University of Nevada, Reno

Nutrients, Cormorants, and Rainbow Trout In An Urban Lake, Reno NV

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Hydrologic Science

by

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Abstract

There are two chapters in this thesis, apart from this chapter (Introduction) and Chapter Four: Discussion and Final Remarks. Chapters Two (*Nutrient Contributions By An Avian Community To An Urban Lake, Reno NV*) and Three (*Impact of Double-crested Cormorants On Rainbow Trout Stocked In An Urban Lake*) were developed as independent manuscripts, though the research for each was conducted at the same place, Virginia Lake, in Reno, NV. Chapter Two is an investigation of nutrient contributions by an avian community to an urban lake in Reno, NV. Chapter Three is an investigation of the impact of double-crested cormorants on rainbow trout stocked in the same lake, Virginia Lake.

Constructed in 1938, Virginia Lake is a 9 ha impoundment lake within the city limits of Reno, which, in recent times, has been plagued by poor water quality. In addition, the Nevada Department of Wildlife has suspected double-crested cormorants of depleting the stocked rainbow trout fishery, though it was unclear if stocked fish numbers were depleted primarily by predation or by water quality, including excessively warm temperatures and periods of eutrophia within the lake, including depleted concentrations of dissolved oxygen in water.

The intent of our study, which was supported with funds from the Nevada Department of Wildlife and the Nevada Agricultural Experiment Station, was to examine the relative effects of each type of stress (predation and unfavorable aquatic environment) on stocked fish populations. At the outset, our study focused on mixing dynamics and phosphorus loading to the lake, including intensive measurement of temperature

supplemented by other indicators of water quality in the lake. As the study progressed, we adopted the following objectives:

(1) to estimate the allochthonous total phosphorus (TP) loads derived from bird droppings,

(2) to compare bird-derived TP loads with loads from influent Truckee River water and total phosphorus (TP) mass present in the lake,

(3) to estimate survival of stocked rainbow trout, and

(4) to estimate harvest of these fish by anglers and double-crested cormorants.

Our studies for Chapters Two and Three relied on two primary methods: a census and sampling approach to estimating the type and number of birds resident at Virginia Lake over a 9 month period and a novel sampling approach to estimating predation losses among newly stocked trout, based on mark—recapture modeling and recovery of tags from tagged trout in a cormorant nesting area. These approaches are meant to provide insights useful to those trying to manage Virginia Lake to ensure that the lake remains an attractive resource for urban residents. We hope the results and recommendations contained in this document are useful to the agencies (the City of Reno Department of Parks and Recreation and the Nevada Department of Wildlife) and urban residents who appreciate this valuable urban resource.

Dedication

This research was supported by a grant from the Nevada Department of Wildlife (NDOW) and the Hatch program administered by the Nevada Agricultural Experiment Station. We thank the staff of NDOW, without whose support this project would not have been possible. Specifically, we would like to thank: Mark Warren, Kim Tisdale, Mike Sevon and Rich Haskins. In addition, a number of people donated significant amounts of time so that our field work could be completed. Those people are: Peter Graf, John Umek, Antonio Salgado, Wendy Trowbridge, Joe Sullivan, Chris Jannusch, Lynell Garfield, Diana Perez-Aranda Serrano, Danielle Johnson, Peter Rissler and Japhy.

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Chapter 1: Nutrient Contributions By An Avian Community To An Urban Lake, Reno NV

Abstract

Urban lakes in the United States are prone to eutrophication as a result of nonpoint sources of nutrients. Nutrients may come from many sources, including fecal matter from waterfowl. We present a model of total phosphorus (TP) sources from the combined droppings of birds for a small urban lake in Reno, NV. The model depends upon systematic observations of waterfowl activity in the vicinity of the lake, estimates of fecal mass from waterfowl, estimates of nutrient content of fecal matter from previous studies and a proportionality term representing the likely mass of TP from droppings that reach the lake. We compare model estimates with water quality trends in the lake to estimate the relative contributions of nutrients by waterfowl over an eight month period of observation.

Introduction

Urban lakes are usually man-made and are created in or near cities. Their proximity to urban areas ensures their utility for recreation, nutrition (fishing), and community aesthetics. It is the proximity to cities and use by urban residents that makes management and study of these lakes highly important. However, relative to natural lakes in rural areas, urban lakes have received less attention from scientists and resource managers.

Urban lakes present unique challenges for local management agencies. Lakes are typically classified according to their trophic state: oligotrophic, mesotrophic, eutrophic, or hyper-eutrophic. Characteristically shallow with small volumes, urban lakes often have poor circulation and can be subject to high nutrient inputs. These characteristics make them particularly prone to eutrophication. The United States Environmental Protection Agency (US EPA) evaluated 3,700 urban lakes and classified more than 80% as either eutrophic or hyper-eutrophic (US EPA 1986) Eutrophic lakes are characterized by intense primary productivity (e.g. algal growth), which is commonly limited by the macronutrient phosphorus or nitrogen. Intense primary productivity can lead to unstable chemical and physical conditions. In small, shallow lakes, resident organisms may be exposed to extreme and rapid changes associated with episodic nutrient inputs in drainage from adjacent landscapes, from internal loading associated with anoxic benthic sediments, or both (Wetzel 2001). Identifying nutrient sources and estimating loading rates, particularly episodic nonpoint drainages, is an important task and can be used to manage or reduce nutrient inflows. Because eutrophication often leads to aesthetic degradation and in extreme cases complete system failure, understanding the relative magnitudes of nutrient sources and options for control is a first step in setting priorities to minimize the risk of eutrophication.

Among the many sources of nutrients within the watersheds of small urban lakes, migratory waterfowl are often highly visible and numerous, especially when natural and subsidized food sources are plentiful. Because droppings from flocks of waterfowl can be seen on lawns and other landscaped surfaces, homeowners associations have called for further study and possible control of waterfowl populations to protect the aesthetic and functional qualities of their surroundings.

Various studies and models have investigated nutrient contributions and water quality effects of birds. In 1988, Portnoy (1990) used gull roosting times, defecation rates, and total phosphorus (TP) content of feces for two species of gulls (*Larus argentatus* and *L. marinus*) to estimate TP loading to Gull Pond, MA. On only one occasion did Portnoy observe a gull feeding on the lake. Thus, all TP contributed to the pond was assumed to be allochthonous. Implying a relationship to eutrophication, Portnoy (1990) concluded his estimates sufficiently explained summer secchi depths. By contrast, Marion et al. (1994) reported human sewage and agriculture runoff was a greater source of TP than birds in the largest natural lake in France.

Manny et al. (1994) applied a simple nutrient load-response model to expected annual TP loads from birds and reported that waterfowl caused poor water quality conditions in Wintergreen Lake, MI. Scherer et al. (1995) employed an approach similar to that of Manny et al. (1994), but reported only 13% of bird-loaded TP to Green Lake, WA, was allochthonous and not correlated to other water quality indices. Post et al. (1998) used bioenergetic models and bird counts to estimate TP loads in the Bosque del Apache National Wildlife Refuge, NM. They reported TP loads contributed by Lesser Snow Geese (*Chen caerulescens caerulescens*) and Ross's Geese (*Chen rossii*) were similar to surface water inputs. Using a similar approach to Post et al. (1998), Olson et al. (2005) reported Snow Geese contributed 85 – 93% of TP to Middle Creek Reservoir, PA (surface area of 162 ha), from February to March, 2001. Hahn et al. (2007) considered phosphorus contributions to Dutch freshwater wetlands from carnivorous birds. Using food-intake and excretion models, Hahn et al. (2007) estimated allochthonous and autochthonous nutrient loads over a three year period. In the same study, autochthonous TP loads (25.2-39.2 metric tonnes) were estimated to have been approximately twice as high as allochthonous TP loads (16.7-18.2 metric tonnes), but were a minor porportion on a landscape scale. Two species of gulls (*Larus ridibundus*, *Larus canus*) were the largest sources of external TP loading, while great cormorants (*Phalacrocorax carbo*) and grey herons (*Ardea cinerea*) were the largest sources of internal TP loading. In another study, Hahn et al. (2008) considered TP contributions of herbivorous birds and estimated 34.7 ± 2.3 metric tones of allochthonous TP were loaded to Dutch wetlands. Again, Hahn et al. (2008) concluded TP from herbivorus birds represented a small proportion of the total TP contributed to Dutch freshwater wetlands, with geese contributing the most TP for herbivorous birds. In a mesocosm experiment, Unckles and Makarewicz (2007) observed little or no impact on water quality or phytoplankton concentrations with increased additions of Canada geese droppings.

Likewise, Pettigrew et al. (1998) reported nutrients from waterfowl feces did not appear to have a significant effect on the local foodweb.

The objective of our study was to estimate the allochthonous TP loads derived from bird droppings to a small urban lake in Reno, NV – Virginia Lake. In addition, we sought to compare bird-derived TP loads with loads from influent Truckee River water and the mass of TP present in the lake. Our primary goal was to provide information that could be used to improve management and mitigate poor water quality conditions in small urban lakes with resident and migratory bird communities similar to our study site.

Study site

Virginia Lake is an impoundment lake within the city limits of Reno, Nevada. The lake was intended for swimming, boating, fishing, and skating (US WPA 1938). Although boating, skating and swimming are no longer permitted, the lake remains an important resource for recreation, nutrition, and community aesthetics.

Like most urban lakes, Virginia Lake is shallow with a maximum depth of about 3 m. Its surface area is approximately 9 hectares and the volume is approximately 150,000 m^3. The primary inflow and outflow are located at the northern and northeastern sides of the lake, respectively. The inflow consists of water diverted from the nearby Truckee River through a buried aqueduct that opens approximately 100 meters from the lake inlet. The lake is equipped with a vertical drain of fixed elevation that maintains constant water level (and lake volume) unless inflow ceases.

Located on the Pacific flyway, Virginia Lake hosts an abundance of migratory and resident aquatic birds. An approximately 500 m^2 island near the south-western end of the lake hosts breeding colonies of double-crested cormorants (*Phalacrocorax auritus*), ring-billed gulls (*Larus delawarensis*) and snowy egrets (*Egretta thula*).

Potential nutrient sources that could influence the lake's water quality include: (1) a municipal golf course, which is presumably fertilized periodically and is less than 2 km away and drained by a tributary to Virginia Lake, (2) a dog park, with substantial amounts of accumulated feces less than 50 m from the south eastern edge of the lake, (3) the south-eastern shoreline, which was disturbed by a landscaping project during the study period, potentially mobilizing nutrients otherwise sequestered in soils, (4) resident and migratory waterfowl, which received large food subsidies from residents, and (5) residential and publicly managed areas with landscaping, including fertilized lawns. Our focus was on estimating TP loads from bird defecation in the lake and on shoreline and adjacent areas.

Methods

Water quality: We monitored changing water quality conditions at an index station in Virginia Lake (Figure 1). We measured temperature and dissolved oxygen biweekly using a YSI 556 Multiprobe system. Beginning on February 2, 2005 after ice had melted from the surface of the lake we collected water samples biweekly at depths of 0.5 and 1.5 m from the surface using a Van Dorn sampler. Sampling ended on October, 7, 2005. We integrated water samples in an acid washed HDPE 3½ gallon bucket, then split samples into two 500 ml acid washed HDPE bottles. Water samples were analyzed for TP using EPA method 365.3 and a Shimadzu UV-160 Spectrophotometer and are based on reactions and persulfate digestion. TP measurements taken from the lake were later regressed against TP estimates contributed by birds.

We used Truckee River water quality data, supplied by the Nevada Division of Environmental Protection (NDEP) (http://ndep.nv.gov/bwqp/truckeemap.html), to estimate inflow concentrations and loadings of nutrients to Virginia Lake. These data were collected approximately 1.5 km upstream of the aqueduct from the Truckee River to Virginia Lake diversion and, as noted, the aqueduct was buried and unlikely to have been a significant source of TP between the Truckee River and the lake. Flow measurements were made at the inflow of Virginia lake by current meter discharge measurement (U.S.G.S., 1982), using a Swoffer model 2100 current meter.

To assess the trophic condition of Virginia Lake throughout the scope of our study, we used a trophic state index (Carlson 1977):

$$TSI(TP) = 14.42 \ln(TP) + 4.15$$

in which TSI is the trophic state index and TP is total phosphorus concentration (mg/l). In this equation, TSI is a function of TP because phosphorus is often the limiting nutrient in aquatic systems. TSI values greater than 50 indicate eutrophic conditions and values greater than 70 indicate hyper-eutrophic conditions (Wetzel 2001). In addition to TSI, we measured clarity in Virginia Lake with an 8 inch diameter Secchi disc (Preisendorfer 1986). Intuitively, we expected TSI to be inversely related to water clarity.

Bird contributions: We estimated the total amount of TP that entered the lake from birds as droppings (Table 1). We used a modification of the equation described by Scherer et al. (1995) to estimate TP loading rates:

$$TP = (B)\,(D)\,(C_p)\,(p_1) \qquad \text{Equation (1)}$$

in which TP was the TP loading rate (kg * month^{-1}), B was the number of bird days at the lake (bird-d * month^{-1}), D was the estimated dry weight (kg DW) of droppings produced per bird per bird-day (kg DW droppings * bird-d^{-1}), C_p was TP content of droppings as a percent dry weight (mg TP * mg DW droppings^{-1}), and p_1 was the proportion of droppings that entered the lake. Methods for estimating each term are described below.

Number of bird-days (B)

We conducted bird counts weekly for all species of birds shown in Table 1 from February 22, 2005 to October 7, 2005. For our counts, we divided the lake into quadrants and counted all the birds with 8 x 40 binoculars. Presence-absence counts were conducted semi-daily the rest of the week. Bird counts were primarily conducted in the late afternoon before sunset. For our analysis, we sought estimates of the number of birds present on each day of the month, so for days with no data or days with only presence-absence data, estimated numbers were based on observations from previous bird counts. Daily bird counts were used for monthly estimates, which yielded the number of bird-days per month (bird-day * month^{-1}). We did not assume that if a bird was counted near the lake it was there for 24 hours (a complete day). We used a proportionality term (p_1 in equation 1) to account for variations in length of stay and to represent the proportion of the mass of droppings that would reach the lake (see below).

Rate of production of Droppings (D)

We assumed that birds defecated approximately 2.25% of their body weight per day (Scherer et al. 1995) (Table 1). Nutrient content of droppings was estimated from values reported from previous studies. Manny et al. (1994) reported the mean dry mass of a Canada goose dropping was 1.17g (n = 30) and the mean proportional mass of phosphorus was 0.015 ± 0.006. Thus, we assumed that 1.3% of the average goose dropping was phosphorus. Furthermore, we assumed the nutrient concentrations from Manny et al. (1994) were similar for all other birds, whether herbivore or piscivore. Thus, $C_{phosphorus} = 0.013$.

Proportion Of Droppings That Enter The Lake (p_1).

Two factors affected the proportion of droppings that entered the lake – the proportion of a 24 hour period that birds were at the lake (which is related to the total expected mass of droppings) and the mechanisms that introduce droppings into the lake. Both are related to the roosting and foraging habits of birds. For example, geese and mallards circulate daily among lawns, municipal golf courses, and parks throughout the city of Reno, including Virginia Lake. At a single location, waterfowl frequent a range of environments. In the immediate vicinity of Virginia Lake, waterfowl were observed on the lake, and in adjacent residential and public lawns and open space. Some of the constituent nutrients deposited in these areas were washed into the lake episodically during precipitation and snow melt events and possibly during lawn irrigation, while other nutrients were likely sequestered as part of plant tissues and removed (for example as lawn clippings). Another proportion of nutrients may have been washed into surrounding storm water drains, some of which were routed away from the lake.

To account for the fact that the proportions reaching the lake were less than 1.0, we assigned a fractional constant for each bird species included in the study, based on our observations of bird presence and absence. The proportional estimates were subjective and scaled for each species. This approach was similar to that taken in the design of a watershed-scale model of nonpoint source water contamination from varied land uses

(Haith 1985). The model "Generalized Watershed Loading Functions" estimates nutrient delivery to a watershed outlet as the combination of dissolved nutrients and those sorbed to transported sediments. However, the model accounts for inefficiencies in nutrient transport by using a sediment delivery ratio (≤ 1.0) to represent the difference between the mass of nutrients mobilized from runoff-generating storms and base flow by soil erosion and in dissolved form and the amount expected to reach a watershed outlet over the simulation period. For our analysis, the values assigned to p_1 for different species of birds reflect the observation that many species of birds did not necessarily spend an entire 24-hour cycle at the lake. Birds emigrated and foraged elsewhere during the day. In addition, almost all bird species at the lake, including the typically piscivorous common merganser, were observed taking advantage of food subsidies (e.g. bird seed and bread crumbs). We did not directly account for the introduction of these subsidized food resources in our models. Instead, after having identified the subsidized food resources and the propensity for birds to forage elsewhere during the day, we assumed that nutrients introduced in bird droppings were allochthonous, which is different than Scherer et al. (1995). We assumed that all of the nutrients contributed to the lake from geese were imported from surrounding feeding areas outside the immediate vicinity of the lake. Likewise, we assumed that all nutrients contributed to the lake by cormorants were imported with their prey items, such as stocked rainbow trout, and all of the nutrients contributed by mallards were imported as bread crumbs, birdseed, etc.

Results

Lake water quality: The inflow to the lake was highly variable, reaching a maximum of 6 cfs in May, 2005 (Fig. 2a; Table 2). Secchi depth and TSI generally exhibited an inverse association throughout the scope of this study. At all times during our study, the trophic state of Virginia Lake was eutrophic or hyper-eutrophic. Lake clarity decreased to the lowest levels on September, 15 2005 (Fig. 2b; Table 2).

The estimated TP mass in the lake varied with time (Fig. 2c; Table 2), with a large increase on September 15, 2005. Based on estimates of TP mass in the lake (TP concentration at the index station × estimated lake volume), bird and inflow contributions were two orders of magnitude lower than estimated TP mass in the lake (Fig. 2c). DO and water temperature also exhibited an inverse relationship, until August, 2005, when DO rose sharply (Fig. 2d).

Bird presence: Gulls, mallards, double-crested cormorants, and Canada geese were the most abundant birds at the lake, comprising 35, 27, 13, and 10% of the totals, respectively (Fig. 3). On September 15, 2005, birds were counted on five occasions throughout the day. Over the course of the day, goose counts were lowest in the late mornings ($n = 11$) and highest after the sun set ($n = 296$). The greatest number of geese returned between sunset and darkness. Even after visibility diminished and geese could no longer be counted, they could be heard calling or landing on the lake. For this reason, our counts may underestimate the total number of geese present on a given day. Furthermore, our semi-daily bird counts were conducted in the late afternoon and early evenings and may not have captured the greatest abundance of Canada geese in a typical

24-hour cycle. We compensated by increasing the proportion of nutrients from the droppings that would enter the lake (p_1) (Table 1).

On September 15, 2005, Double-crested cormorants exhibited similar behavior, with as few as seven counted in the late morning and 51 counted at sunset. From our diel count, we observed that mallard and gull abundance exhibited minimal change.

Nutrient loading estimates: With the exception of February, monthly TP loads, contributed by birds, remained relatively constant (Fig. 4) and we estimated 30.5 kg (3.4 kg ha^{-1}) of TP was contributed to the surface of Virginia Lake by all species of birds at the lake, during the 8 month period of study. Cormorants contributed the greatest amount of TP with an estimated 10 kg of TP (Table 3). Canada geese contributed the next greatest amount of nutrients with an estimated 8 kg of TP.

Lake Total Phosphorus and Bird TP Contributions: We investigated the relationship between estimated TP mass in the lake with estimated TP loads from water fowl to explain the changing levels of in-lake TP throughout the course of this study. We hypothesized that TP estimated from birds was related to TP measured in the lake. However, we found no relationship between in-lake TP mass and estimated TP contributed by birds ($P = 0.43$) (Fig. 5), which is consistent with the findings reported by Scherer et al. (1995). We investigated the association between influent TP and TP mass estimated in the lake. The mass of TP in the lake was two orders of magnitude greater than what would have been expected from the river, based on the estimated concentrations from inflow. In addition, the peaks were separated by about 175 days, an unlikely lag given the direct connection through a covered aqueduct. From these analyses, we concluded that the majority of TP likely came from other sources.

Discussion

We estimated 30.5 kg of TP from bird droppings and 36.8 kg from the inflow were loaded to Virginia Lake in our eight month study, 2006. In the months of August and September alone, nearly 50 kg of TP was measured in the lake. Although TP contributions to lake by birds and the inflow appear high over the course of our study, they could not explain the large increase of TP measured in the lake in August and September.

After normalizing for lake surface area (9 ha), our eight month estimate (3.4 kg ha^{-1}) was similar to that of Manny et al. (1994), who estimated waterfowl loaded 5.9 kg ha^{-1} yr^{-1} of TP to Wintergreen Lake, Michigan, which has a surface area of 16 ha. At Green Lake, near Seattle in Washington State (with a surface area of 105 ha) Scherer et al. (1995) estimated contributions of 1.67 kg ha^{-1} of allochthonous TP from bird droppings. Marion et al. (1994) estimated a loading rate of 0.7 kg ha^{-1} from bird droppings in Grand-Lieu Lake, France, which has a surface area of 3500 ha. Hahn et al. (2007; 2008) estimated 0.12–0.16 kg TP ha^{-1} of TP was loaded to Dutch wetlands by carnivorous birds, while 0.09–0.l0 kg TP ha^{-1} was loaded by herbivorous birds. Post et al. (1998) estimated geese loaded about 2.2 kg ha^{-1} of TP per year to wetlands in the Bosque del Apache NWR, New Mexico, which includes approximately 3680 ha of surface water and wetlands. At a kettle lake in Cape Cod National Seashore, Portnoy (1990) estimated gulls contributed 1.8 kg ha^{-1} of TP per year. Olson et al. (2005) estimated snow geese at the Middle Creek Reservoir, PA, loaded 5.25 kg ha^{-1} of TP before Fall emigration. Our estimates of TP loaded/ha to Virginia Lake were higher than those reported in similar studies, yet appear to be modest given the small surface area of the lake, the location on the Pacific fly-way, and anthropogenic subsidized food resources.

One potential source of TP to Virginia Lake not measured or estimated in our study is atmospheric deposition, which could be significant. Jassby et al. (1994) estimated that atmospherically deposited soluble reactive phosphorus loads were four times higher than run-off (inflow) loads to Lake Tahoe, CA. We believe atmospheric deposition was a source of TP to Virginia Lake, but we do not believe it explains the extreme fluctuations that we observed.

On the southern banks of the lake, a landscaping project took place for nearly the entire duration of our study. At the construction site, heavy equipment moved earth near the south-western shore of Virginia Lake. Studies have shown that construction sites contribute TP to lakes and rivers (Daniel et al. 1979; Daniel et al. 1982). In 1999, the US EPA estimated that 20 to 150 tons acre^{-1}year^{-1} of sediment were lost from construction sites like these (US EPA 1999). It is likely that soil erosion and sediment runoff contributed TP to the lake.

Residential lawns and golf courses treated with fertilizers may also have contributed TP to the lake. In addition, being surrounded by impervious surfaces, storm runoff from lawns and golf courses had little chance of being attenuated or sequestered. Drainage to the lake, including storm drainage and drainage from excess irrigation, may have been a significant episodic source of nutrients (Lavalle 1975; Waschbusch et al. 1999).

Another potential source of TP was internal loading (Hutchinson 1973; Wetzel 2001), which may have released phosphorus from lake sediment into the overlying water.

Upon entering an aquatic system, organic and inorganic TP settles and binds to mineral and organic sediment, which accumulates in the benthic zone of lakes. Although recent studies have linked internal loading to changes in parameters other than dissolved oxygen (Jensen and Andersen 1992; Xie 2006), it is generally believed that TP is released from lake sediment as biologically available ortho-phosphorus when water conditions become anaerobic (Mortimer 1941). Lake sediment can be a significant source of TP and in many cases internally loaded TP can exceed external loading (Schindler 2006), which can cause blooms of algae.

The mechanism most commonly thought to release ortho-phosphorus into overlying water involves reduction and subsequent release of phosphate (PO_4^{3-}) from iron (Fe(III)) oxide, which is associated with high water temperature, high metabolic activity, high pH, and intense primary production, consumption of, and ultimately, depletion of dissolved oxygen.

Our observations of water quality and physical characteristics of Virginia Lake suggested TP was reduced and internally loaded from lake sediment into the overlying water. In early August, water temperatures were very high and although oxygen concentrations were also high (Fig. 2d), we measured a sudden DO depletion in mid August, 2006. The sudden and dramatic decline in DO measured in mid-August was accompanied by the lowest measured Secchi depths and the highest calculated TSI. The sudden change in water quality suggested a systemic shift from aerobic to anaerobic water quality conditions. It is possible that while water temperature, rates of photosynthesis, and pH levels increased, dissolved oxygen and redox potential at the sediment level decreased, thus liberating ortho phosphorus from the sediment.

Throughout our study, we made numerous assumptions which could be refined by further investigation. For example we assumed that birds defecated approximately 2.25% of their body weight per day. This assumption was applied to all species of birds, regardless of bird size, prey preference (e.g. piscivory or herbivory), or rates of metabolism. More research is needed to improve the accuracy and species specificity of this term.

We also assumed that 1.3% of the average goose dropping was phosphorus. Likewise, we assumed the nutrient concentrations reported by Manny et al. (1994) were similar for all other birds, whether herbivore or piscivore. This assumption should be investigated in future studies because it is likely that scaling TP contributions of herbivorous birds underestimates TP contributions from carnivorous birds (Marion et al. 1994).

We used assumptions and field observations to estimate p_1, thereby introducing a non-quantifiable amount of uncertainty. For future studies, we recommend an approach that would divide the lake into zones. Using the four zones, we could assume that the quantity of nutrients added to the lake from droppings was from: (a) the quantity deposited directly in the lake (for which $p_1=1.0$), (b) the quantity deposited on shore areas (proportional to the amount of time spent on shore areas, for which $p_1=k_1<1.0$), (c) the quantity deposited in areas beyond the perimeter of the lake (defined by a paved street, for which $p_1= k_2 \leq k_1<1.0$) and (d) the quantity deposited outside the boundaries of the watershed, for which $p_1=0$. We could then create proportionality constants (which could vary with time, according to changes in bird behavior) using proportions of time spent in each zone as a weighting factor.

$$\pi_{(spp)i} = \left[0.417 \sum_{j,k=1}^{j,k=4} t_j \cdot p_k \right]_i$$

in which: 0.417 is the denominator for weighting (1/24), $\pi_{(spp),i}$ represents the time-weighted proportion for species of waterfowl (spp) and month (i, January =1), t_i represents the average number of hours per day that geese were observed in zone j (j=1—4, as described above) and associated proportion k (as described above). This approach differs from that taken by Scherer et al. (1995).

The scope of our study was eight months, from February to October, 2006. We believe the scope of future studies should be conducted for at least one calendar year, so the impact of migratory species can be more accurately estimated. For example, migratory Canada geese reside on Virginia Lake during the winter months and our observations from 8 months likely underestimate their annual TP contributions to the lake. Simply averaging the monthly TP contributions to predict annual contributions may not provide adequate estimates for migratory species.

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Tables and Figures

Table 1. – Parameter values used to estimate nutrients contributed from bird guano. Body weights were taken from literature estimates. Where more than one estimate existed the highest estimate was used, a mid range value was chosen. The rate of guano production (D) is 2.25% of the body weight per day. The phosphorus (C_p) nutrient content of the guano is 1.3% percent of D. The proportions of bird droppings entering the lake (p_1) were derived observationally.

Common Name	Body Weight (Kg)	D (g)	Reference	p_1
American White Pelican	6.10	137.25	(Behle 1958)	0.8
American Coot	0.52	11.66	(Gullion 1952)	0.8
Canada Goose	3.63	81.68	(Terres 1987)	0.6
Chinese Goose	3.63	81.68	(Terres 1987)	0.7
Common Merganser	1.30	2.84	(Cramp and Simmons 1977)	1
Common Goldeneye	0.94	21.11	(Palmer 1976)	1
Double-crested Cormorant	2.00	45.00	(Palmer 1976)	0.9
Gulls	0.50	11.14	(Ryder 1978)	0.6
Hooded Merganser	1.30	2.84	(Cramp and Simmons 1977)	1
Mallard	1.20	27.00	(Krapu 1981)	0.6
Northern Shoveler	0.56	12.56	(Dubowy 1985)	1
Pigeon	0.25	5.63	(Scherer 1995)	0.4
Pied-billed Grebe	0.47	10.67	(Muller and Storer. 1999)	1
Ruddy Duck	0.48	10.78	(Euliss et. al. 1997)	1
Redhead	0.99	22.32	(Weller 1957)	1
Snowy Egret	0.37	8.30	(Palmer 1976)	0.9
American Wigeon	0.75	16.85	(Heitmeyer 1995)	1

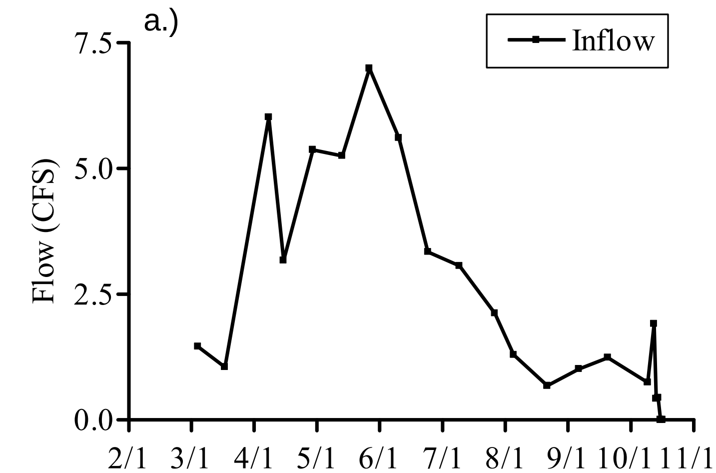
Table 2. – Results of depth integrated samples collected at an index station (fig. 1) in Virginia Lake, Reno, NV.

Date	TP-P (kg)	TSI	Secchi Depth (cm)	Temp (°C)	DO (mg/L)
2/17/05	15.4	72.7	54.0	5.1	11.3
3/4/05	10.9	67.7	75.0	8.7	10.9
3/17/05	9.1	65.0	210.0	10.1	8.5
4/4/05	9.1	65.0	196.0	9.9	11.4
4/19/05	7.9	62.9	202.0	11.1	
4/28/05	5.9	58.7	201.0	12.6	9.2
5/18/05	8.0	63.2	183.0	15.4	8.7
6/1/05	7.3	61.9	127.0	18.1	8.8
6/16/05	10.4	67.0	145.0	18.9	8.4
7/1/05	8.8	64.6	220.0	22.2	7.7
7/18/05	12.0	69.0		25.9	6.7
7/29/05	22.5		110.0	24.8	5.7
8/16/05	18.4	75.2	52.0	22.8	10.1
8/31/05	46.7	88.7	22.0	21.3	10.4
9/15/05	48.9	89.3	11.0	17.6	1.7
10/7/05	26.1	80.3	40.0	14.6	6.3

Table 3. – Nutrient contributions to Virginia Lake estimated for each species or for a group of species (e.g. gulls), in kilograms. Estimates are for the eight month period of study from February to October, 2005.

Common Name	**2/15**	**3/15**	**4/15**	**5/15**	**6/15**	**7/15**	**8/15**	**9/15**	**10/15**	**Total (kg)**
American Coot	0.03	0.14	0.10	0.01		0.01	0.02	0.03	0.06	0.40
American White Pelican						0.01				0.02
American Wigeon									0.01	0.02
Canada Goose	0.72	1.28	0.25	0.35	0.46	0.49	1.42	0.75	2.32	8.04
Chinese Goose	0.01	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.40
Common Goldeneye		0.01								0.01
Common Merganser	0.02	0.07	0.01	0.02	0.01	0.03	0.03	0.03	0.13	0.36
Double-crested Cormorant	0.03	1.14	1.49	1.92	2.41	1.83	1.06	0.25	0.26	10.39
Hooded Merganser	0.02	0.13								0.15
Mallard	0.21	1.16	0.96	0.26	0.45	0.93	1.28	1.15	0.85	7.24
Northern Shoveler								0.03	0.03	0.06
Pied-billed Grebe									0.01	0.01
Pigeon	0.01	0.04	0.06	0.02	0.04	0.04	0.02	0.03	0.04	0.28
Redhead									0.01	0.01
Ruddy Duck	0.02	0.12	0.04				0.01	0.01	0.01	0.21
Snowy Egret					0.01	0.01	0.02	0.01		0.04
Gulls	0.12	0.37	0.86	0.43	0.37	0.53	0.19	0.17	0.31	3.35
Total Phosphorus (kg)	1.16	4.35	3.80	3.04	3.78	3.90	4.06	2.48	3.99	31.00

Figure 1. –Virginia Lake, Reno, NV.



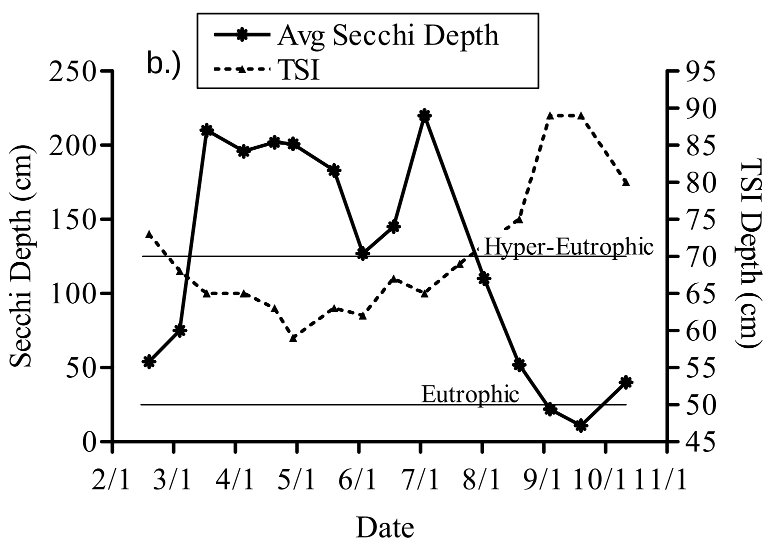
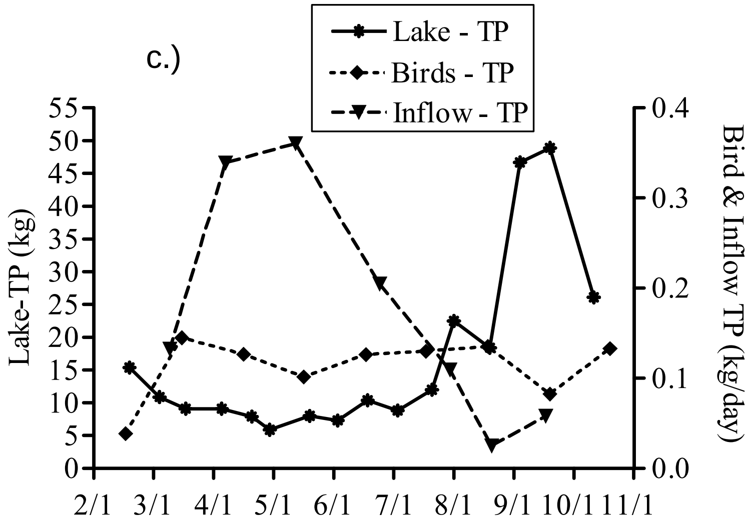


Figure 2a-d. – Measurements for a.) Inflow, b.) Secchi Depth, c.) Total Phosphorus (TP) and d.) Dissolved Oxygen (DO) at Virginia Lake between February 17, 2005 and December 29, 2005.



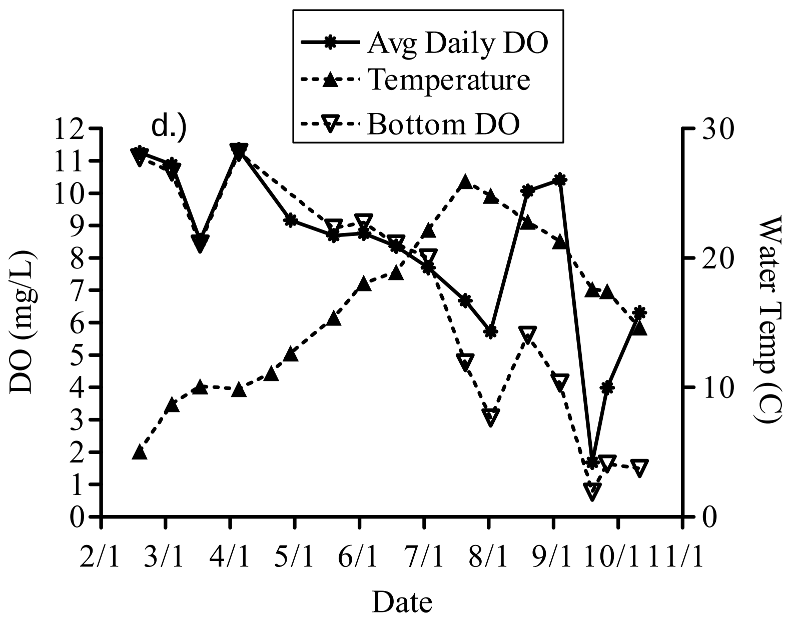


Figure 2a-d (cont’d).

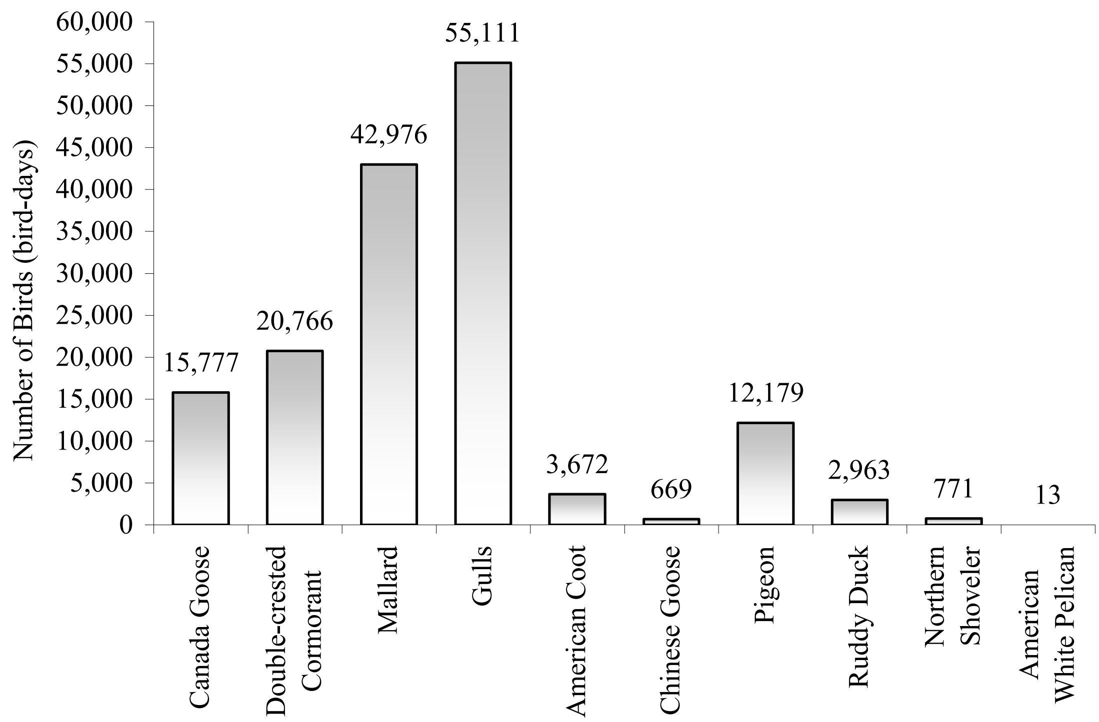


Figure 3. – Estimates for the total number of bird-days, by species or by a group of species from February to October, 2005.

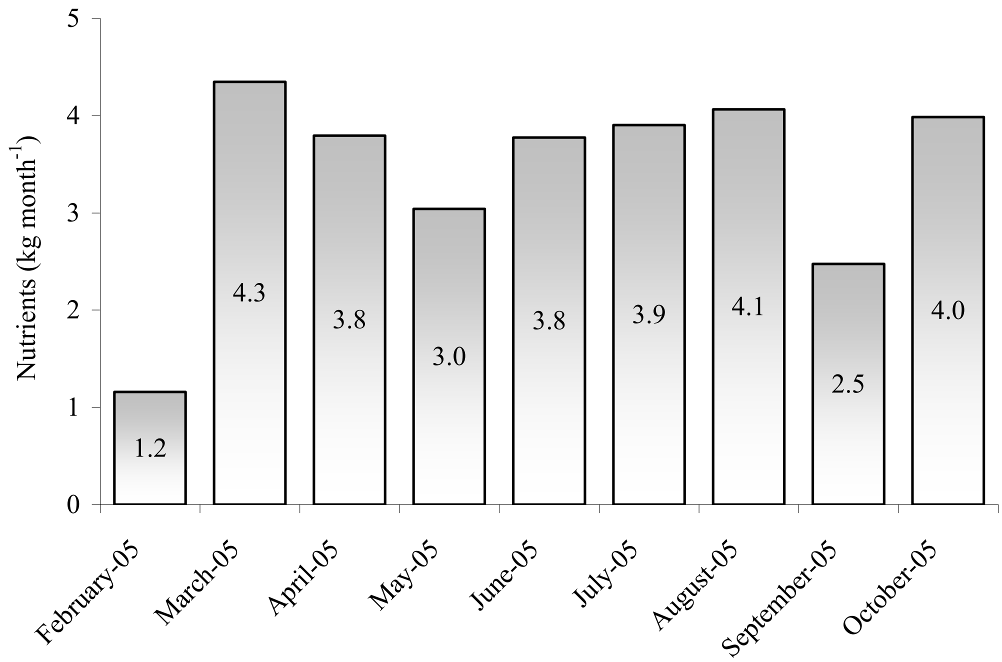


Figure 4. – Estimated monthly TP loads from birds to Virginia Lake, Reno, NV, from February to October, 2005.

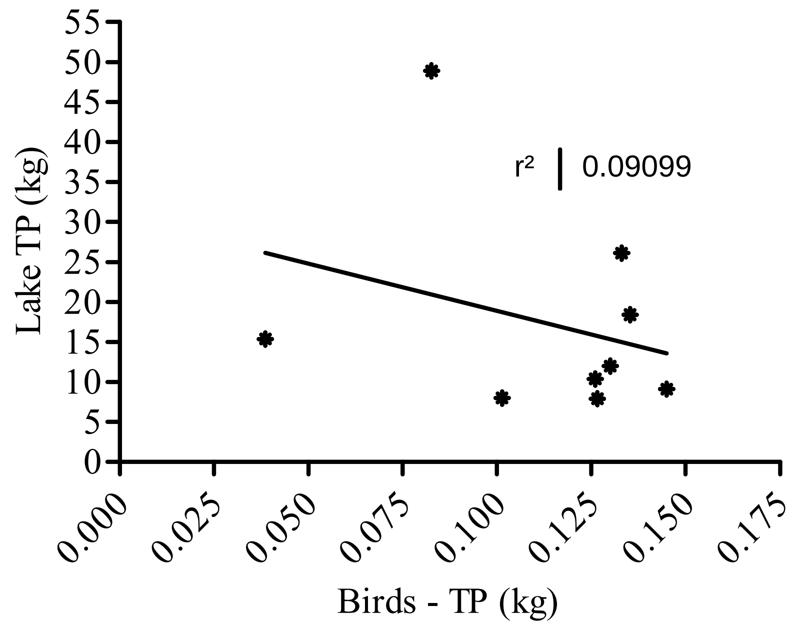


Figure 5. Regression analysis of TP measured in Virginia Lake with TP estimates from birds.

Chapter 2: Impact of Double-crested Cormorants On Rainbow Trout Stocked In An Urban Lake

Abstract

Double-crested cormorants (*Phalacrocorax auritus*) were suspected to have impacted a stocked rainbow trout (*Onchorhyncus mykiss*) fishery in Virginia Lake, Reno, NV. To estimate consumption of rainbow trout by double-crested cormorants, we released 2,248 marked trout into the lake on three occasions, spaced about 1 month apart. We then sampled a cormorant nesting island in the lake weekly following each release to recover tags of rainbow trout eaten by double-crested cormorants. We used band recovery models and temporal symmetry capture-mark-recapture models in program MARK to estimate predation rate on rainbow trout and monthly survival probability of rainbow trout. Using Brownie et al. (1985) tag recovery models, we estimated that 19% (95% CI: 14-26%) of rainbow trout survived from the first to the second stocking event, while only 4% (95% CI: 2-9%), of rainbow trout survived from the second to the third stocking event. The probability of recovering a tag increased from 3% (95% CI: 2-4%) to 27% (95% CI: 24-30%) from the first to the second stocking event, then declined to 18% (95% CI: 16-21%), on the third stocking event. Double-crested cormorants recolonized the island between the first and second stocking events. We estimated that the probability of encountering a tag on the island, conditioned on the tag being deposited on the island, decreased from 49% (95% CI: 42-55%) to 32% (95% CI: 26-38%) after the

second and third stocking events, respectively. We also estimated that 48% (95% CI: 47-49%) of tags eaten by double-crested cormorants were deposited on the island. Overall, we estimated that the probabilities of a rainbow trout being eaten by a double-crested cormorant after the second and third stocking events were 1.14 (95% CI: 1.00-1.28) and 1.18 (95% CI: 1.03-1.32). Our very low survival estimate (0.04) for rainbow trout, combined with our high harvest estimate (≥ 1.0), were consistent and suggested that double-crested cormorants consumed virtually all stocked fish, once double-crested cormorants had returned to the lake.

Introduction

Urban fisheries have been drawing attention from user groups and resource managers. The attention has in large part been due to their value as proximate and easily accessible recreational resources in urban areas. In 2005, the United Nations estimated that 80% of Americans lived in urban environments, with the percentage increasing to 87% by 2030 (U.N., 2008). Urban lakes provide fishing opportunities to people who may be unable or unwilling to travel far to fish. Twenty nine percent of Americans 16 years and older fish recreationally (The Interagency National Survey Consortium, 2005), and Fletcher and King (1988) found that travel distance was an important consideration to 29% of inland anglers in California.

However, the viability of fish in urban lakes can be a concern. In particular, double-crested cormorants (hereafter cormorants) have been known to impact rainbow trout populations. Cormorants prey on wild, managed and cultured fisheries (Schramm, French et al., 1984; Derby and Lovvorn, 1997; Elrod, 1997; Glahn, Rasmussen et al., 1999; Collis, Roby et al., 2001; Collis, Roby et al., 2002; Glahn and Dorr, 2002; Johnson, Ross et al., 2002; VanDeValk, Adams et al., 2002; Ryan, Smith et al., 2003; Schreck, Stahl et al., 2006). Modde and Wasowicz (1996) found that cormorants had a much greater predatory effect on a population of stocked rainbow trout than on a more abundant fish species (i.e., Utah chub, *Gila atraria*). Despite these and other studies, Trapp et al. (1999) concluded that cormorants have a minor affect on sport fisheries with localized exceptions. The U. S. Fish and Wildlife Service (2003) also concluded that predatory impacts from cormorants were site-specific and localized, with the effect to local fisheries being most significant in artificial, highly managed situations.

Other studies have indicated that cormorants are important predators of stocked rainbow trout. On the Platte River, Wyoming, Derby and Lovvorn (1997) showed that stocked rainbow trout consumption increased from 17% of a cormorant's diet before stocking to 60% post introduction. Modde and Wasowicz (1996) showed that stocked sub-adult rainbow trout in Minersville Reservoir, Utah, comprised 75% of the diets of the cormorants sampled, even in the presence of a more abundant species, Utah chub.

This study estimated survival of stocked rainbow trout in a small urban lake, and harvest of these fish by anglers and cormorants during 2006. Our approach represented a unique application of existing band recovery models (Brownie, Anderson et al., 1985) combined with capture-mark-recapture (CMR) models (Pradel, 1996). We utilized band recovery models to estimate survival of rainbow trout between monthly stocking events and recovery rate of tags from fish eaten by cormorants. Additionally, we double-tagged fish to estimate the proportion of tags consumed by cormorants that were deposited on the primary nesting island for cormorants. We then used CMR methods to estimate rate of deposition of tags on the island, persistence of tags, and the probability of detecting a tag, conditional on the tags being on the island. We used parameter estimates from both models to estimate the harvest of rainbow trout by cormorants. This approach differs from previous studies, in that bio-energetic data, materials egested from cormorants (i.e. pellets, boli, defecation) and cormorant stomach contents were not used to estimate harvest.

Methods

Study Site: Virginia Lake is a man-made lake located within the City of Reno, Nevada, USA (Fig. 1). The 9 hectare lake was constructed in the 1930's and was intended to provide a facility for swimming, boating, fishing, and skating (WPA, 1938). Like most urban lakes, Virginia Lake is shallow (max depth = 3 m, mean depth = 1.6 m). There is an inlet at the north end of the lake and source water originates from the Truckee River. There are two outlets at the north eastern shore of the lake.

The fishery has been maintained by regular stocking. Since 2000, the Nevada Department of Wildlife (NDOW) has stocked more than 52,000 rainbow trout in the lake. In recent years, stocking has decreased due to the lack of successful catch by the urban angler. NDOW managers were reluctant to continue stocking the lake because of their belief that cormorants (*Phalacrocorax auritus*) were depleting the Virginia Lake rainbow trout fishery (Warren, 2004).

A 500 m^2 island near the southwestern end of the lake hosts a breeding colony of about 125 adult cormorants during the peak of the breeding season. Cormorants have not been observed roosting anywhere else around the lake. Based on informal observation, managers from NDOW believed that the local breeding population increased in the late 1980s, and by the 1990s, NDOW became concerned about cormorant consumption of stocked rainbow trout in the lake. Cormorants are pursuit piscivores and can easily dive to depths greater than the maximum depth of Virginia Lake to acquire prey (Ross, 1976).

Rainbow Trout Tagging: Rainbow trout were marked with T-bar anchor tags (Nielsen, 1992) (hereafter referred to as tags), each with a unique identifying number and released in the lake in 2005 and 2006 (Tables 2,3). Marking took place less than 48 hours before stocking. At the time of stocking, we recorded fork length of each fish. Palmer (1962) reported that cormorants eat fish in the size range 30 – 400 mm and prefer fish less than 150 mm. At the time of stocking, rainbow trout were within the ingestible range (average length = 241 mm) for cormorants. In 2005, 4,023 tagged rainbow trout were stocked in Virginia Lake (April 14, May 12, May 26 and September 16). Four hundred seventy five of those rainbow trout were double-tagged with the intention of estimating tag loss rate (described below). During Spring 2006, approximately 750 rainbow trout were stocked on each of three separate occasions (n = 2,248) in Virginia Lake (Table 3).

Estimates of numbers of cormorant: We counted the number of cormorants at the lake approximately every two days. For our counts, we divided the lake into quadrants and counted all birds with 8 x 40 binoculars. Bird counts were primarily conducted in the late afternoon before sunset. For our analysis, we sought estimates of the number of birds present on each day of the month. For days with no data estimated numbers were based on observations from previous bird counts.

Fish Sampling: Cormorants consume a variety of fish species, so we conducted an intensive fish sampling effort to characterize the fish community in the lake. From March 22, 2005, to September 14, 2005, we collected fish from Virginia Lake using electrofishing, experimental Swedish gill nets, modified fyke nets and creel surveys. When samples produced less than 30 fish, we measured and recorded species fork length and mass of all fish captured. When samples exceeded 30 fish or if fish exhibited stress, species were counted and released without measuring other parameters. All rainbow trout were tagged and released, unless they were recovered dead or too stressed to withstand processing. Creel surveys were performed semi-daily and flyers were posted around the lake, asking anglers to report tagged fish. Fork lengths of tagged rainbow trout were recorded when possible and compared with lengths taken at the time of stocking.

Tag Recovery: Prior to stocking in 2006, a grid with $3m^2$ cells was placed on the island to help quantify tags. Once a week, from March 10, 2006, until May 19, 2006, each grid cell was sampled for tags. Sampling one grid cell at a time reduced the likelihood of double counting or overlooking tags. Tags found on each sampling occasion were identified, recorded and then returned to where they were found. Our approach differed from that of Collis et al. (2001) and Ryan et al. (2003) in which egested passive integrated transponders were recovered and removed from cormorant breeding colonies. By replacing tags, we made them available for subsequent sampling. In this way, we treated tags on the island as marked individuals that could be relocated, which allowed us to estimate the appearance rate of tags on the island, the probability of a tag surviving on the island between sampling occasions, and the probability of finding a tag present on the island.

Estimating Survival Rates: We used classic band recovery models (Brownie, Hines et al., 1986) to estimate survival of stocked rainbow trout between stocking events based on the recovery rate of tags on the island. We defined a tag recovery (n = 402) as finding a tag on the island, which was assumed to represent a consumed rainbow trout.

In our study, recovery rate was the product of three other probabilities: the probability that a tagged rainbow trout was consumed by a cormorant, the probability that the tag was deposited on the island, and the probability that the tag was found on the island conditioned on having been deposited. We included only tags found during the first two sampling occasions after each stocking event (i.e. the first ten days after each stocking event were pooled) to reduce heterogeneity in recovery rate associated with continuous sampling (Williams et al. 2002). We also assumed that rainbow trout did not emigrate from the lake, that a tag found on the island could only be deposited there by a cormorant, that recoveries were most likely over a relatively short period of time following stocking, and that the fate of each marked rainbow trout was independent of the fate of other marked rainbow trout in the lake (Brownie, Anderson et al., 1985).

In our analysis, we used Program Mark (White and Burnham 1999) to consider models that allowed both survival (S) and recovery rates (f) to vary with time ($S_t f_t$), where time corresponded to stocking events and the intervals between them. For example, f_1 was the recovery rate following the first stocking event, while S_1 was the probability of surviving from the first to the second stocking event. We also considered more constrained models in which survival, recovery rates or both parameters were constant with respect to time: models Sf, Sf_t, $S_t f$, $S_t f_t$, where the subscript “t” defined a model parameters with time dependence.

We used Pradel capture-mark-recapture CMR models (Pradel 1996) to estimate the probabilities of encountering a tag on the island conditional on the tagged fish having been consumed and the tag deposited on the island and the probability that a tag on the island remained available to be found from one sampling occasion to the next (survival in the traditional sense). Pradel (1996) models also allow the estimation of the probability that a tag present on one sampling occasion was present during the preceding sampling occasion, called seniority by Pradel (1996). The complement of seniority was the probability that a tag was deposited on the island between two sampling occasions.

We estimated the probabilities of encountering a tag present on the island during one of the first two searches of the island following the second stocking of the lake (*P(EN₂)*) as follows:

$$P(EN_2) = p_{21} * \gamma_{22} + \gamma_{22}(1 - p_{21}) * \phi * p_{22} + (\gamma_{23} - \gamma_{22}) * p_{22}, \qquad (2)$$

in which p_{ij} was the probability on the *j*^th island visit following the *i*^th stocking event, γ_{ij} was the probability a tag was present on the visit before the j^{th} island visit following the i^{th} stocking event, and ϕ was the probability a tag remained on the island available to be sampled between weekly searches. The probability of encountering a tag during the first two visits to the island after the third stocking *(P(EN₃))* was:

$$P(EN_3) = p_{31} * \gamma_{32} + \gamma_{32}(1 - p_{31}) * \phi * p_{32} + (\gamma_{33} - \gamma_{32}) * p_{32} \qquad (3)$$

These equations combine the probabilities of three events for the i^{th} stocking; (1) tags were present and detected on the first visit $(p_{i1} * \gamma_{i2})$; (2) tags were present and not detected on the first visit but detected on the second visit $(\gamma_{i1}(1 - p_{i1}) * \phi * p_{i2})$; and (3) tags were deposited between the first and second visit and detected on the second visit $(\gamma_{i3} - \gamma_{i2}) * p_{i2}$.

For our Pradel analysis, we used Program Mark to consider models that allowed survival, detection probability and seniority to vary with time (i.e., across stocking events and searches of the island) following a given stocking event. We also considered simpler models where parameters were independent of time and where parameters were fixed. For all of our models we applied a logit link for parameter estimation. We evaluated models for the Brownie and Pradel analyses using Akaike's Information Criterion (AIC) (Burnham and Anderson, 1998; Cooch and White, 2005).

We calculated the proportion of second tags deposited on the island conditional on finding a first tag from the same fish. The first tag indicated that the fish had been consumed by a cormorant. Thus, the second tag allowed us to estimate the probability that the tag from a rainbow trout was deposited on the island, conditional on the fish having been consumed. This calculation required three assumptions. First, the probability of deposition of each of two tags from a double tagged fish was independent of the other. Second, both tags from the same fish had the same detection probability. Third, tags were not lost during the study. Sensitivity analysis was conducted on the *deposition* parameter by estimating the percent change in our final estimate of harvest, given a 5% and 20% change in deposition on the island. Finally, we used the probability that a tag was deposited on the island combined with estimates of tag recovery rates estimated from Brownie models and the probability we found a tag from CMR models to estimate total proportion of rainbow trout eaten by cormorants.

Results

Fish Population Composition: Tui chub (*Gila bicolor*) and green sunfish (*Lepomis cyanellus*) comprised 89% of the fish sampled in the lake, with fork lengths averaging 84 $\pm$36 mm and 81 $\pm$41 mm, respectively (Table 1). The next most abundant fish was rainbow trout (3%), which had an average fork length of 363 $\pm$ 76 mm.

Fathead minnows (*Pimephales promelas*) and common carp (*Cyprinus carpio*) comprised 3% and 2% of the overall catch, respectively. Collectively, channel catfish, bow-cutts and Tahoe suckers (*Catostomus tahoensis*) comprised only 2% of the total fish sampled in the lake (Table 1).

In spring and summer of 2006, 13 tagged rainbow trout were reported by anglers. We distinguished between rainbow trout that had been reported by anglers in 2006 and stocked in 2005 from rainbow trout caught and stocked in 2006 (Table 2). Of the three stocking events in 2005 (two spring, one late summer), no tags were reported from the two spring stocking events. More than half of the total tags reported in 2006 were from rainbow trout stocked on the third stocking event in 2005.

Consumed Trout: Of the 2,248 rainbow trout stocked in the lake in 2006, tags from 402 rainbow trout were found on the island. Within the first ten days of the first stocking event, 19 tags were found on the island, while 202 and 137 tags, all from unique fish, were found within the first ten days following the second and third stocking events, respectively (Table 3).

For the Brownie analysis, model selection favored a model in which rainbow trout survival and tag recovery rate varied with time (S_t,f_t) (Table 4). Survival estimates (probabilities that a trout would survive) from the Brownie model decreased from 0.19 (95% CI: 0.14-0.26; SE: 0.01) to 0.04 (95% CI: 0.02-0.09; SE: 0.02) between the first and second, and the second and third stocking events, respectively. We also estimated that the probability of recovering tags increased by an order of magnitude, from 0.03 (95% CI: 0.02-0.04; SE: 0.01) after the first stocking event to 0.27 (95% CI: 0.24-0.30;

SE: 0.02) after the second stocking event. Following the third stocking event, tag recovery rate declined to 0.18 (95% CI ± 0.16-0.21; SE: 0.01).

For the Pradel analysis, the best supported model was one in which tag survival on the island was constant and seniority exhibited a positive linear trend (i.e., seniority probabilities increased over time) across sampling occasions following each stocking event (Table 5). We allowed encounter probabilities to be fully time dependent except the first encounter probability. The encounter probability following the first stocking event was fixed at 0, because we recovered no tags on the first sampling conducted after the first stocking event. We first considered a more general model (ϕ_t, p_t, γ_t) in which all of the parameters were time dependent. However, the model-fitting algorithm did not converge and 14 of 21 parameters were not estimated. We fixed γ_1 to 0 because it could not be properly estimated, given p_1 was constrained to 0. A model with full time dependency in seniority also failed to converge. We also considered a model in which seniority probabilities were additive across stocking occasions. That is, tags that survived the first stocking event could have influenced seniority estimates following the second and third stocking events. This model received relatively little support (ΔAIC = 2.6, Akaike weight = 0.09). We also hypothesized that seniority probabilities could be time dependent following a given stocking event, but equal for the i^{th} sampling occasion following a stocking event (e.g. $\gamma_{1i} = \gamma_{2i} = \gamma_{3i}$). This model ($\phi$, $p_{1,t}, \gamma_{1,t,g1}$) was selected for use on the basis that it exhibited a low ΔAIC (0.64) and it had consistent real parameter estimates (13 parameters estimated) (Table 5).

Seniority estimates, calculated from the selected Pradel model, which followed each of the three stocking events, indicated that 0.93 ± 0.14 of the tags found on the third sampling occasion had already been on the island on the previous sampling occasion. All of the tags found on the fourth sampling occasion following each stocking event were present on the third occasion (Table 7). The probability that a tag survived on the island from each sampling occasion to the next, was 0.65 ± 0.03. Probabilities of encountering tags after the first sampling occasion ranged from 0.10 ± 0.03 to 0.48 ± 0.04.

Using parameter estimates from the selected Pradel model (Table 6) and Equations 1 and 2, we estimated our probability of finding a tag was greater after the second stocking event (0.49 (95% CI: 0.43-0.55)) than after the third stocking event 0.32 (95% CI: 0.26-0.38). We did not produce estimates following the first stocking event because data were too sparse (e.g. no tags were found on the first sampling occasion).

We found tags from 79 double tagged rainbow trout on the island. Of the 79 trout, 38 paired tags were found on the island indicating that second tags had a probability 0.48 (95% CI: 0.47-0.49) of being deposited, given that a first tag was deposited. Sensitivity analysis showed that a 5% change in the estimate of deposition probability would cause a 5% change in our estimates of harvest by cormorants and a 20% change in deposition would cause a 17% change in harvest estimates.

Using our estimates for probability of recovering tags, the probability of encountering tags deposited on the island, and probability a tag from a harvested rainbow trout was deposited on the island, we estimated the probability that a rainbow trout was consumed by a cormorant after stocking events two and three:

$$P\ (\text{Consumed}_2) = (0.27/\ (0.48 * 0.49)) = 1.14\ (95\%\ \text{CI: } 1.00\text{-}1.28) \quad (1)$$

$$P\ (\text{Consumed}_3) = (0.18/\ (0.48 * 0.32)) = 1.18\ (95\%\ \text{CI: } 1.03\text{-}1.32) \quad (2)$$

Where, P (Consumed_2) and P (Consumed_3) were our estimate of the probability that a rainbow trout from the second and third stocking events, respectively, was consumed by a cormorant. Thus, since it is impossible to harvest more than 100% of stocked fish, we estimated that following both stocking events, 100% of the stocked rainbow trout were consumed by cormorants.

Cormorants were just beginning to recolonize the island before the first stocking event, as is evident by bird counts (Fig. 2). We observed a seasonal pattern of arrival, beginning in March, and departure, beginning in August. The average number of cormorants present after the initial stocking event was 48, ranging from 19 to 64 (Table 3). Following the next two stocking events, the average number of cormorants increased to 102. Tag recovery rates were positively associated with cormorant abundance, while rainbow trout survival was negatively associated with cormorant abundance (Fig. 3).

Discussion

We estimated that virtually all of the rainbow trout stocked in Virginia Lake during Spring, 2006 were consumed by cormorants, once the cormorant population had reached about 70% of peak levels. Cormorant abundance increased threefold between our first and second stocking events. The temporal association among increased cormorant numbers, increased tag recovery and reduced rainbow trout survival is certainly consistent with the hypothesis that cormorants substantially reduced rainbow trout survival. Our estimates of predation rate by cormorants are also consistent with our direct estimate of 96% mortality of rainbow trout between the second and third stocking events, based on Brownie tag recovery models.

Seniority estimates provided indirect evidence that the presence of cormorants affected the survival of rainbow trout in the lake. Ninety two percent of the tags from stocked rainbow trout that eventually reached the island were present on the island within 10 days of the stocking event. That is, cormorants consumed 92% of the rainbow trout they would eventually eat within 10 days of a rainbow trout being stocked. When combined with our very low estimates of survival between the second and third stocking events and our estimates of harvest (≥ 1.0, or 100% of stocked fish), it appears that once the local cormorant population stabilized, they rapidly consumed the stocked rainbow trout in Virginia Lake.

Our Brownie analysis estimated that a small proportion of rainbow trout survived from one stocking event to the next, which might be the result of cormorants switching to more abundant prey species (Roselaar, 1979) or the result of learned-predator avoidance by surviving rainbow trout (Leduc, 2007). Based on tags and boli found on the island, we observed that cormorants also ate green sunfish and tui chubs. Because we did not mark other fish or analyze gut contents of cormorants, however, we did not estimate consumption rates of alternative prey. We could not, therefore, determine if cormorants did in fact switch prey items. However an alternative food source would have been necessary after stocked rainbow trout were eliminated from the lake. Double crested cormorants probably did not fledge young until June, indicating they used alternative prey after rainbow trout were depleted in early May.

Anglers had a minimal effect on the Virginia Lake rainbow trout fishery; out of the 2,248 rainbow trout stocked in 2006, only six catches were reported. From these sparse creel data more than half of the tags reported by anglers in 2006 were from rainbow trout that had been stocked the previous Fall (n = 7) (Table 1) and the average fork length of rainbow trout reported by anglers from Fall, 2005 was 378 mm, which may be close to the maximum size a cormorant can ingest (Palmer, 1962). This suggests the possibility that rainbow trout stocked in the Fall (when cormorants are generally not present) can grow beyond the size where they are vulnerable to cormorant predation before cormorants return in Spring. Thus, a fall stocking regime might reduce loss of stocked fish due to immediate predation, because most of the cormorants have already emigrated out of the area for the season thereby allowing rainbow trout time to grow sufficiently large to escape cormorant predation the following spring.

Our analyses could be refined significantly by addressing two aspects of the models that were uncertain. First, the sample of second tags deposited on the island was relatively small (38 tags), reducing precision of our estimates of the proportion of tags deposited on the island. Second, we could not validate the assumption that deposition of both tags from double tagged rainbow trout was independent of each other. If probability of deposition positively co-varied for tags from the same fish, we overestimated deposition of tags on the island and underestimated harvest rate. Conversely, if tags were lost we underestimated deposition of tags on the island and overestimated consumption by cormorants.

Our study indicated that the current practice of stocking rainbow trout in Spring is ineffective at providing angler opportunity because of competition with cormorants. Based on seniority estimates, anglers have only a narrow window of time to catch fish (about two weeks) before cormorants harvested nearly all of the rainbow trout stocked in the lake. We also demonstrated the effectiveness of cormorants as predators on rainbow trout below 400 mm fork length in a relatively shallow lake of limited size. Based on the presence of abundant and edible alternative species of fish in the lake, we can speculate that the cessation of stocking rainbow trout in the lake would have little effect on the local cormorant population. For managers, these findings are sufficient to suggest alternative management practices, e.g. stocking rainbow trout in Fall. The Virginia Lake system also lends itself to more detailed studies of foraging behavior by cormorants and predator-prey dynamics in a well defined system.

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Tables and Figures

Table 1. – Species assemblage and average fork lengths from March 22 to September 1, 2005. Fork length means ($\bar{x}$), sample sizes (n), standard deviations (SD) and the sub-sample sizes used for mean fork length calculations (n_f) are reported.

Species	Capture Method	Fork lengths at the time of capture (mm)			
		$\bar{x}$	SD	n	n_f
Tui chub	MFN[a], G[b], EF[c]	83	34	450	46
Green sunfish	MFN, G, EF	80	41	217	33
Rainbow trout	MFN, G	362	75	25	25
Fathead minnow	EF	45	8	23	20
Common carp	MFN, G, EF	640	128	17	14
Channel catfish	G, EF	469	71	9	9
Bow-cut (hybrid)	MFN, G	452	58	8	6
Tahoe sucker	TN	138	0	1	1

[a]Modified fyke nets (MFN) were deployed for 160 hours

[b]Gill nets (G) were deployed for 362 hours

[c]Electrofishing equipment (EF) was used for 3 hours

Table 2. – Number of tagged rainbow trout stocked in Virginian Lake, Reno, NV, during fall 2005 and spring 2006. Number of tagged rainbow trout caught by anglers during 2006 from each stocking period. We report fork lengths of stocked fish and those caught by anglers.

Marking events (2005-2006)	Fork lengths of stocked rainbow trout (mm)			Fork lengths of rainbow trout reported by anglers, 2006 (mm)		
	$\bar{x}$	n	SD	$\bar{x}$	n	SD
Summer, 2005	218	3024	24	NA	0	0
Fall, 2005	264	999	24	378[a]	7	51
Summer, 2006	241	2248	26	347[b]	6	53

[a] Calculations from five trout. Seven trout were reported; two without lengths.

[b] Calculations from three trout. Five trout were reported; two without lengths.

Table 3. – Rainbow trout released on each marking occasion (n = 2,248), and number recovered after stocking events (n = 402).

Marking occasion	Rainbow trout released	Recovery period 1.	Recovery period 2.	Recovery period 3.
March 6, 2006	751	19	37	3
March 27, 2006	748		202	4
April 25, 2006	749			137

Table 4. – Model selection for Brownie (Brownie, Anderson et al., 1985) models generated by MARK, which estimate recovery (f) and survival (S) rates for marked rainbow trout in Virginia Lake, Reno, NV, 2006. Model notation shows each parameter S and f as time dependent (t) or time independent (.). Table includes AIC estimates (Burnham and Anderson, 1998), model weights and the number of model parameters estimated.

Model	AIC_c	ΔAIC_c	Model Weights	Model Parameters
S_t,f_t	2,154.42	0.00	1.00	5
S.,f_t	2,168.56	14.14	0.00	4
S_t,f.	2,356.97	202.55	0.00	3
S.,f.	2,376.71	222.29	0.00	2

Table 5. – Model selection for Pradel models generated by MARK, which estimate apparent tag survival (ϕ), detection (p), and seniority (γ) for marked rainbow trout in Virginia Lake, Reno, NV, 2006. Subscripts are defined below.

	Model[a]	AICc	ΔAICc	AICc Weights	NP	Deviance
Selected model	ϕ,p_t,γ_t	3354.58	0.00	0.42	14.00	146.62
	$\phi,p_{t1},\gamma_{t1,g1}$	3355.22	0.64	0.30	13.00	149.33
	ϕ,p_t,γ_{t1}	3356.46	1.88	0.16	15.00	146.42
	$\phi,p_{t1},\gamma_{t1,g2}$	3357.23	2.65	0.11	14.00	149.27
General time dependent model	ϕ_t,p_t,γ_t	3367.38	12.80	0.00	21.00	144.71
	ϕ,p_t,γ	3435.40	80.82	0.00	12.00	231.59
General time independent model	ϕ,p,γ	3854.64	500.06	0.00	3.00	669.23

a Model notation generally followed text in Lebreton et. al. (1992

t Time-dependence among sampling occasions

1 First parameter fixed (0)

g1 Sampling occasions grouped among marking occasions, but constrained to the same additive slope.

g2 Sampling occasions grouped among marking occasions, but not constrained to the same additive slope.

Table 6. – Parameter estimates and standard errors for the selected Pradel model, $\phi, p_{1,t}, \gamma_{1,t,g1}$. Subscripts denote time periods after sampling events.

Label	Estimate	Standard error
ϕ_{ij}	0.65	0.03
ρ_{11}	0.00	0.00
ρ_{12}	0.10	0.03
ρ_{13}	0.42	0.08
ρ_{21}	0.26	0.05
ρ_{22}	0.48	0.04
ρ_{23}	0.44	0.05
ρ_{24}	0.27	0.05
ρ_{31}	0.22	0.04
ρ_{32}	0.22	0.04
ρ_{33}	0.15	0.03
ρ_{34}	0.10	0.03
γ_{11}	0.00	0.00
γ_{12}	0.93	0.14
γ_{21}	0.18	0.03
γ_{22}	0.93	0.14
γ_{23}	1.00	0.01
γ_{24}	1.00	0.00
γ_{31}	0.18	0.03
γ_{32}	0.93	0.14
γ_{33}	1.00	0.01
γ_{34}	1.00	0.00

Figure 1. – Virginia Lake, Reno, NV

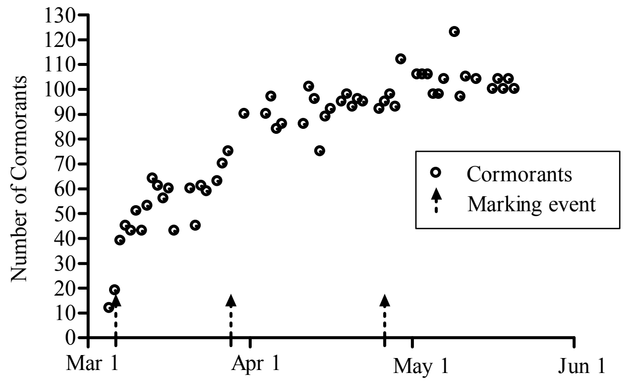

Figure 2. –Cormorant counts (N = 402) and marking events.

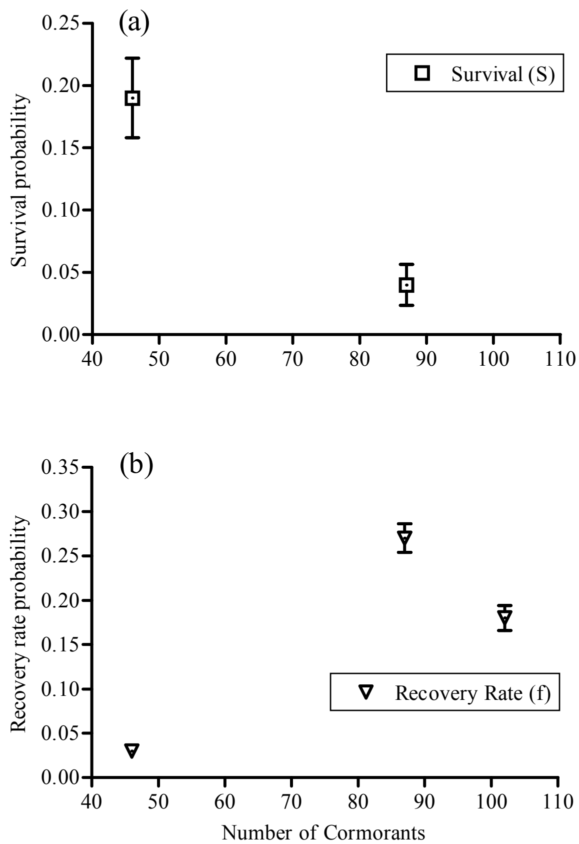

Figure 3. -- Brownie model estimates of rainbow trout survival (a) and tag recovery (b) versus the number of cormorants counted at Virginia Lake, Reno, NV, 2006.

Chapter 3: Discussion

For centuries, humans have been sculpting the environment around them, in a way that makes them feel closer to the environment. For example, city parks and lakes can provide access to a managed version of wild nature within the context of urban convenience, comfort, control and safety. When comparing city parks to urban lakes, an urban lake is to a natural lake as a landscaped terrestrial park is to a wild grass meadow. One of the challenges of creating such environments is managing and maintaining them in a way that meets the expectations that users have of analogous natural systems. However, unlike natural systems, urban environments are constructed on a much compressed time scale without the complex ecological influences that exist in natural systems. As a result, created environments such as urban lakes present significant challenges that arise from blending human abilities to construct and control some aspects of the environment (for example, building and stocking a small lake) with those that are much more difficult to control (for example, influences of migratory birds).

Our study investigated the nutrient contributions from birds to an urban lake and the interactions between migratory bird communities and a stocked population of rainbow trout. Both investigations were, in essence, a study of the interactions between birds and human society. The conclusions derived from our study are intended to benefit society by providing resource managers with information and recommendations.

We also modeled the amount of TP loaded to Virginia Lake by birds. Our model combined estimates of bird use, defecation rates, nutrient content of feces and the source of nutrients. Our results showed that birds were a large source of TP to the lake that exceeding the amount contributed by Truckee River inflow. High and temporally fluctuating in-lake masses of TP were also measured in the lake. The in-lake mass of TP did not correlate to TP loads contributed by inflow or birds, which implied another source of P, possibly internal loading.

Like the predation models, our TP loading estimates also provided useful data to resource managers. In addition to identifying birds as a source of TP and even larger masses of in-lake P, we observed people supplying large amounts of bird seed and bread to the diets of resident and migratory birds at the lake. Similar to the way ducks, geese, pigeons and gulls took advantage of bird seed and bread from people, cormorants took advantage of another anthropogenically subsidized food resource, stocked rainbow trout.

Our work investigated a community of piscivorus birds (double-crested cormorants) and modeled the predatory effect on a population of stocked rainbow trout. We estimated cormorants ingested 100% of the rainbow trout stocked in Virginia Lake. By modeling the number of stocked rainbow trout eaten by cormorants and making fisheries management recommendations based on our estimates from observation and modeling, we provided a service to NDOW and the citizenry affected by management decisions. Our modeling approach was a unique extension and combination of other modeling approaches and should provide insights about management to resource managers, especially with respect to enhancing stocking success by releasing fish when the cormorant population is at a minimum. We used band recovery and CMR parameter estimates to construct an ad hoc model, which estimated harvest of rainbow trout by cormorants.

We regard our predation modeling work as an innovative and successful study, with results that are very useful to lake managers. However, like most first time studies, our approach could be improved. For example, it would be useful to develop a more precise way of estimating the rate at which cormorants deposited tags on the island. Our estimate of deposition was based on the ratio of tags from double-tagged fish encountered on the island, but we could not validate the assumption of independence of deposition of both tags from double tagged rainbow trout was independent of each other.

Although our TP loading investigation did not identify or estimate all of the TP sources to the Virginia Lake, we feel that our investigation helped identify a nutrient loading problem at the lake. That is, we identified a large, fluctuating reservoir of TP in the lake. More research is needed to identify and estimate the additional nutrient sources. In addition, future studies can improve upon our TP loading work in a number ways. For example, our limited technical resources caused us to make numerous model assumptions and generalizations (see Chapter Two). Those assumptions and generalizations included the quantification of bird habitat use, bird foraging times, the nutrient content of excrement and rates of defecation. These were useful as components of a general approach to estimating the relative loading rates of TP from birds, but because of the scale of the lake and the potential magnitude of contributions from the different species observed at the lake, it would be useful to refine these estimates with data collected from the bird species resident at the lake itself, rather than results from experiments conducted elsewhere.

We believe the results and recommendations supplied in this study can be used to improve the management of the Virginia Lake. For example, our investigations produced evidence that suggested rainbow trout predation could be reduced if the temporal stocking pattern were changed. We believe that if rainbow trout were stocked later in the summer, after cormorants emigrate from the lake, and at a slightly greater fork length, they may grow beyond a size vulnerable to cormorant predation.

Our water quality and nutrient loading study stops short of making management recommendations because more research is needed. Still, our results provide lake managers with some things to consider. Although N is likely the limiting nutrient in Virginia Lake, the large reservoirs of TP in the lake may have long term deleterious water quality effects, even if all the known sources of TP are eliminated. This is especially true if TP is being released from sediment that has accumulated in the lake. TP does not have a gas phase like carbon or nitrogen, and with poor lake circulation, TP may be retained in the lake for years, contributing to seasonal water quality instability. There are different management options for lake managers to consider. Those options range from surface water treatment with aluminum sulfate to draining and dredging the lake, thereby removing the TP saturated sediment.

Based on observations, managers should also place the social practice of feeding birds under careful review. Although birds are a source of nutrients to Virginia Lake, it would be irresponsible for society to place blame on the birds, when people subsidize the food resources of the birds at the lake. In an extreme view, birds are a mere conduit of human based nutrients.