WISCONSIN TRUMPETER SWAN RECOVERY PROGRAM: PROGRESS TOWARD RESTORATION, 1987-2005.

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INTRODUCTION

The Wisconsin Department of Natural Resources (WDNR) began its Trumpeter Swan (*Cygnus buccinator*) Recovery Program in 1987, hoping to achieve a recovery goal of 20 breeding and migratory pairs by the year 2000 (Matteson *et al.* 1986, 1988). In 1987 and 1988, while waiting in line behind Minnesota to go to Alaska to collect Trumpeter Swan eggs, we utilized cross-fostering as a reintroduction technique, using Mute Swans (*Cygnus olor*) as foster parents at a marsh site in southeastern Wisconsin. We used 35 Trumpeter Swan eggs from avicultural sources and experienced poor hatching success and survival, with only two cygnets reaching fledging age. This technique was discontinued after the 1988 season and replaced by an innovative technique called decoy-rearing, developed by the University of Wisconsin's Department of Wildlife Ecology in partnership with the WDNR. Decoy-rearing involved imprinting cygnets on life-size Trumpeter Swan decoys immediately after hatching, and transporting cygnets at age 3-5 days to sites in northern Wisconsin, where they followed floating decoys manipulated by University of Wisconsin interns in camouflaged float-tube blinds (Matteson *et al.* 1996).

Decoy-rearing and a second technique, captive-rearing (cygnets raised in captivity until 2 years, flight feathers trimmed, and the birds released at selected wetland sites) formed the basis for our restoration efforts, which began in full in 1989, when we flew to Alaska to collect Trumpeter Swan eggs for transport back to the Milwaukee County Zoo, where all of the collected Alaskan eggs were incubated during 1989-1997. During this period, through the cooperation of the U.S. Fish and Wildlife Service (USFWS) and direct assistance of pilot/biologist Rodney King, we collected a total of 385 eggs in the Nelchina Basin of southeastern Alaska and in the Minto Flats region of central Alaska. Terry and Mary Kohler of Sheboygan, Wisconsin, personally flew the WDNR team to Alaska, or arranged for private transportation to do the same. The Milwaukee County Zoo staff, under the direction of curators Ed Diebold and Kim Smith, placed the eggs in artificial incubators and hatched 356 (93%) during 1989-1997. Mean weights of the eggs collected (all years) ranged from 221.2 g to 242.8 g, with a weighted mean of 231.8 g.

NUMBERS RELEASED AND ANNUAL MONITORING

During 1989-2005, we released a total of 394 Trumpeter Swans to the wild. This number included 196 cygnets via the decoy-rearing technique, 159 subadults from the captive-rearing technique, 32 from captive-parent rearing (a complementary technique involving cooperators with private pairs, whose young produced were released as yearlings), six released as captive-reared yearlings, and one bird of miscellaneous origin released independently.

Annual monitoring of released birds and subsequent breeding activity occurred regularly during 1989-2005. Each spring, aerial surveys of potential wetland breeding habitat to locate nests took place; some of these surveys were part of Bald Eagle and Osprey survey flights. We also followed up on incidental/additional nesting reports from the public. Ground-truthing to determine clutch size at nests also occurred where and when possible.

The number of wild Trumpeter Swan active nests began slowly, with 1 in 1989 and 11 by 1995. After 1998, when we documented 18 nesting pairs, the number grew markedly. Between 1999 and 2005, the number of nesting pairs increased nearly 200% to a high of 92 nesting pairs in 2005. In 2005, breeding pairs occurred in 16 counties, with 55 (59.8%) clustered in northwestern Wisconsin, 18 (19.6%)

occupying wetland sites in northern Wisconsin, 16 (17.4%) in central Wisconsin, 2 (2.2%) in southwestern Wisconsin, and 1 (1.1%) in southeastern Wisconsin.

Observations of family groups occurred throughout the summer months, and these included an August pre-banding aerial survey to locate families and count cygnets.

During August and September from the mid-1990s through 2005, round-ups of cygnets and occasional molting subadults/adults occurred following a standard procedure: 1) a pilot in a small plane located a swan family, 2) pilot, with the swan family in sight, circled overhead and directed a flotilla of kayaks/canoes to the family group, where cygnets were captured by hand or with long-handled nets; 3) each captured bird was marked with a USFWS leg band and a yellow (formerly green, in earlier years) plastic collar with an alpha-numeric code; 4) health sampling followed: 5-6 cc of blood removed to test for lead poisoning, avian influenza, Newcastle's Disease, West Nile virus, and to determine sex via DNA analysis; 5) each bird was weighed and then carefully released back into its wetland.

Finally, fall (late September/early October) flights occurred to determine production.

During 1989-2005, we documented a total of 504 active nests, with 360 (71.4%) producing (fledging) 1,160 young (2.3 young/active nest; 3.2 young/successful nest—successful defined as producing at least 1 young). In examining nesting success by period, 1989-1994 (when we last reported on program progress), and during 1995-2005, it is evident how productive the growing population has been over the past decade. During 1989-1994, 30 nesting attempts produced 62 fledglings (2.07 young/active nest; 2.7 young/successful nest). For the period 1995-2005, 474 nesting attempts produced 1,098 fledglings (2.3 young/active nest; 3.3 young/successful nest).

In 2004, we examined the known origin of Wisconsin's breeding pairs and found that 62% were wild-produced birds, 14% were comprised of captive-reared and released birds, 11% were decoy-reared birds, 8% came from out-of-state, and 5% were captive parent-reared birds.

HABITAT CHARACTERISTICS

We identified the following Trumpeter Swan breeding habitat characteristics for the period 1989-2005: 1) shallow (1-2 m deep or less) waterfowl production areas and cranberry impoundments/flowages, with sedge and cattail marshes; 2) shallow State Wildlife Area (WLA) flowages, marshes, small farm ponds (<2 ac, 1 ha), and glacial potholes, with abundant submergent and emergent aquatic plant species (represented by *Elodea, Sagittaria, Najas, Nitella, Potamogeton, Sparganium,* and *Zizania*); 3) several Waterfowl Production Areas and WLAs dominated by wild rice or cattails/sedges; 4) backwater sloughs, beaver ponds, bogs, and hardwood swamps with small marshy islands/islets and abundant submergent foods (e.g. *Elodea, Potamogeton* spp.); 5) lake bay marshes and lake edge marshes; and 6) nests often constructed on small islands/islets or built-up mounds of detritus and *Typha, Zizania*, or *Scirpus*.

Marking nearly 1,500 trumpeters, including most cygnets produced, and all birds released during the program, has allowed us to track the migration and wintering of hundreds of birds. From fall 1999 through spring 2001, we equipped and tracked 16 trumpeters with satellite transmitters to learn more about migration distances and habitats used during winter. We learned that the shortest migration distance between breeding site (Shiloh Lake, Polk County) and wintering site (Lake Mallalieu, Hudson area, St. Croix County) was 41 miles (66 km), and the longest migration from breeding site (Little Turtle Flowage, Iron County) to wintering site (Union County WLA in southwestern Illinois) was 607 miles (971 km). We found that wintering habitats were generally similar to breeding habitats. For example, the breeding sites of central Wisconsin swans were shallow, diked pools/impoundments on State WLAs and cranberry lands. Wintering sites for central Wisconsin breeding swans were reclaimed strip mines managed for waterfowl in southwestern Illinois: habitats that looked like home.

CAUSES OF MORTALITY

We studied the causes of 226 known Trumpeter Swan mortalities during 1987-2005 and found that lead poisoning (n = 48), shooting (n = 46), and powerline collisions (n = 35) accounted for 57.1% of all mortalities. Seven additional factors ("undetermined"—13.3%, "other"—9.7%, "trauma/blood loss"—8.0%, "morbidity"—4.9%, "fish line/drowning"—2.7%, "human defense"—2.2%, "vandalism"—2.2%) comprised the remaining 42.9% of known deaths. In examining known mortalities by period, 1987-1994 and 1995-2005, the order of the three leading causes changed slightly: shooting (32.8%), lead poisoning (27.6%), and powerline collision (15.5%) during 1987-1994, and lead poisoning (19.0%), shooting (16.1%) and undetermined (17.9%), followed by powerline collision (15.5%), during 1995-2005. There were nearly three times as many mortalities during 1995-2005 (n = 168) than during 1989-1994 (n = 58), but the comparison is skewed because of the unequal number of years involved. Nevertheless, although shooting and lead poisoning remain important, they have declined proportionately when comparing the percentages of each for each time period. The same is not the case for powerline collisions, whose percentage of swan mortalities did not change between the two periods.

In 2004, after two different breeding adults (from adjacent wetland territories) died from colliding with the same powerline in central Wisconsin, the WDNR worked with Alliant Enegy to install 200 "firefly" bird flapper diverters along a 1-2 km north-south stretch of the powerline. These diverters (3.5 inches by 6 inches, acrylic plastic, UV-stabilized, with fluorescent reflective yellow-green patches on the front and fluorescent orange on the back), designed by Timothy Chervick of Swift Creek Consulting and produced by PR Technologies, Inc., were recommended by The Trumpeter Swan Society (Madeleine Linck, pers. comm.). We will be monitoring their effectiveness in the coming years. (Other bird diverters were installed in the 1990s in St. Croix County to address similar powerline collision issues.)

POPULATION VIABILITY ANALYSIS

Finally, we undertook a population viability analysis (PVA) to determine if the Wisconsin Trumpeter Swan population had achieved a stable, self-sustaining state. With the assistance of Paul Rasmussen of the WDNR's Bureau of Integrated Science Services, a quantitative evaluation of extinction risks and management options was achieved. Utilizing a VORTEX (Miller and Lacy 2005) software package, which simulates the fate of individuals using discreet events with probabilistic outcomes and incorporates both deterministic and random (stochastic) factors, we determined the rate of population change and probability of extinction under varying conditions. VORTEX is an individual-based population simulation model. Using input information that specifies the distribution of demographic parameters, it follows the fate of simulated individuals in the population and keeps track of these individuals as they are born, give birth, and die for generations (Miller and Lacy 2005, Lacy 2000). Because the life history events of the simulated individuals are determined by random processes with specified parameters (e.g., mean and variance), their fate is the result of both deterministic and stochastic factors. The simulation results thus portray the consequences of deterministic and stochastic factors on the population.

Values for model parameters were based on analyses of data from Trumpeter Swans in Wisconsin, published information for Trumpeter Swans in other areas of North America, and published information on other large birds such as Whooping Cranes. The parameters listed in Table 1 follow the format required for VORTEX; other models may use the same information in a different form. Because results of population modeling depend critically on parameter values, the parameters will be discussed following the order of Table 1.

Effects of inbreeding depression in the model were not included because Wisconsin's restored population originated primarily from Alaskan Trumpeter Swans, and probably incorporated considerable genetic diversity. It was assumed that the environmental factors affecting adult survival were primarily different from those affecting reproduction, so a good year for survival would not necessarily mean a good year for reproduction (in VORTEX language, environmental variation (EV) in reproduction and survival would not be concordant). Two catastrophe types, poor weather and disease, were included and will be discussed further below.

Most of the parameter estimates related to reproduction came directly from observations on Wisconsin Trumpeter Swans. Considerable effort has been allocated to observing Trumpeter Swan pairs in the spring, finding nests, and following their fate. This information is summarized in Table 1. The median age of first reproduction is used in simulating breeding behavior by VORTEX.

In Wisconsin, Trumpeter Swans may first breed at the age of 2, 3, and 4 years based on our field observations. Data from established western U.S. populations suggest breeding begins at 4 years or later (Mitchell 1994). Explorations with deterministic models showed it was difficult to match observed rates of Wisconsin Trumpeter Swan population increase unless breeding first occurred at least by age 3. Simulations were run with first breeding at each of the ages 2, 3, and 4 years. We have no information on density dependence in breeding. The percentage of females successfully breeding was calculated as the proportion of adult females attempting to breed (estimated during 1998-2000 as 64%) multiplied by the percentage of attempted nests that successfully fledged at least one swan (72% during 1996-2004). The estimated value of 46% seemed to be relatively high, so some simulations were run with the value of 36%. The percent of successful nests producing fledglings was estimated directly from observed Wisconsin nests during 1996-2004 (Paul Rasmussen, pers. comm.).

Although we have many observations of neck-banded Wisconsin Trumpeter Swans, we were not able to account for re-sighting probabilities and collar loss to obtain estimates of mortality directly for Wisconsin swans. The most careful study of Trumpeter Swan survival described in the literature provided an estimate of annual adult survival of 88%, or mortality of 12% per year (Anderson *et al.* 1986). This is consistent with estimates of adult survival for other species of swans (Bart *et al.* 1991). Even though the literature suggests low annual adult mortality in swans, model simulations were also run with higher values of 15% and 20% mortality per year. Estimates of survival for younger swans were less precisely estimated, but were somewhat lower than adult rates (Mitchell 1994). Estimates of standard deviation in mortality rates were not available. We used a slightly larger value (5%) than that used for simulations of Whooping Crane populations (3%; Mirande *et al.* 1997). Additional simulations used a standard deviation of 10% (Paul Rasmussen, pers. comm.).

Catastrophes are extreme and infrequent events that may cause large reductions in survival, reproduction, or both. It is obviously difficult to estimate the frequency and effect of catastrophes because they are unusual and infrequently observed. Computer simulations of Whooping Crane populations assumed the frequency of disease was 5% (1 in 20 years) and that the impact was primarily in reduced survival for adults (Mirande *et al.* 1997). We followed these guidelines, except we increased the severity (70% of normal survival instead of 90%). We assumed that the primary effect of catastrophic weather would be during nesting, so that reproduction would be reduced substantially, and adult survival reduced by a small amount. Two values were used for the frequency of weather catastrophes: 2% (1 in 50 years) or 10% (1 in 10 years) (Paul Rasmussen, pers. comm.).

Because the current Wisconsin trumpeter population is increasing, there are more young birds than in a stable age distribution. For simulations, we made the more conservative assumption that the population had a stable age distribution. We started most simulations with an initial population of 300 and assumed the carrying capacity in the state was 700 swans, which may likely be an underestimate, but provided a reasonable approach for the purposes of our modeling.

Stochastic factors become especially important in determining the fate of small populations. In larger populations deterministic factors dominate (Lacy 1994). Deterministic projection matrix models were used to determine if the population parameters specified for Trumpeter Swans resulted in plausible behavior of the modeled population, in the absence of stochastic variation. We were primarily interested in determining what combinations of parameter values could result in population growth as large as that observed in Wisconsin. During the period 1998-2004, the number of active Trumpeter Swan nests in Wisconsin increased by approximately 25% per year. Although no true population estimates are available, approximate estimates of the number of swans of all ages in Wisconsin during 1998-2000 indicated that the total population was increasing even faster than the number of active nests during that time.

Although in western U.S. populations, Trumpeter Swans do not begin reproducing until age 4 or greater (Mitchell 1994), the earlier (age 2-3) reproduction observed in Wisconsin's swans may have resulted from different environmental conditions, or may be a characteristic of a restored population in an environment with abundant nesting opportunities. The best estimates of input parameters (based on the literature for survival and Wisconsin data for reproduction) resulted in lower projected growth rates than that observed in Wisconsin under the deterministic model. This suggests that these estimates are conservative. The age distribution of Wisconsin Trumpeter Swans may also contribute to their larger growth rate (there are a large number of young swans).

Stochastic models were implemented using VORTEX (Lacy *et al.* 2005). The final results of any PVA are critically dependent on the form of the model and the values of the input parameters. Trumpeter Swans have a relatively simple life history, with adults forming long-term, monogamous relationships and breeding once a year. This type of life history is well modeled by VORTEX. Values of demographic parameters can never be known with certainty and, in some cases, small changes in parameters can have large effects on extinction risk and population growth rate. Sensitivity testing of a quantitative PVA involves examining results of simulations for a range of plausible values for the uncertain parameters. This can lead to an arbitrarily large number of simulations, if additional permutations of possible values are considered. Simulations under 23 distinct combinations of parameter values (Table 2) were run, and for each combination 100 simulations for 100 years each were run as well. The probability of extinction calculated is thus the probability of extinction during this 100 year period. Also computed was the probability of the population falling below a population size of 100 swans during 100 years (Paul Rasmussen, pers. comm.).

Simulated populations based on the best estimates of input parameter values for Wisconsin's Trumpeter Swans increased 6% per year and had essentially no chance of extinction within 100 years (Table 2; parameters in bold). All simulated populations increased steadily until they reached carrying capacity and then leveled off. As already mentioned, this simulated rate of population increase is lower than that observed in Wisconsin over the last decade, so these parameter estimates are probably conservative. Because some of the input parameters were estimated directly from the increasing

Wisconsin population (reproductive parameters, especially), we should expect that they would result in simulations of increasing populations. Despite this potential circularity in reasoning, this initial model represents the current Wisconsin population of Trumpeter Swans and suggests that the population is likely to grow to carrying capacity and fluctuate at that level, with little chance of extinction (Paul Rasmussen, pers. comm.).

The effect on extinction risk of varying the input parameters from the best estimates can be evaluated from other simulation results in Table 2. Simulations suggest that unless adult mortality is considerably larger than the best estimate (20% instead of 12%), factors affecting adult mortality alone are not likely to result in a declining population or substantially increased extinction risk. Other input parameter combinations that resulted in a decreasing population growth rate included either an increased median age at first breeding (age 4) or a decreased percentage of successful nesting (36% instead of 46%). These may represent conditions that are more likely as the Wisconsin population occupies available nesting habitat. Increased variability in juvenile and 1-2 year mortality and increased frequency of weather-related catastrophe increased the extinction risk somewhat, although these populations increased on average. Decreased initial population size resulted in a small increase in extinction risk, unless coupled with decreased nest success, which increased extinction risk more substantially (Paul Rasmussen pers. comm.).

What the models show is that the restored Wisconsin population of Trumpeter Swans has increased rapidly in the last decade even as releases of birds hatched from Alaskan eggs have stopped. Simulations reported here using the best estimates of demographic parameters for Wisconsin imply that the population should continue to increase with little likelihood of extinction or even significant decline. Even with moderately increased environmental variation and increased likelihood of weather-related catastrophes, simulations indicated little chance of extinction or decline. There is uncertainty involved in the estimation of all input parameters for the simulations, but parameters would have to be substantially different from the best estimates before extinction risk would increase significantly. Because mortality rates were based on estimates from western U.S. populations, it would be useful to obtain mortality estimates from Wisconsin birds for a future PVA (Paul Rasmussen pers. comm.).

Comparison of the Wisconsin Trumpeter Swan population to western U.S. populations suggests that all the populations probably have low adult mortality, but that the Wisconsin population differs from the western U.S. populations in having a lower age of first reproduction and greater nest success. The restored Wisconsin population may be in the process of filling up available breeding habitat; as the population increases, it may eventually be limited by breeding habitat. As that happens, the age of first breeding and nest success may change to levels closer to those seen in established western U.S. populations, leading to a decline in the population growth rate. Continued monitoring of age at first breeding and nest success are recommended (Paul Rasmussen, pers. comm.).

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Table 1. Values of parameters used in population modeling. Parameters and parameter names follow the usage of the software package VORTEX (Lacy *et al*. 2005).

Parameter	Input value		Comments
Species Description			
Inbreeding depression	N		Eggs originate from diverse Alaskan population
EV concordance in survival and repro	N	Factors affecting young and adults differ	
Number of catastrophe types	2	Disease, weather	
Reproductive System			
Breeding system	L-t M	Long-term monogamous	
Female breeding age	3 – WI 4 – West		Median age of first breeding
Male breeding age	3 – WI 4 – West		
Maximum age	15	Maximum age of reproduction; lifespan up to 25+ Known to breed at age 12 from WI;	
Sex ratio	0.5		?
Maximum brood size	8		WI data
Density dependent Breeding	N		
% females breeding	46%		WI data – probability that a given adult female will successfully produce offspring: .64 x .72 = .46
EV in % breeding	10		10 used for Whooping Cranes
Brood size	1 – 26 2 – 18 3 – 14 4 – 14 5 – 12 6 – 11 7 – 4 8 – 1		WI data, 1996-2004
Mortality rates			
Females and males (same)			
Age 0 – 1	rate	45	From literature and WI analyses
	SD	5	
Age 1 – 2	rate	30	
	SD	5	
Age 2 +	rate	12	
	SD	5	
Catastrophes			
Disease			
Frequency	5%	Whooping crane model	
Severity – Reproduction	1	No effect; assume disease is not occurring during breeding	
Survival	.7		
Weather			
Frequency	2%	10% used in some simulations	
Severity – Reproduction	.5		"
Survival	.9		"
Mate monopolization			
% male breeders	90	Not known	
Initial population			
Stable age distribution	Y		

Initial population size 300
Carrying capacity 700
Harvest N
Supplement N?

Notes on Breeding: The percentage of adult females breeding is the probability that a given adult female will successfully produce fledglings in a given year. The percentage was calculated from the product of the proportion of females attempting to breed (.64) and the proportion of those females that produced at least 1 fledgling (.72). Annual survival rates were for: 1) fledging to 1 year later, 2) 1+ to 2 years old, and 3) 2+ to 3 years old.

Table 2. Extinction risk and population growth rate under specified combinations of input parameters using VORTEX. All simulations began with an initial population of 300 swans with a stable age distribution. In each case 100 populations were simulated for 100 years. Conditions in **bold** are the best estimates based on Wisconsin data and literature values.

Breeding Age	Adult Mortality	Juvenile Mortality	Juvenile Var	Age 1 – 2 Mortality	Age 1 – 2 Var	Successful Breeding	Frequency of bad Weather	Probability of Extinction	Probability of N < 100	deterministic % annual change
2	12%	45%	5%	30%	5%	46%	2%	0.00	0.00	10.4
2	15%	45%	5%	30%	5%	46%	2%	0.00	0.00	8.1
2	20%	45%	5%	30%	5%	46%	2%	0.00	0.01	4.3
3	12%	45%	5%	30%	5%	36%	2%	0.00	0.01	2.2
3	**12%**	**45%**	**5%**	**30%**	**5%**	**46%**	**2%**	**0.00**	**0.00**	**6.0**
3	12%	45%	10%	30%	10%	36%	10%	0.06	0.25	0.7
3	12%	45%	10%	30%	10%	46%	10%	0.00	0.01	4.5
3	12%	55%	5%	30%	5%	36%	2%	0.14	0.54	-0.7
3	12%	55%	5%	40%	5%	36%	2%	0.66	0.99	-2.8
3	12%	55%	5%	30%	5%	46%	2%	0.01	0.02	2.8
3	12%	55%	5%	40%	5%	46%	2%	0.03	0.24	0.6
3	15%	45%	5%	30%	5%	46%	2%	0.00	0.00	3.5
3	15%	45%	10%	30%	10%	46%	10%	0.01	0.10	2.0
3	20%	45%	5%	30%	5%	46%	2%	0.21	0.55	-0.7
3	20%	45%	10%	30%	10%	46%	10%	0.58	0.90	-2.1
4	12%	45%	5%	30%	5%	36%	2%	0.06	0.53	-0.3
4	12%	45%	5%	30%	5%	46%	2%	0.00	0.01	2.9
4	15%	45%	5%	30%	5%	46%	2%	0.04	0.32	0.3
4	20%	45%	5%	30%	5%	46%	2%	0.93	1.00	-4.0

Additional simulations with conditions same as best estimates for Wisconsin except for parameters listed below.

Initial Population	Successful Breeding	Probability of Extinction	N < 100	% annual change
100	36%	0.07	0.17	2.2%
100	46%	0.00	0.00	6.0%
200	36%	0.01	0.05	2.2%
200	46%	0.00	0.00	6.0%