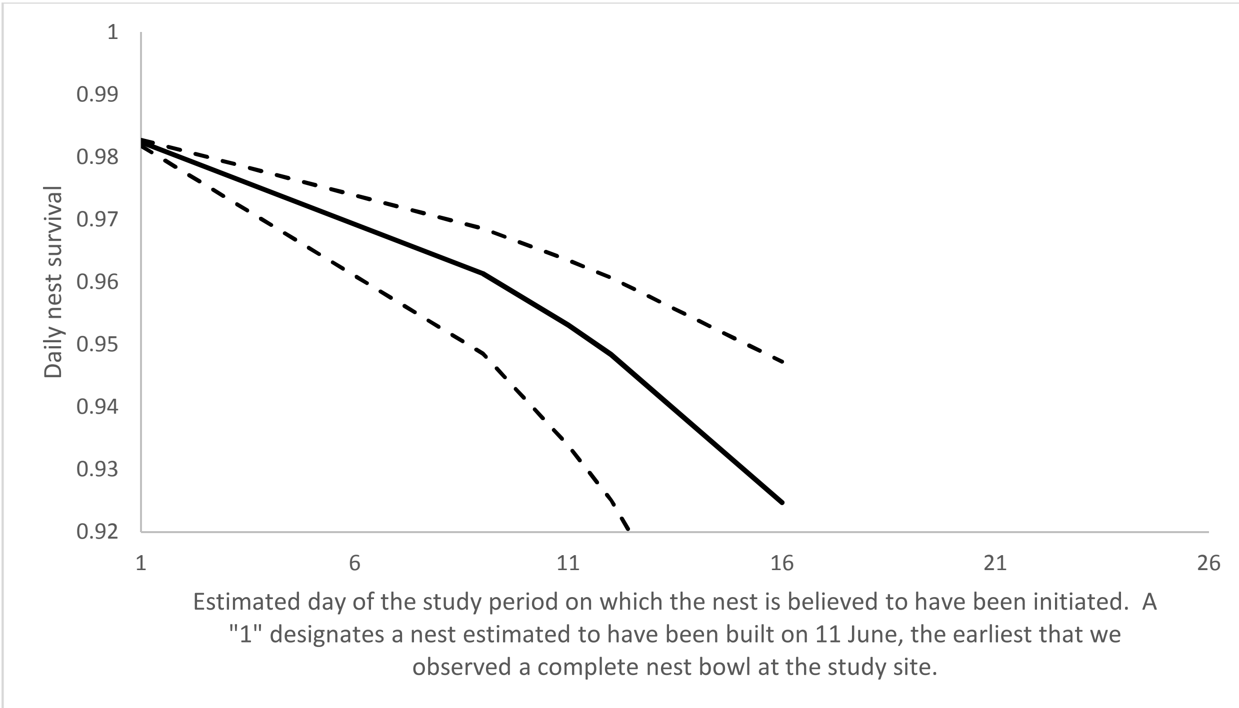


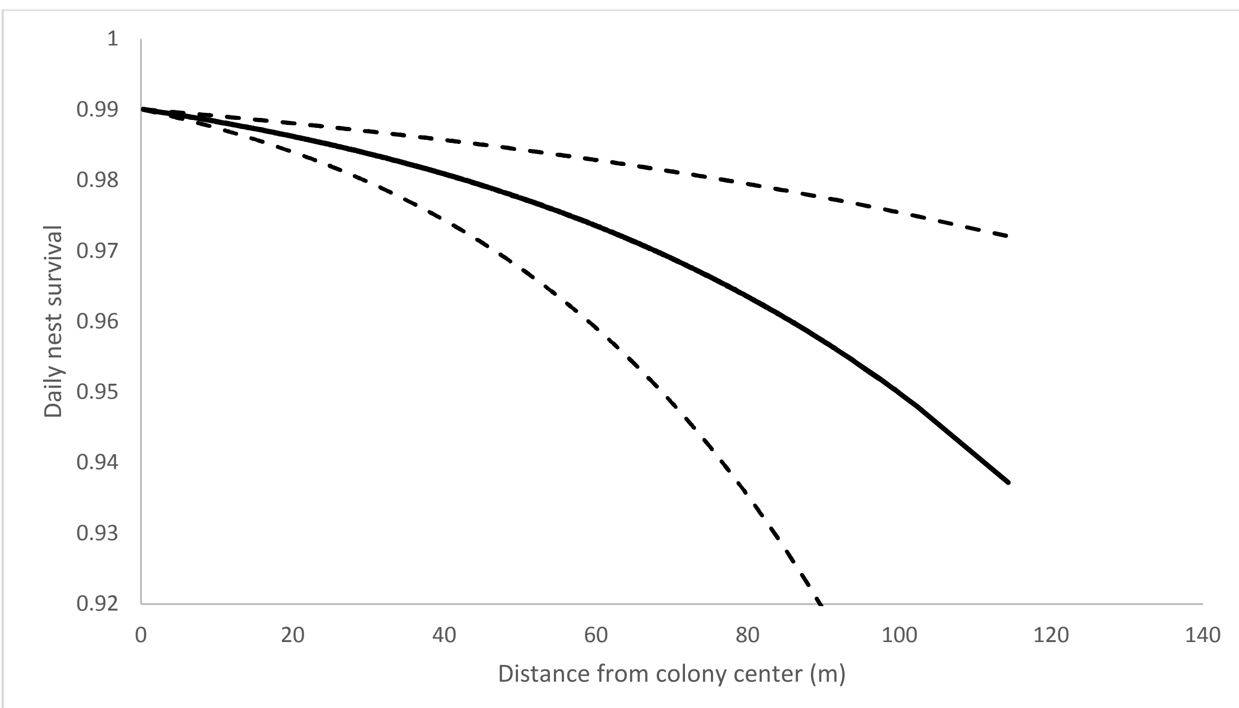
Figure 3.2

. Bathymetry sampling points in purple (n=142) and grebe nests in yellow (n=1059) overlaid on the 2018 grebe colony at Cascade Reservoir. The size of the bathymetry points are proportional to water depth with larger symbols depicting deeper water. The mean water depth of these points was 57.9cm, SD = 14.1cm, min = 24.0cm, max = 100.0cm.

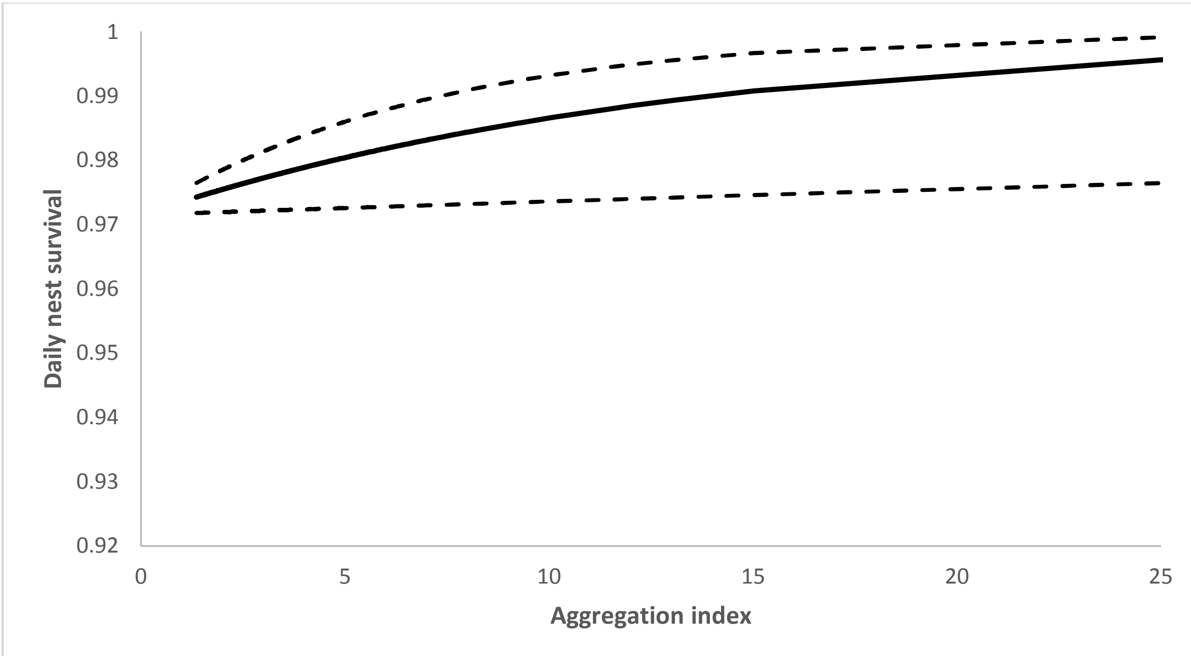
A)


1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
Daily nest survival
1
6
11
16
21
26
Estimated day of the study period on which the nest is believed to have been initiated. A "1" designates a nest estimated to have been built on 11 June, the earliest that we observed a complete nest bowl at the study site.

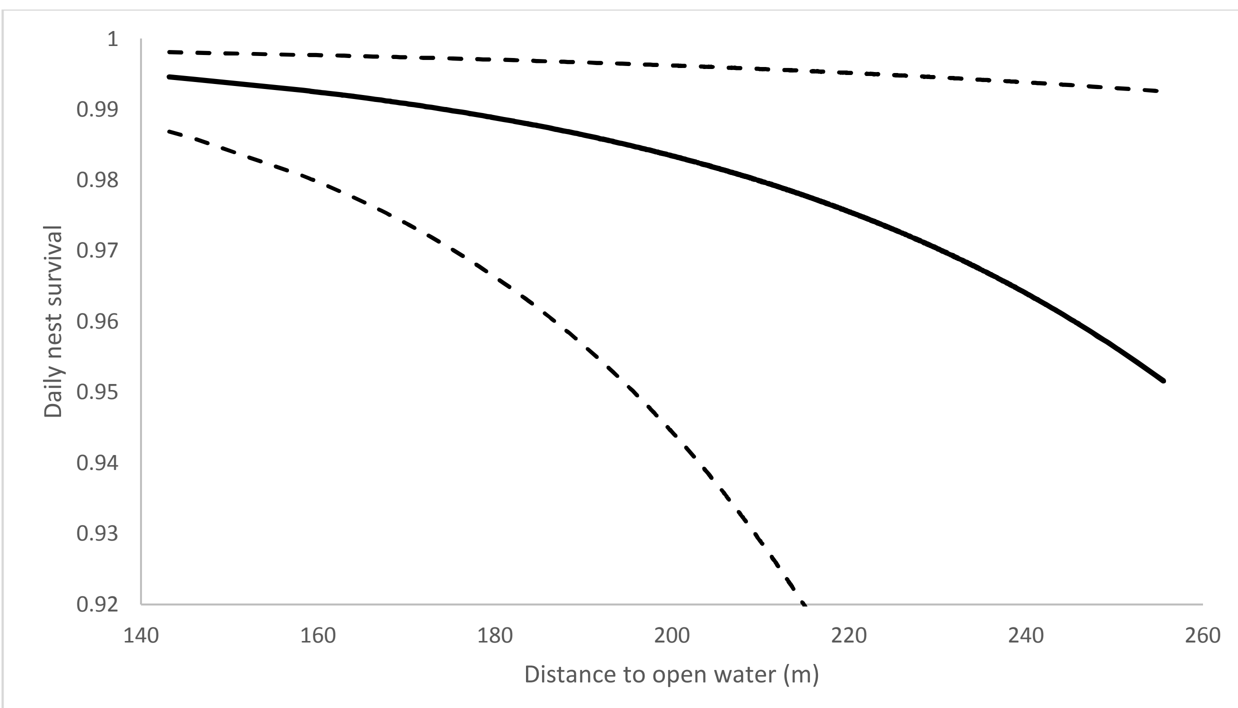
B)


1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
Daily nest survival
0
20
40
60
80
100
120
140
Distance from colony center (m)

C)


1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
Daily nest survival
0
5
10
15
20
25
Aggregation index

D)


1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
Daily nest survival
140
160
180
200
220
240
260
Distance to open water (m)

E)

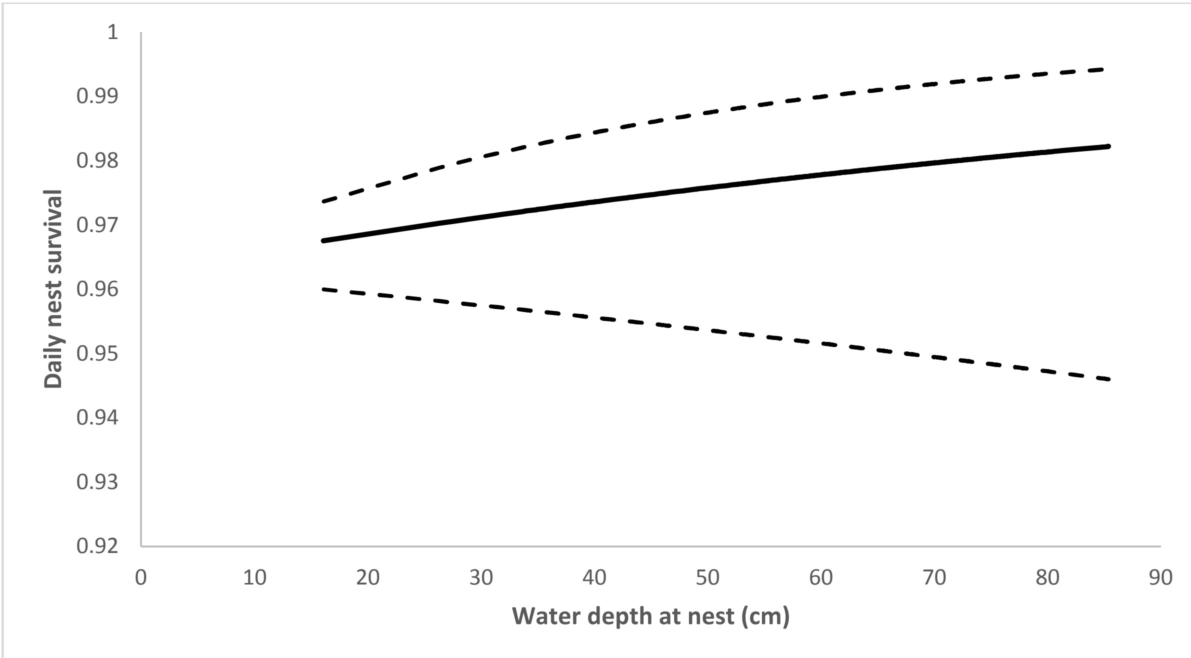


Figure 3.3 Partial-effects plots from the top nest survival model that show the relationship between daily nest survival and nest initiation date (A), distance of the nest from the center of the colony (B), mean distance to the five nearest neighbors (C), distance of the nest to open water (D), and the estimated water depth at the nest (E). The dotted lines are 95% confidence intervals.

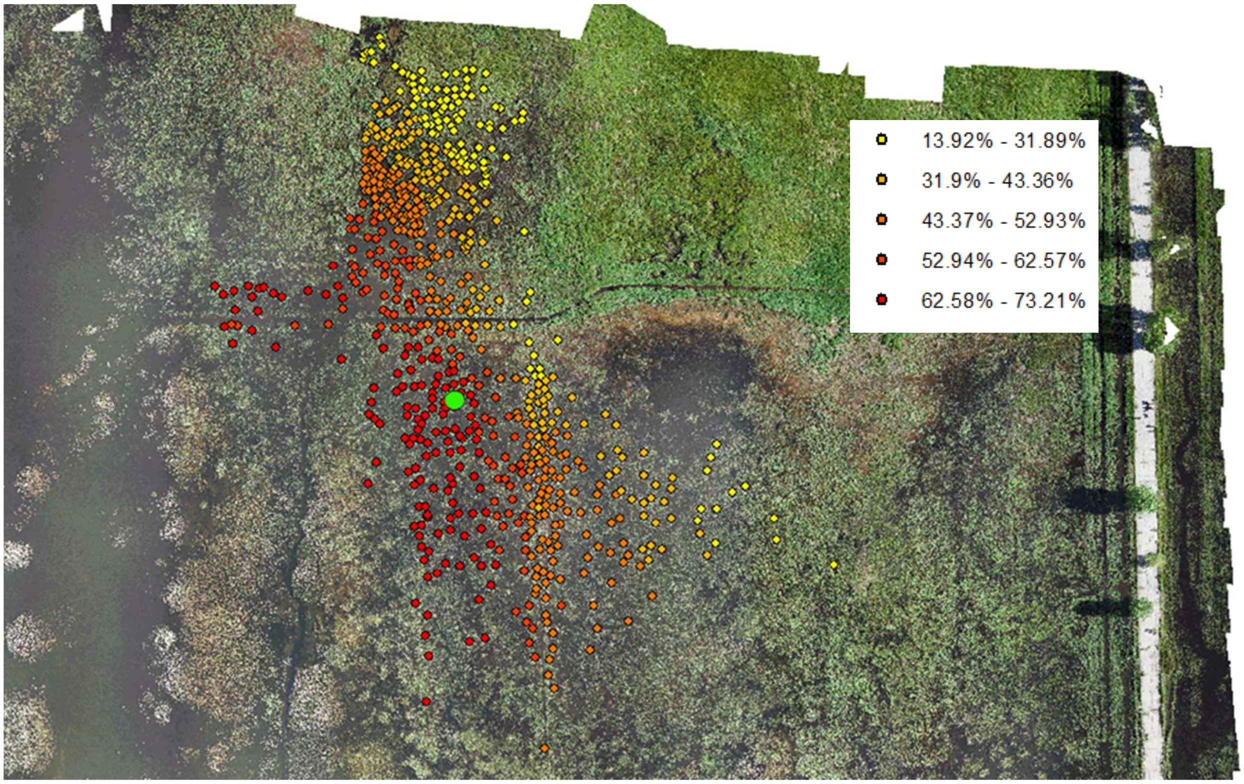


Figure 3.4 Modeled probability of a grebe nest surviving the nesting period for each nest location used in the analysis (*n* = 709).

Chapter 4: Conclusion

We explored how multiple habitat variables influence nest-site selection and nest survival. Western Grebes preferred nesting in areas with water depths between 40 and 80cm. Similarly, nests that occur in deeper water within that range had higher nest survival. Draw downs in water level may have a detrimental effect on nest survival of western grebes. Those nests that were constructed later in the breeding season had lower survival, possibly because they could not successfully fledge a brood before their nest site had dried out. The Western Grebes in our study breed on a reservoir where agriculture needs dictate water levels. The results of our study can help inform conservation and management practices to find a balance between human and wildlife needs. If the amount of available wetlands continues to decrease, understanding the impacts of water availability on waterbirds becomes increasingly important.

Future Research

Our use of drone technology allowed us to non-invasively map and monitor an unprecedented number of grebe nests without disturbing incubating females. We were not able to use all of the nests in the colony in our survival analysis due to difficulty tracking individual nests between our 6 surveys. Future researchers should continue to refine the photo-processing and geo-referencing of the orthomosaics and to fly more frequently to ensure that all nests are displayed in the highest quality image possible so that they may be accurately tracked from image to image. Similarly, future researchers could potentially apply machine learning to automate the digitizing of nests in each orthomosaic. Also, due to our hesitance to cause disturbance, we had to create a predictive model for water depth for a majority of our nests. Going forward, researchers should attempt to conduct a more thorough bathymetric survey prior to nest construction so that maximum amount of area can be surveyed without interfering with grebe nesting. If possible, the bathymetric points should be resurveyed once the colony has been abandoned. We focused on water depth and distance to open water when constructing our resource selection function model. Other environmental variables may also be worth exploring, such as vegetation cover, water quality, and exposure to wind-driven waves. This would produce a more robust resource selection function model.