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Modeling of Common Terns, *Sterna hirundo*, on Lake Champlain and Predictions for the Future

A Thesis Presented  
by  
Rochelle Streker  
to  
Rubenstein School of the Environment and Natural Resources  
and  
Honors College  
of  
The University of Vermont

In Fulfillment of the Requirements of the Honors College Degree  
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ABSTRACT

The Common Tern, *Sterna hirundo*, is a small, migratory water bird whose extensive range includes nesting islands on Lake Champlain. The history of Common Terns in Vermont includes population declines from hunting and predation, leading to their addition to the state’s Endangered Species List in 1989. Since then, they have been managed intensively such that their population in Vermont has made a comeback, rising close to the threshold for downlisting to threatened: 200 breeding pairs with a reproductive rate of 0.6 fledglings per pair. This thesis analyzed past data to project the tern population size into the future to assess whether the Common Tern should be down listed. My model showed that while the population can maintain an average of 200 breeding pairs over 50 years, it was unable to reach 0.6 fledglings per pair rate, a second requirement for down listing. The model also evaluated the effect of high water events -which decrease chick survival- on the tern population’s probability to reach the recovery goals. An increase in the probability of a high water event above the current rate of 0.38 yielded a tern population that could not reach either of the recovery criteria. Without reaching a rate of 0.6 fledglings per pair, the Common Tern population cannot be down listed; however given the results it is unknown if the population can reach or maintain this rate. Now the question of down listing lies with the Scientific Advisory Group on Birds and the Endangered Species Committee as to whether the recovery goals should be relaxed or to maintain the goals with limited probability for recovery.
ACKNOWLEDGEMENTS

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LITERATURE REVIEW

Introduction

A white blur whirls out of nowhere, like a boomerang, on curved wings with blackened tips. Color slices through the white body with a black cap slashed across the head like war paint on a linebacker on game day leading down into a bright reddish-orange dagger of a beak. They swirl in the air like snowflakes, and as they flock and fly together, they create a snowstorm in the middle of summer. There is a certain elegance about birds in flight, almost like a dance, and it has fascinated me since I was young. As a child I lived on the coast and spent most of my life with seabirds flocking above me, weaving in and out of the air.

I have always taken this dance for granted, and when I moved to Vermont I was happy to learn that Lake Champlain is also home to one of the best dancers in the sky, the Common Tern, *Sterna hirundo*. A small migratory seabird, Common Terns’ flock together creating their own troupe on the islands in Lake Champlain on which they nest colonially. Their acrobatics in the sky may be wonderful to watch, but this species has been on the Vermont List of Endangered Species since 1989 (LaBarr 1996).

The Vermont Fish and Wildlife Department has been managing the species since 1989 and have been quite successful (LaBarr 1996). Because the Common Tern is a state endangered species, it is important to understand how their population changes through time and predict how it will change in the future. The importance of modeling Common Tern population trends as an endangered species is only amplified by the recent discussion to down list the species after they reached their 5 year population goal as set out by the recovery plan.

Since management has been successful, the Common Tern is being considered for down listing, which would change its status to threatened. As this question is considered, a better understanding of Vermont Common Tern population trends and history in Vermont is required. This thesis will model data collected by the Vermont Fish and Wildlife Department and Audubon Vermont, during the management of the species- to better understand past population trends and predict these trends into the future.

Biodiversity

Biodiversity is defined as the variety of life in the world or in a particular habitat or ecosystem, or the number of species, flora and fauna, within a given ecosystem (Nijihuis 2012). Species inhabit specific niches in an ecosystem and co-evolve together, making biodiversity an
important factor in ecosystem health. However species biodiversity worldwide has been declining in recent years due to factors such as over-harvesting, pollution, invasive species, and global warming.

Loss of even a single species loss can negatively affect an ecosystem, as their role in the ecosystem in no longer filled. With the absence of a top predator, the structure of an ecosystem may change drastically. Without top predators, ecosystems may experience a meso-predator release, an increase in middle predators, and many of the prey species increase altering ecosystem function. For example, the extirpation of wolves, *Canis lupus*, cougars, *Puma concolor*, and other top predators from the eastern United States has led to a massive increase in white-tailed deer, *Odocoileus virginianus*, in the USA, their primary prey, and an increase in coyotes, *Canis latrans*, a common meso-predator in the ecosystem (Negro et al. 2012). The combined effects of over-browsing by increased deer populations and the increased population of coyotes leading to more negative human interactions have severely degraded much of the eastern United States ecosystem (Beschta et al. 2009).

Empty niches in an ecosystem also allows for invasion by exotic species (Negro et al. 2012). Invasive and exotic species are a huge problem in the United States, with such species as Asian carp (Cyprinidae) filling the void left by local extirpations, and pushing more native species into decline (Negro et al. 2012). Because species adapt and co-evolve in ecosystems together over thousands of years, a sudden change in species composition and decline in biodiversity can have wide ranging implications across the entire ecosystem.

To combat species loss, steps need to be made to stop the decline of species worldwide. The first step to stopping biodiversity decline is working to facilitate population growth of species that are in decline. In response, the United States enacted the Endangered Species Act which helps protect and increase populations of species in decline or nearing extinction. Any species experiencing a significant decline, or nearing extinction, can be petitioned to be put on the National Endangered Species List or a list for a particular state. If accepted it will be protected against “takes” - of both the species and its habitat, and management will begin to increase population numbers (more details on the Endangered Species Act below). Increasing these populations of threatened and endangered species helps ensure that their role in an ecosystem will continue and the ecosystem will not decline or collapse.
Avian and Endangered Species Management

*Endangered Species Act*

The Endangered Species Act was passed in 1973 after being signed into law by President Nixon. Shifting attitudes toward conservation and several less sweeping laws protecting endangered species led the way for creation of the federal Endangered Species Act (ESA). Since extinctions and declines in bird species, such as passenger pigeons (*Ectopistes migratorius*) and whooping cranes (*Grus americana*), were heavily publicized and used to propel conservation into the national consciousness. Avian conservation has played a large part in the creation of the ESA.

The Endangered Species Act delegates authority to two agencies to oversee the creation of the list and protection of the species on it; the US Fish and Wildlife Department for terrestrial and fresh water species and the National Oceanic and Atmospheric Administration for salt water and marine species. There are two ways to list a species under the ESA. The first is to have the species directly added to the list by either the US Fish and Wildlife Service or the National Oceanic and Atmospheric Administration (NOAA) through their candidate assessment programs. Species can also be added to the list by an individual or organization petitioning either of the agencies to add a species (USFW 2013). Once a petition has been received, the agency has 90 days to screen the petition. After the 90 screening period, the petition is either accepted or denied due to a lack of evidence.

If the petition is accepted, a status review of the species is done by either the US Fish and Wildlife or NOAA with three possible outcomes. The first is that the status review finds the petition ‘not warranted’ and the species is denied listing. The second is ‘warranted but precluded’ and the species is put on a 12 month waiting list until another status review can be done and the decision changed. The final is ‘warranted’, where the species is accepted and listed. US Fish and Wildlife or NOAA will then agree to do 12 months of monitoring within a year of the ‘warranted’ status to determine whether the species will be listed as ‘endangered’ or ‘threatened’. After this final decision, the species is officially listed on the ESA and a recovery plan is required to outline the specific steps needed to be taken in order to protect and recover the species (USFW 2013).
To be delisted from the ESA, a species must meet all of the goals stated specifically in the recovery plan for at least 5 years (USFW 2013). These recovery goals will vary from species to species, as they are based upon monitoring data, but commonly include a population goal that must be reached. Once the species has reached its recovery goals, the US Fish and Wildlife Service or NOAA meets with those involved in the recovery process to decide if the species can be delisted. If the species has met the recovery goal, it is delisted and management intensity is decreased (USFW 2013). If the species is not ready to be delisted, but has been showing improvement in population trends, the board can also choose to down list the species to threatened status.

Endangered Species and Avian Management

Once a species is listed, a recovery plan is created. NOAA has no specific time line as to when the recovery plan must be created, but US Fish and Wildlife Service does have a requirement of having a recovery plan in place 3 years after the initial listing of the species (USFW 2013). As required by law, a recovery plan must include a description of management activities in site-specific areas of concern, objective measurable criteria to evaluate the recovery of the species, and an estimation of the money and resources needed. Because of the depth and specificity of the recovery plan, it is often used as a management plan for the species as well.

Endangered species management uses many of the same techniques and practices as the management of all wildlife, but invasiveness of techniques is a concern. Because endangered species have small population sizes, many invasive techniques, such as banding bird species, tagging or collaring animals, or inserting any type of tag into the species’ skin, must be considered carefully. The health of the individuals are more important to recovering the population’s size than the information gained through such invasive techniques, so non-invasive methods are more typically utilized. Killing of species for scientific analysis is rare in endangered species management for the same reason. In many cases, autopsies, stomach content analyses, and other scientific analyses for endangered species are done on previously collected and preserved specimens. Alternatively animals found dead, either by road-kill, poachers, or natural causes may be used.

Birds are mobile and therefore there are challenges to understanding their population dynamics. While there are a lot of data on birds throughout the world, there are large gaps in our
knowledge of many bird species because they are hard to track over time. Our inability to fly or follow birds easily has made avian conservation and management difficult until the creation of tags and bands. Bird banding, a technique where a metal band is attached to a bird’s leg to identify individuals within a population and understand that individual’s natural history and movement, is now a commonly used technique. Information gained from individuals can then be generalized to better understand the natural history of the species. Migration also makes avian management difficult because certain species are only found in specific locations during certain times of the year. Migrations span different countries and even continents, making international efforts necessary to properly manage the species. However international efforts are hard to coordinate and have only recently become more common as a management technique (Nijihuis 2012).

**Population Modeling**

Modeling has become an important tool in wildlife conservation. Using data collected by field biologists, meta-analyses and other modeling tools can help predict population trends and how interactions between different factors can affect a population’s viability. There are several ways to model avian populations, including specific models that take into account migration and other avian specific factors that affect population size and success. For avian conservation, it is important for field biologists and avian modelers to begin to work together to improve management decisions for bird populations. Models that can be used for management include population viability model, individual based models, habitat-based models, and Monte Carlo simulations. The most basic for population modeling, and the template for all other population models is:

\[
N_{t+1} = N_t + B + I - D - E
\]

where \( N_{t+1} \) is the population size one year in the future, \( N_t \) is the current population size, \( B \) is the number of births, \( I \) is the number of immigrants, \( D \) is the number of deaths, and \( E \) is the number of emigrants. This includes all the factors that affect population size.

One of the specific modeling techniques used to assess trends over time is population viability analysis (PVA). A PVA is used to determine the probability that a population will survive over a given time frame with a specific starting population size. The equation revolves around the variation in the parameter \( \lambda \), which is the finite rate of growth and calculated as:

\[
\lambda = \frac{N_{t+1}}{N_t}
\]
\[ \lambda = \frac{(N_{t+1})}{N_t} \]

where \( \lambda \) is the rate of increase and \( N \) is population size at time \( t \). \( \lambda \) can also be written as \( r+1 \), where \( r \) is the birth rate minus the death rate. This is a relatively simple equation, but it can be used over multiple generations to create a picture of population trends. To successfully develop a PVA, one must have data on many life history traits, such as survival rate, recruitment rates, and their variation over time. By using these data to create a population model, a PVA can be used to assess the probability that a population will persist into the future. Although PVAs can be powerful tools for understanding population threats, to be truly useful, they require a lot of data. Ideally a model would have all of the data on factors mentioned above, such as birth, death, and immigration rates, but also habitat specific variation in population parameters. Collecting all of these data are rarely feasible in the field: at a minimum, population size, number of births and number of deaths are necessary.

**Common Tern**

The Common Tern is a small black and white water bird commonly found along the East Coast. It is a migratory species, breeding in the summer in the north-eastern United States and Canada and wintering along the coast of Central America (Figure 1). Common Terns eat primarily live fish, though individuals have been recorded eating dead fish left by fishermen and commercial fishing operations as well as some invertebrates. Terns nest colonially, flocking in large numbers and occasionally with other seabirds on small islands or secluded beaches. Terns prefer islands because they nest on the ground which makes both the adult and the eggs vulnerable to predation. Both parents incubate the eggs, brood the young, and feed the nestlings. The species is socially monogamous.

Common Terns, like many other seabirds, were widely hunted in the past. From the 1870s to the 1880s, Common Terns were hunted to near extinction for their feathers, which were fashionable at the time as adornments for hats. Legislation protecting seabirds and other threatened species was passed shortly thereafter, and in the 1930s the Common Tern had returned to a majority of its former range. However, Common Tern populations remain low due to other threats, such as gull predation, loss of breeding sites, and toxic chemicals. They are a widely studied bird for these reasons, and because their population is moderately large, they have been used as a model to test conservation management strategies.
History of Common Terns in Vermont

Common Terns are believed to have been breeding on Lake Champlain since the late 1880s, with a historical population of approximately 300-400 breeding pairs. Lake Champlain is the only breeding site for Common Terns in Vermont, but is close to other breeding colonies in Canada on the St. Lawrence River. Due to chronic low breeding success, nocturnal predation from owls, loss of breeding sites to gulls, human disturbance and hunting, there were only 50 breeding pairs of Common Terns on Lake Champlain by 1988. In 1989, the Common Tern was listed as an endangered species in Vermont. The recovery threshold for the species was then set at 300 nesting pairs with “sufficient productivity” on at least 2 of the 6 islands (Figure 2). Since then, significant management efforts have gone into recovering the breeding population of Common Terns on Lake Champlain.

There are currently 6 islands that host breeding colonies of Common Terns on Lake Champlain and they have been intensively managed to ensure reproductive success. Many different management techniques have been utilized, including placing netting the ground on breeding islands to deter gulls and using wooden decoys and audio playbacks of a tern colony to attract Common Terns to colonize new islands on the lake. Birds have also been marked and recaptured to assess population size and dispersal. However, with the modest success of some of the management activities and lack of available funding, management activities have decreased in recent years. The current management includes banding all chicks as fledglings, as well as estimates of the total adults breeding each year.

Due to these efforts, the Common Tern has made a comeback in Vermont and has recently reached its population threshold for down listing from the state’s Endangered Species List. However the decision to down list has still not been made, and 2011’s heavy rains left many of the breeding islands underwater and hurt the reproductive success of the Common Terns that year.

GOALS AND OBJECTIVES

The objectives of this research is to: 1) build a model of the tern population based on historical data collected on survival and birth rates; 2) examine how the population will change over time using deterministic and stochastic models; and 3) assess whether the species should be down listed or delisted in Vermont.
METHODS

Research on Common Terns in Lake Champlain, was conducted during the summer every year since the recovery plan was approved in 1989. All data were collected by LaBarr (1989-2013) to create a population model for the Common Tern.

The data collected each year varied among years. In the early years all adults were banded as well as new chicks, and the total breeding population was counted. Banding data of adult Common Terns stopped around 2008 when adult banding was deemed too intrusive by Vermont Fish and Wildlife Department. In the subsequent years, number of pairs were determined by counting birds flying and doubling the number of nests. Also as the population grew, the number of visits each summer decreased leading to less data on adult activity and decreased accuracy on timing of fledgling.

Data from LaBarr were analyzed through modeling, which allowed for a better understanding of how the Common Tern population has been changing in Lake Champlain and served as the basis for the population model. LaBarr’s data were also compared to the model’s projections. I also used data from the literature for the recruitment rate, adult survival rate, and starting population size for the model.

Modeling and Projections for the Future

I created a model in Excel to mimic the tern population survival and recruitment for 50 years into the future (APPENDIX A). Recruitment rates, chick mortality rate, fledging rate, and breeding population size were based on averaged data sets from years 2008-2013. The probability of a high water event, 0.38, was calculated from the National Weather Service’s Advance Hydrologic Prediction Service, which has depth monitors in several locations on Lake Champlain. The closest depth monitor on Lake Champlain to the nest islands of the Common Terns is the Rouse’s Point depth monitor. The National Weather Service’s flood categories for Lake Champlain were also used in determining what constituted a high water event.

The model used the following time line. Breeding adult terns return to Lake Champlain in early summer, and build nests on the islands. In June, the eggs are laid and chicks begin to hatch. It is at this time that the high water affects the chick survival. If the water is greater than 100 ft above msl, Lake Champlain’s flood state, chicks can die at a higher rate due to exposure. During this time, nests, eggs, and chicks are counted and banded by Audubon Vermont personnel. The
adult population is censused through full adult counts while birds are in the air and by multiplying the nest count by 2. In late summer and early fall the adults and the surviving chicks leave Lake Champlain and do not return until the next summer.

Basic inputs to the model were two recruitment rate, chick mortality, adult population size, and chance of high water event. The values used in these cells are given in Table 1. The outputs were the end total population size at 50 years, the number of high water events, and number of fledglings per pair. The equations involved in the model were as follows:

- The chance of a high water event was determined by assigning each year a random number. An IF equation was used which stated if the random number was less than or equal to the chance of high water, a high water event occurred. If the random number was greater, no high water event occurred in the model.
- Adult survival was calculated by multiplying last year’s total terns by the adult survival rate to give the number of terns that survived to return to breed in the subsequent year.
- Recruitment was calculated by multiplying recruitment rate by number of females, which is equivalent to the number of pairs.
- Chick survival was calculated by using an IF equation. If a high water event had occurred, the recruitment rate was multiplied by the high chick mortality rate. If a high water had not occurred, the recruitment was multiplied by the low chick mortality rate.
- The total tern population was then calculated as a late summer census by adding the adult survival to the chick survival. The number of surviving chicks is added to the number of surviving adults to become the starting population for the next year.

A model can never fully simulate the real world, so certain assumptions must be made to create a model that best answers the specific research questions one is addressing. Here, I assumed that all high water events occurred after chicks hatched, and therefore only affected chick survival. It is possible that high water events occurred before hatching, and may even occur throughout the summer; however this possibility was not included to minimize the
complexity. A sex ratio of 0.5 was also assumed for the model to minimize complexity. Another assumption was that adult mortality occurs before breeding and recruitment. It is also assumed that adult mortality occurs in the non-breeding season in the model.

The final assumption was that all chicks that survived to fledging survive to the next year and breed in the subsequent year. Terns, however, begin breeding at year 3 (Nisbet et al. 2002). This could not be included in the deterministic and stochastic model (Appendix A). A separate model was created to assess how this delay in breeding affects the population and compared to the other models (Appendix B). This model, called the ‘Breed at 3’ model, projected the Common Tern population into the future, much the same as the deterministic and stochastic model, with two key differences. For one, recruitment rate was stochastic in the ‘Breed at 3’ model depending on whether a high water event had occurred. In the deterministic and stochastic model, this parameter was a constant and the variable parameter was chick survival. Also, as the name suggests, this model only added terns to the breeding population once were 3 years old. Chicks from 0 to 1 were recruited into the population by multiplying the number of females by the recruitment rate, and then I used a survival rate of 0.68 and 0.85 for years 1 to 2 and 2 to 3 respectively.

The results of the model were determined through running different simulations to compare, contrast, and determine if the population can reach and maintain the recovery goals of 200 breeding pairs and a fledging per pair rate of 0.6. The model has a stochastic input, whether or not a high water event has occurred, which determines which chick survival input will be used. This creates variation in the end population at year 50 between different runs of the model, making the model stochastic. However to understand how the inputs affect the population, the I started with a deterministic model with the chance of high water set to 0.

The model was then made stochastic again by changing the chance of high water to 0.38, the current rate as determined from National Weather Service’s Advance Hydrologic Prediction Service’s data on Lake Champlain. With a stochastic model, every run of the model will produce a new set of random numbers and therefore a new end population at 50 years and number of high water events. The model will show the possibility of Common Tern populations falling below the recovery threshold, 200 breeding pairs, in 50 years, as well as the total amount of high water events that occurred during the 50 year span. The number of fledglings per pair was
also analyzed to determine if the recruitment rate reached the 0.6 fledgling per pair goal in the recovery plan. After 300 trials at the current chance of high water, the chance of high water was increased to 0.45 and 0.5 to determine the effects of increased high water events on the Common Tern population.

RESULTS

Deterministic Model

Using baseline inputs for adult survival, chick survival, and starting population size were kept 0.85, 0.5, and 556 individuals, respectively. I found an end population of 1497 total terns at year 50 and a fledging per pair rate of 0.4 under these conditions (Figure 3).

Using the deterministic model, I created a table using adult survival and chick survival rates to determine which parameter had the greatest effect on the final population. The results show the total population of terns at year 50 given the different adult and chick survival rates (Table 2). Looking at the table row of 0.85 adult survival, the baseline value used in the model, one can see that the tern population increased to >37,000 at year 50 changes with increasing chick survival rates. The same can be done at 0.5, the baseline chick survival rate without high water events. Table 2 shows that the population increased from 0 to >5 million at year 50 with 0.5 chick survival, suggesting greater sensitivity to adult survival.

Stochastic Model

The stochastic model was created to assess the effect of variation in the probability of high water events on the tern population. In this case, the variation around the baseline chance of high water events, 0.38, triggered a variation in chick survival rate. All other values were kept at their baseline values noted above. The model was run 300 times, with the outputs of the minimum, maximum, and mean total population at 50 years and number of high water events (Table 3; Figure 4). The range of the total population was 217-751 individuals at year 50, with a mean of 411 individuals. The range of high water events was 10-28 events occurring over 50 years, with a mean of 19 high water events. The average number of fledglings per pair over 50 years was 0.34.

Also under these conditions, I created a model similar to the one that was used in the original recovery plan (Figure 5). With an end population of 432 individuals after 50 years and 18 high water events, the closest simulation possible in the model to the mean numbers
calculated, the total adults, females, and chick survival were plotted from 2013-2063 (Figure 5). The model’s fledglings per pair output over the 50 years was compared to LaBarr’s collected fledglings per pair (Figure 6). It showed that the recovery goal of 0.6 has been hit in the past, but the model was unable to achieve this component of the recovery goal under current conditions.

Increased flooding on Lake Champlain is a growing concern for the recovery and management of this breeding tern population. ‘Worst case scenarios’ were modeled in which the probability of a high water events was increased to 0.45 and 0.5. The model was run 300 times at each value, with the minimum, maximum, and mean total population at 50 years and number of high water events recorded. At 0.45 chance of a high water event yielded an increase of 3 high water events and a decrease of 84 individuals from the population (Table 3; Figure 7). An increase to a 0.5 chance of a high water events yielded an increase of 6 high water events, and a loss of 137 individuals from the population at year 50 (Table 3; Figure 8).

‘Breed at 3’ Model

At the most realistic chance of a high water event 0.38, this alternative model was run 300 times to determine minimum, maximum, and mean of the number of high water events, tern population at year 50, and mean from 2013-2063 recruitment rate (Table 4). Since recruitment rate is a stochastic parameter, these multiple runs are needed and the recorded value for the recruitment rate is an average of the variation in the 50 years. The tern population at year 50 had huge range of 99-855 with a mean of 295 and the number of high water events had a range of 9-28 events with a mean of 19. Number of fledglings per pair over 50 years had a range of 0.45 - 0.66 with a mean of 0.55.

DISCUSSION

The deterministic model showed a huge increase in the Common Tern population, especially when compared to all other iterations of this model. The end population at year 50 was 1497 individuals, 1,084 greater than the stochastic model (Figure 3). It is possible that Lake Champlain could not support a population of this size, with few islands containing sufficient suitable habitat. It is questionable that the islands of Lake Champlain could hold this many breeding terns. While the deterministic model is an over-estimate, it does show what the population would look like in perfect conditions. This serves as a reference point when
discussing other iterations of the model. It is also important to note that even in this ideal setting the fledgling per pair is 0.4, not the recovery goal of 0.6 (Figure 3).

In a comparison of the sensitivity of the population to variation in two inputs, adult survival and chick survival, the deterministic model showed how much variation in each parameter affected the population at year 50 (Table 2). I found that adult survival has a greater effect on the population end size at 50 years more than chick survival because a greater adult survival rate is needed just to create a breeding population size and variation in adult survival leads to greater final populations. However the difference in effects on the total population size between the two parameters is minimal, so both factors do play large roles in determining the total tern population at year 50.

With a 0.38 chance of a high water event, the current rate of high water events on Lake Champlain, the stochastic model gives the most realistic description of the long-term dynamics of the tern population on Lake Champlain. The 300 trials showed a range of 217 to 751 individuals and 10 to 28 high water events. While the range of individuals may be large, the mean of the range is at 411, very close to the recovery goal of 200 breeding pairs. While it is a good sign that the population has still remained above the recovery threshold, with the population declining slowly throughout the 50 years and the end point being almost exactly the threshold, it appears that the population will just maintain slightly above the down listing goals and could fall below the threshold. The average number of fledglings per pair over 50 years was 0.34, still not at the recovery goal of 0.6 fledglings per pair. In Figure 6, LaBarr’s past fledgling data was compared to the closest simulation possible in the model to the 0.38 averages, with an end population at 50 years of 432 individuals and 18 high water events. A comparison of these two shows the recovery goal of 0.6 has been reached in the past; however it is not a rate that has been reached in multiple, consecutive years. In fact, my model never reaches a fledglings per pair rate of 0.6. Part of this could be explained by the dilution of fledglings per pair, due to the over estimation of adults through the counts of total (not just breeding population) reducing the number of fledglings per pair; however there is also a chance that 0.6 per pair is an unattainable goal for this tern population. It should also be noted that with decreased monitoring efforts on the island, reported field data are the minimum fledgling per pair rate. In fact, there have been occasions when banded nestlings were assumed to have died prior to fledgling, only to return to the island in subsequent years. However the model was unable to reach an average over 50 years
of 0.6 fledglings per pair without extreme manipulation, which supports the idea that 0.6 may be an unrealistic goal for the population.

This realistic simulation of the stochastic model can be compared to the ‘Breed at 3’ model results. When run at the same chance of a high water event, 0.38, the ‘Breed at 3’ model produced the same mean number of high water events and a similar range. However the mean of the tern population at year 50 in the stochastic model was 411 individuals and with the ‘Breed at 3’ model it was 295 individuals (Table 3 and 4). This is a sharp difference in averages, which can indicate many things. For one, this supports the previous statement that the stochastic model produces an over-estimate of the breeding population of terns. It is also important to note that the breeding population does not reach the recovery goal of 400 breeding individuals in the ‘Breed at 3’ model. While the ‘Breed at 3’ model produced slightly lower fledgling per pair rates than the stochastic model, these differences were not substantial.

When increasing the probability of a high water event, the purpose was to understand how the population would change in a ‘worst case scenario’. With climate change and the possibility of an increase in flooding on Lake Champlain, this is a concern to managers. For this reason, it was included in my analysis using the stochastic model. Changing the probability of high water events to 0.45 and 0.5 both resulted in mean population sizes below 400 individuals (Table 3). With the increase from 0.45 to 0.5, there was also an increase of 3 high water events. Further analysis of more flooding events would be needed before making direct conclusions from these results. There is no obvious relationship between the change from 0.45 to 0.5 in the tern population at 50 years; however neither final populations meets the 400 individual recovery goal. Even with the 0.38 chance of high water, the overall population trend was downward; however when the chance of high water increases beyond this point, the population no longer can no longer reach the recovery goal at year 50. The model hints that 0.38 may be a tipping point in terms of reaching the recovery threshold for the Common Tern population on Lake Champlain.

With the decision to down list the species still in question, the model was designed to shed light on the population dynamics of Lake Champlain’s Common Terns and whether they can persist into the future without additional management. The stochastic model with a 0.38 chance of high water was the most realistic model and can be used to consider the next steps for the management of the species. In this model, the mean tern population at year 50 was 411 individuals, exactly at the 200 breeding pairs recovery goal. With a mean right at the recovery
goal, any changes could put the population in jeopardy of not meeting this recovery goal at year 50.

The more interesting part of the recovery goal is the 0.6 fledglings per pair, which is not reached in any of the simulations. The number of fledglings per pair at 0.38 chance of high water was 0.35, just over half of the recovery goal which was never achieved in any of the simulations. Even the empirical field data showed that while 0.6 had been reached in the past, it was not a value that was maintained over several years, important since the language of the recovery goal requires an average of 0.6 fledglings per pair over 5 years. Other possible explanations for this low fledglings per pair rate while reaching goals for total breeding pairs, could be the interaction of the Lake Champlain population of Common Terns with other inland colonies. Colonies of Common Terns exist on the St. Lawrence and Lake Oneida, and these colonies have been shown to emigrate from and immigrate to the Lake Champlain colony as shown through band recoveries. These breeding colonies could be acting as a meta-population, with fledglings from other breeding sites bolstering the population of other sites in subsequent years. This could explain why the Lake Champlain population continues to increase with low recruitment. Data on emigration and immigration between these populations will be required to estimate whether the population exists as a metapopulation.

A question facing the Scientific Advisory Group on Birds and the Endangered Species Committee is whether to delist a species that has reached part, but not all, of its recovery goals or to keep a species on the list perhaps indefinitely. If 0.6 fledglings per pair is in fact an unreachable goal for the Lake Champlain population of Common Terns, then the species will never reach the recovery goal for down listing and remain on the Endangered Species List of Vermont. The recovery goal could be altered to an attainable rate, but the question then becomes will the population still be able to persist with a lesser rate of fledglings per pair? If the population is being subsidized by immigrant, then the viability of Lake Champlain’s population could be dependent on the viability of other nesting colonies in the region. The model shows that the population can persist 50 years into the future, with a breeding pairs reaching the recovery goal and fledglings per pair well under the goal. This bodes well for the population persisting at a lower fledglings per pair rate than the recovery goal.
Table 1: Baseline Values for the Common Tern population model.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recruit rate</td>
<td>0.8</td>
<td>Kress, Wienstein et al 1998</td>
</tr>
<tr>
<td>Adult survival rate</td>
<td>0.85</td>
<td>Kress, Wienstein et al 1998</td>
</tr>
<tr>
<td>Sex Ratio</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>No high water Chick Survival</td>
<td>0.5</td>
<td>LaBarr 1996-2013</td>
</tr>
<tr>
<td>High Water Chick Survival</td>
<td>0.3</td>
<td>LaBarr 1996-2013</td>
</tr>
<tr>
<td>Starting Population Size</td>
<td>556</td>
<td>Labarr 2013</td>
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</table>
Table 2: Deterministic model outputs with variation in adult and chick survival rates

<table>
<thead>
<tr>
<th>Chick Survival</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
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<tr>
<td>1496.522944</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.65</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>0.75</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>15</td>
<td>72</td>
</tr>
<tr>
<td>0.8</td>
<td>0</td>
<td>2</td>
<td>13</td>
<td>72</td>
<td>372</td>
<td>1820</td>
</tr>
<tr>
<td>0.85</td>
<td>8</td>
<td>48</td>
<td>275</td>
<td>1497</td>
<td>7711</td>
<td>37715</td>
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<td>0.9</td>
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<td>4787</td>
<td>26077</td>
<td>134364</td>
<td>657202</td>
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<tr>
<td>Adult survival</td>
<td>0.95</td>
<td>2007</td>
<td>12364</td>
<td>71475</td>
<td>389330</td>
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<tr>
<td>0.95</td>
<td>2007</td>
<td>12364</td>
<td>71475</td>
<td>389330</td>
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<tr>
<td>1</td>
<td>26077</td>
<td>160685</td>
<td>928911</td>
<td>5059844</td>
<td>26071082</td>
<td>127518523</td>
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</table>
Table 3: Outputs of the stochastic model showing results from 300 trials with 0.38, 0.45, and 0.5 chance of a high water event. Minimum, maximum, and mean number of high water events and tern populations at year 50 are shown.

<table>
<thead>
<tr>
<th>300 Trials</th>
<th></th>
<th>Chance of High Water Events</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.38</td>
<td>0.45</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Number of High Water</td>
<td>min</td>
<td>10</td>
<td>14</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>max</td>
<td>28</td>
<td>33</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>19</td>
<td>22</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Tern pop at year 50</td>
<td>min</td>
<td>217</td>
<td>154</td>
<td>143</td>
<td></td>
</tr>
<tr>
<td></td>
<td>max</td>
<td>751</td>
<td>570</td>
<td>496</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>411</td>
<td>331</td>
<td>274</td>
<td></td>
</tr>
</tbody>
</table>
Table 4: Results from the ‘Breed at 3’ model incorporating stochasticity in fledgling rates based on 0.38 chance of a high water event over 300 trials.

<table>
<thead>
<tr>
<th>300 trials @ 0.38 chance of high water</th>
<th>min</th>
<th>max</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of high water events</td>
<td>9</td>
<td>28</td>
<td>19</td>
</tr>
<tr>
<td>Tern pop. At year 50</td>
<td>99</td>
<td>855</td>
<td>295</td>
</tr>
<tr>
<td>Mean Recruit Rate</td>
<td>0.45</td>
<td>0.66</td>
<td>0.55</td>
</tr>
</tbody>
</table>
Figure 1: Range Map of Common Terns in the Americas (Nisbet 2002).
PART II. STRATEGIES AND RECOMMENDATIONS FOR RECOVERY OF COMMON TERNs IN VERMONT

Recovery Plan Goals: There are 3 recovery plan goals, these are:

Goal 1) A minimum Lake Champlain breeding population of 200 pairs of common terns with sufficient productivity over 5 years to maintain population stability (average > 0.6 fledglings/pair) would allow consideration of this species for downlisting from endangered to threatened status.

Goal 2) A minimum breeding population of 300 pairs nesting on at least 2 sites (2 sites are deemed necessary to support 300 nesting pairs) with sufficient productivity over 5 years to maintain population stability (average > 0.6 fledglings/pair) would allow this species to be considered for delisting from threatened status.

Goal 3) To secure and manage a minimum of 3 of the 6 known nesting locations, these include: Popasquash, Hen or Rock, and Grammas islands. Protection of the 3 remaining islands, including Savage and Gull should also be pursued.

Figure 2: Goals for down listing and de listing the Common Tern in Vermont
Figure 3: Results of the deterministic model for the Lake Champlain tern population over 50 years
Figure 4: Tern population at year 50 versus number of high water events based on 300 trials with 0.38 chance of a high water event
Figure 5: Total population number of females and number of surviving chicks from the stochastic model with a 0.38 chance of a high water event over 50 years.
Figure 6: Comparison of fledglings per pair rate of the stochastic model and LaBarr’s collected values
Figure 7: Tern population at year 50 versus number of high water events based on 300 trials with a 0.45 chance of a high water event
Figure 8: Tern population at year 50 versus number of high water events based on 300 trials with a 0.50 chance of a high water event
Appendix A: My population model for Common Terns in Lake Champlain

Appendix B: The second model I created in order to account for breeding at age 3
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