ABSTRACT

STAHALA, CAROLINE. Demography and Conservation of the Bahama Parrot on Great Abaco Island. (Under the supervision of Thurman L. Grove)

The status of the Bahama Parrot throughout the Bahamas Archipelago has been of concern since 1976, when the species was listed as endangered. To recover the species, two recommendations were put forth in the 1980s. First, to minimize the impact of mammalian predation on the Abaco population, secondly, reintroduce the species to historical portions of its range. Lack of sound biological information has precluded determining the status of the populations and potential of either parrot population to serve as a source for a translocation program. The goal of this study was to ascertain the current status of the population in Abaco and assess its viability. To meet this goal, I estimated population size and juvenile survival rates. I augmented information regarding reproductive ecology of the population by estimating nest density, nest success using the Mayfield method, estimating effects of mammalian predation upon nest survival and breeding adult survival rates. I used these data to determine if nest survival differed as a function of nest density, habitat condition (e.g., burned-unburned), and location (e.g., in or outside the Park). I used period survival of adults to assess the costs of reproduction on adult breeder survival rates. I also collected data on food availability and distribution of parrots to qualitatively assess seasonal habitat use and food availability. Finally, I used program VORTEX to determine the status of the species and address the following questions: 1) what is the viability of the Abaco population?; 2) by how much do predators and hurricanes undermine the persistence of the Abaco population?; 3) to which

parameters is the Abaco population most sensitive to, and 4) what is the combination of lowest values for selected vital parameters that would lead to a persistent population?.

Population numbers of the Bahama Parrot estimated in May 2002 to 2004 ranged from 1578 to 2600. In 2005, only 1/3 of parrot detections were made as compared to previous years. I believe passage of hurricanes Frances and Jeanne in September 2004 contributed to this drop. Breeding productivity in 2003 was 1.23 fledglings per nest attempt. In 2004, breeding productivity was 0.8. Nest success was 0.5. Daily survival probability did not differ between high density areas (0.025 nests/ha) when compared to nests in lower density areas (0.008 nests/ha). On 10 July 2004 a lightning ignited fire burned over 1,850 m^2 of the study area. None of the nests in the path of the fire were lost to its immediate impact. Nest success of these nests did not differ significantly from unburned nests 0.47 vs 0.51 respectively. The total estimated number of nests in the study area was 289 (SE = 85). In 2004, 578 (95% CI = 238-918) birds were breeding, or 22% of the estimated population. Survival of breeding adults during the nesting cycle was estimated to be 0.87 for females and 0.92 for males. Thirty-one nestlings where instrumented in 2003, of which 3 died after climbing out of the nest. The estimated first-year survival probability for the remaining 28 juveniles was 0.76 (95% CI = 0.53 - 0.99).

Birds concentrated in two areas to the north and southwest—Crossing Rock and Sandy Point. Distribution patterns corresponded closely with patterns of food availability. Food availability was lowest during the winter, the period with the highest mortality of juveniles.

Population simulations yielded a persistence probability for the Abaco population of 0.997 over 100 years. However, the stochastic-r was -0.012, resulting in a decline of

population size over this period. The only scenarios that yielded a positive stochastic-r was one with no predation by introduced mammals, or one with a breeding productivity of 1.4 chicks/nest attempt.

I view the Abaco population vulnerable to extinction. An "endangered" designation is not justified at this moment because both populations enjoy relatively large population sizes, and with the exception of mammalian predation, no imminent threats to their continued existence. In order to prevent an "endangered" designation, my results strongly suggest that Abaco non-breeding habitat be protected and that an effective predator control program needs to be implemented. Translocations continue to be central to the conservation of the species. Currently, the Inagua population is the preferred source of birds for translocations due to its tree-nesting habit, which offers a mechanism to deal with threats of mammalian predation at reintroduction sites. Translocations should be supported by sound demographic data and a genetic assessment that would identify ways to maintain maximum genetic diversity of the species and its multiple populations.

DEMOGRAPHY AND CONSERVATION OF THE BAHAMA PARROT
ON GREAT ABACO ISLAND

BY

CAROLINE STAHALA

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
Requirements for the Degree of
Master of Science

ZOOLOGY

Raleigh

2005

APPROVED BY:

_____   _____
Dr. Thurman L. Grove   Dr. Nick Haddad
Chair of Advisory Committee

_____   _____
Dr. Frank Rivera-Milán   Dr. Kenneth H. Pollock

BIOGRAPHY

I, Caroline Stahala, was born in Basel, Switzerland where I lived until 1986. Cornelius, NC is the town I grew up in until I left for college at the University of North Carolina at Chapel Hill where I majored in Biology and discovered the field I am currently pusuing.

I have always had an interest in animals and the environment but had no idea how to pursue what I loved, much less how to make a career of it. I realized field research was the path I wanted to follow thanks to Dr. R. Haven Wiley and his vertebrate field zoology class. I can thank Dr. Wiley for introducing me to birds and how to truly appreciate their splendor and diversity. After graduatinf fro UNC I tried to take in as many experiences in the field as I could. I was lucky enough to work with animals such as prairie dogs, ferrets, sparrows and primates. My fondest experiences come from the time I spent at Bowdoin National Wildlife Refuge in Malta, Montana and Merritt Island National Wildlife Refuge in Florida.

My next adventure leads me back to Florida. I am now what I have always wanted to be, a Biologist. I am pursuing my passion in Panama City Florida working with more Endangered Species for the Fish and Wildlife Service.

ACKNOWLEDGEMENTS

Gina Mori, Garth Herring and Nancy Albury for their encouragement during the time at

NC State and in Abaco.

TABLE OF CONTENTS

List of Tables

Chapter 1

List of Figures

Chapter 1

Chapter 2

List of Maps

Chapter 1

Map 7. Distribution pattern of instrumented Bahama Parrots (adults and
juveniles) with respect to a fruit availability index over southern Abaco
for May 2005. I created "areas" where the birds were likely to be,
bounded by the farthest distance a bird could be detected from my position
(i.e., ca. 2 km). The food availability index follows an abundance scale
from 0 to 10. Data were collected at 52 vegetation plots randomly
selected across the study area. North ridge only depicted by location

Introduction

Bahama Parrots (*Amazona leucocephala bahamensis*), formerly found throughout

the Bahamian archipelago, are currently restricted to the islands of Abaco and Great

Inagua (Snyder et al. 1982, Gnam 1991). Low population numbers and predation

pressure prompted concerns about the species' persistence and led to its designation as an

endangered species by the Bahamas Government and CITES. Other factors believed to

adversely affect the species are hurricanes, habitat loss or alteration (e.g., fire), and

poaching.

The Abaco population is unique among psittacines because nesting occurs

underground in limestone cavities. This nesting habit may place the Abaco population at

greater risk of local extinction than the one at Great Inagua, which nests in tree cavities.

The risk stems from predation by feral cats (*Felis sylvestris*) and rats (*Rattus rattus*;

Gnam 1991, Gnam and Rockwell 1991a). Concerns about the possible impact of

raccoons (*Procyon lotor*), introduced in the early 1990s, have been heightened by reports

that they are becoming more abundant and widespread on the island. These mammals are

highly efficient predators (Gnam 1991, Strong et al. 1991, VanderWerf 2001). The

implications of mammalian predation to the demography of parrots gains greater

importance because nesting adults, particularly females, are also vulnerable.

Snyder et al. (1982), Gnam (1991), and Wiley et al. (1992) made two basic

recommendations to foster the continued survival of the Bahama Parrot, namely,

minimize the impact of predation and reintroduce populations across the species' historic

range. Implicit in these recommendations is the need to assess the demography of parrots

and determine what impact predators have on the nesting population. This was the goal

of my study--to provide a better quantitative demographic framework with which to assess the status of the species and formulate appropriate conservation strategies to insure their continued existence. To address this goal, I addressed several objectives.

In Chapter 1 I summarized data on three objectives. These were: 1) estimate population size and breeding population size; 2) estimate breeding productivity and assess nesting success as a function of two conditions (e.g., fire, nest density); 3) estimate survival rates of juveniles; and 4) assess seasonal food availability and distribution. These data were used to assess the status of the species and the ecological basis for its vulnerability to extinction.

In Chapter 2, I summarized the results of a population viability analysis of the Abaco population. As input for the modeling, I drew primarily from the data generated in this study and previous and recent work on the species (Snyder et al. 1987, Gnam 1991, Wiley et al, 2004, Rivera-Milán et al. 2005). When appropriate, I also drew from demographic data on other Amazona in the West Indies.

It is hoped that the findings presented herein will advance conservation efforts of the species in Bahamas and serve as a model for demographic assessments for the other races of *A. leucocephala, namely, A. l caymenensis*, and *A. l. hesterna*, as well as for other species of *Amazona* in the Caribbean and elsewhere.

Chapter 1

Population Ecology, Impact of Disturbance and Habitat use of Bahama
Parrots on Great Abaco Island.

Introduction

Eight of 20 parrot species in the genus *Amazona* in the West Indies are extinct

(Wiley et al. 2004). The remaining twelve species are categorized as "at risk" to

"critically endangered" by the IUCN 2001 and CITES. One of the underlying reasons for

this pattern is that parrots on islands face a greater risk of extinction than parrots found on

continents (Beissinger and Snyder, 1992). Island species are generally isolated, have

access to limited habitat areas, and exposed to disturbance. In the West Indies, species

are vulnerable to hurricanes. Degradation of feeding resources and habitat are prevalent

in the aftermath of these storms (Wiley and Wunderle 1993, Collazo et al. 2003). Species

on islands with flat topography are particularly vulnerable due to the uniform impact of

the storms on vegetation and lack of refuge, such as leeward slopes. The extinction risks

of *Amazona* species are compounded by anthropogenic pressures. Habitat encroachment

and loss and the introduction of exotic mammals have been linked to population

reduction, extirpation, and extinction of *Amazona* species in the West Indies (see Wiley

et al. 2004).

The Bahama Parrot (*A. leucocephala bahamensis*) is facing the same natural and anthropogenic pressures threatening other *Amazona* species in the region. The species was formerly found throughout the Bahamian archipelago (Olson and Hilgartner, 1982). Until the 1950's when it is believed that the Ackilin's Island population was extirpated (Bond, 1947; 1956a; 1956b). Currently populations of the Bahama Parrot are found only on Great Abaco and Great Inagua Islands (Snyder et al. 1982, Gnam 1990). Low population numbers and limited distribution raised concerns about the species' persistence and led to its designation as an endangered species by the Bahamian Government, US Government, and other conservation organizations (ICBP, 1981; USFWS, 1976, CITES; Collar 1992). The Abaco population is unique among psittacines because it nests in limestone solution cavities on the ground. This nesting habit may place the Abaco population at greater risk of local extinction than the population on Inagua, which nests in tree cavities, due to differential vulnerability to predation. The underground nesting habit has also raised concern about the potential impact fires might have on nesting adults and chicks.

The unique underground nesting habit prompted an investigation of the breeding biology of the Abaco population in the mid 1980's (Gnam 1990). The study showed that feral cats (*Felis sylvestris*) represented the greatest threat to nesting success and nesting adults (Gnam 1990, Gnam and Rockwell 1991a). Gnam and Burchstead (1991) reported that 50% of the nesting females attacked by feral cats in 1988 (14 instances) were killed, thereby, reducing breeding productivity and the effective population size of the population. Incubating females may spend up to 23 hrs a day in the ground cavity nests, making them particularly vulnerable to mammalian predation (Gnam 1990). The impact

of mammalian predation could be exacerbated by raccoons (*Procyon lotor*), introduced in

the early 1990s. Cumulative, but anecdotal information reaching the Bahamas

Department of Agriculture suggest that raccoons are increasing in numbers and

expanding into southern Abaco (D. Knowles, pers. comm.).

Gnam's study, coupled with parallels between the Bahama Parrot and other

declining species of parrots in the region, led to two basic recommendations to foster

their continued survival (Snyder et al., 1982; Gnam and Burchstead, 1991; Wileyet al.,

2004). The first one was to minimize the impact of predation on Abaco Island, and the

second was to reintroduce the species across its historic range. Neither one of these

recommendations have been implemented to date. However, Gnam's study prompted the

creation of the Abaco National Park in southern Abaco in 1994. It is administered by the

Bahamas National Trust and the Government of the Bahamas, and protects the primary

breeding area of the parrot. The park covers 8,302 ha with the Caribbean pine (*Pinus*

caribbaea) and some hardwood coppice stands as the dominant, emergent forest cover.

The creation of the Abaco National Park was an important first step towards

insuring the continued survival of the species. However, similar to the situation of many

other endangered species, framing a comprehensive conservation program is usually

hampered by minimal demographic data and limited information on habitat requirements

(Heppell et al. 2000, Snyder et al. 2000, Hirzel et al. 2002). Available data on roost

counts and on breeding productivity (Snyder et al. 1982, Gnam 1991, Gnam and

Burchsted 1991), although useful, fall short of the data needed to make more definitive

statements about the status of the species, to understand the ecological basis for their

vulnerability to extinction, or to assess the adequacy of the Abaco National Park to meet

year round habitat requirements. Short-comings include roost counts that are not adjusted by detection probability (e.g., Williams et al. 2001), which in the 1980s yielded population size estimates of 800-1100 individuals (Gnam and Burchsted 1991). Data on breeding productivity were thorough and collected over a 4 year period (Gnam and Rockwell 1991a). Parrots fledged an average of 0.88 young per nesting female. A broader assessment of the population's reproductive performance necessitates, however, that nest searches be conducted throughout southern Abaco, not just the suspected core nesting area, and that breeding productivity be evaluated in the context of factors like fire and dispersion (e.g., density).

In this work, I addressed some of the remaining, but fundamental gaps in our understanding of the demography of the Abaco population. My goals were to assess the status of the species and provide a basis to assess the viability of the population in light of various conservation scenarios (e.,g., translocations). To address these goals, I estimated pre-breeding population size (adjusted counts) and first-year survival rates of juveniles. I also expanded Gnam's (1991) work on reproductive ecology in several ways. I estimated nest density across southern Abaco, expressed nesting success as survival probabilities (Mayfield estimates), and estimated survival for nesting adults. I used these data to determine if nest survival differed as a function of nest density, habitat condition (e.g., burned-unburned), and location (e.g., in or outside the Park). I hypothesized that density and fires could influence predation rates by re-enforcing search images and reducing horizontal cover (Martin 1988a, Martin and Ropper 1988, Martin 1996). I used period survival of adults as a means to assess the full impact of nesting in underground cavities because adult breeders, not just chicks, are vulnerable to predation. I hypothesized that

individuals tending the nest, particularly females (Gnam 1991), could have lower annual

survival. Finally, I also collected data on food availability and distribution of parrots

over 10 months to qualitatively assess seasonal habitat requirements, and if those

requirements were being met primarily within the Abaco National Park boundaries.

Study Area

Abaco Island is the northern most island in the Bahamas archipelago. The study

area was restricted to the southern portion of Great Abaco Island from the settlements of

Crossing Rocks (W 77.19 °, N 26.14 °) and Sandy Point (W 77.4 °, N 26.01°) to Hole-in-

the-Wall (W 77.2 °, N 25.89 °) (Map 1). The area encompassed within these locations

was 25,604 ha. Abaco National Park (8,302 ha) is located between Crossing Rocks and

Hole-in-the-Wall (Figure 1). A matrix of old logging roads traversed the study area,

which allowed access to most parts of the study area (Figure 1). Ridges reached a

maximum elevation of 37 m; soils were composed of limestone, and the vegetation was

characterized by species such as Caribbean pine (*Pinus caribaea*), pond top palm (*Sabal

palmetto*), poisonwood (*Metopium toxiferum*), gumbo limbo (*Bursera simaruba*), and

pigeonplum (*Coccoloba diversifolia*). See Snyder et al. (1982) and Gnam (1991) for

more information on Great Abaco Island.

Methods

Population Estimates

Population estimates were obtained using point-transect surveys and analyzed

with a distance sampling method (Buckland et al. 1993). Sampling took place in May

2002, 2003, 2004, and 2005. Results of the 2002 and 2003 surveys were summarized in Appendix 1. Surveys in 2004 were conducted in May 9 - 18, and in 2005, in May 23 - 31. Sampling was conducted during mornings (sunrise to 10:30) and evenings (16:30 to sunset). A sampling grid of point transects was set up in a systematic-random fashion (Rivera-Milan et al 2005). Point count stations were reached using cleared logging roads throughout Southern Abaco. During 2004 and 2005, 199 and 144 stations were surveyed, respectively. At each station, a two-person team recorded distances to individuals or clusters of parrots. Cluster sizes were determined by counting individual birds. Distances were measured using rangefinders. Each count station was monitored for six minutes before moving on to next station. Program DISTANCE 3.5 was used to analyze the point count data (Laake, 1998). Rivera-Milan et al. (2005) detailed procedures, assumptions, and criteria to select best models (i.e., AIC). For comparative purposes, I reported estimates of the same model parameters and results for the 2004 and 2005 surveys. The same models were not always selected for each year. As suggested by Rivera-Milan et al. (2005), I pooled data collected in the mornings and afternoons to improve the quality of density estimates. Before pooling, I also determined that there was no difference between morning and evening density estimates (AM: 0.079 ± 0.025; PM: 0.117 ± 0.051; $Z = 0.67$, $P > 0.05$). I estimated population size by extrapolating density estimates to the area covered by the surveys, which was defined as the area from which points were randomly selected (i.e., $\hat{N} = \hat{D} \times A$; where $A = 25,604$) ha in southern Abaco.

Nest Density Estimates

In 2003, nests were found primarily by walking through the study area and focusing efforts in areas of high parrot activity. Search efforts extended to other portions of the study area, but did not follow a pre-determined sampling scheme. Once in a search area, behavioral cues were used to locate nests. Cues included when birds were perched close to one another but not foraging. Parrots usually perch on a pine branch near the nest. Parrots slowly move to lower branches until right above the nest. One adult usually stays on a pine branch above the nest, while the other hops to the ground beside the nest and moves into the nest cavity tail first.

In 2004, searches followed a stratified random sampling scheme to obtain estimates of nest density and ascertain patterns of distribution. The study area was subdivided into 4 strata based on data from 2003 and pre-breeding season scouting trips in 2004—high-use, mid-use, low-use and no-use nesting areas. Within each stratum, I defined "quads" or sampling areas as the rectangular area created by parallel logging roads (Figure 1). Each quad was assigned a unique number. Quads were selected randomly in all strata but the high-use stratum. There, 2- 4 quads were randomly selected within every "strip" of quads (i.e., formed by parallel logging roads). I followed this approach to obtain the most accurate nest density estimate in the core nesting area.

Searches occurred from sunrise until 10:30, and from 16:00 until sunset. These times were peak activity periods for breeding parrots. As in 2003, behavioral cues were used to locate nests once the searcher reached a sampling quad. The searcher would begin searching from the center of the quad, which was determined by a GPS (Garmin 12X units). Once parrot activity began in the quad the searcher would investigate the

parrot activity to determine if nests were present in the area. A zero (i.e., no nests) was assigned to quads if no parrot activity was recorded, or nests were not found. If parrots exhibited nesting behavior and no nest was found, that area was revisited. An area was also revisited if the searcher felt that he/she was not able to monitor all of the parrot activity within the quad.

Because the area within quads was large (ca. 800 x 250 m), the possibility of missing active nests existed. Therefore, I calculated an estimate for the probability of detecting a nest to adjust density estimates accordingly. The estimate was obtained by sending each nest searcher into 11 quads that the searcher had not visited, but where I knew the location of nest not yet located in 2004 by nest searchers. The assumption was that all nests had the same probability of being found. The fraction of known nests found over all known nests was used as the estimate of detection probability $\hat{p}_N = \dfrac{x}{n}$ where x is # of nests found by searchers and n is the # of nests known of. The

$$SE(\hat{p}_N) = \frac{\sqrt{\hat{p}_N(1-\hat{p}_N)}}{n}$$ from the properties of the binomial distribution.

Nest Monitoring and Nest Survival Estimates

Once nests were found, they were monitored approximately every 4 days. I used either a flashlight or a peeper camera to check nest contents. Daily and nesting cycle survival rates were estimated using the Mayfield Method (Mayfield 1975; Johnson 1979; Etterson and Bennett 2005). Number of exposure days began the day the nest was found until failure or fledging of the nest (90 days incorporating asynchronous egg laying and fledging; Gnam 1991). Decisions concerning days of exposure followed protocols

outlined by the Breeding Bird Research and Data Program

(http://pica.wru.umt.edu/BBIRD/). I used Z-tests to determine if daily survival rates

differed between burned and unburned areas and high nest density areas with lower

density areas. For the latter test, I pooled all nests in the low-density strata categories to

obtain a more reliable Mayfield estimate (i.e., increase sample sizes, Hensler and Nichols

1981). I used a chi-square contingency test to determine if the frequency of predation

was associated with nest density (Steel et al 1997). Finally, I also examined whether

daily survival rates differed between nest occurring in and outside the National Park.

Although this test and the one examining differences in survival rates among density

levels share similarities, they differ in that the Park contained areas of high and mid-

density of nests, not just high density, and I wanted to explicitly address the belief in the

conservation community that a "protected" area was beneficial to parrots in all aspects of

their biology.

I used a variation of the Mayfield method to estimate a breeding period survival

for tending adults, similar approaches have been used for telemetered animals (Heisey

and Fuller 1985). For this estimate, a "failed nest" was defined as those in which an adult

was killed by predation. All other cases, even when either eggs or chicks were lost, were

considered "successful" because the tending adult "lived" to nest again in 2004, or the

following year provided the adult survived the non-breeding season. In other words, the

metric of interest, exposure days, was restricted to the time adults were subject to

predation in the nest. The resultant survival rate (period-specific) for breeders multiplied

by their survival rate during the non-breeding period (e.g., similar to non-breeder adults)

would give me an indication of how much predation undermines survival for breeders

$[(\phi_{breedingperiod})(\phi_{nonbreedingperiod})]$. I estimated this impact on adult breeder annual survival under three scenarios. Under the first one, the female was the only member of the pair caring for the nest and nestlings, thus the only one vulnerable to predation over entire nesting cycle (90 days). Under the second scenario, males and females share nest caring duties and were equally exposed to predation during the entire nesting cycle. The third scenario assumed that females were responsible for incubating the eggs plus staying in the nest 10 days after hatching. Thereafter, the male and female share the responsibility of feeding chicks (Gnam 1991). Under this scenario, females are exposed 90 days, whereas males are exposed only 50 days. As an estimate of non-breeding survival, I used data from the literature and empirical estimates based on a few radio tagged adults.

Juvenile Survival and Seasonal Distribution

A modified Kaplan-Meier procedure was used to estimate juvenile survival rates, allowing for the staggered entry (start of monitoring) of individuals as they fledged (Pollock et al. 1989). Cumulative data were recorded by tracking 28 juveniles that were instrumented with Holohil model SI-2C transmitters two weeks prior to the estimated fledging date (Meyers et al. 1996). An array of 14 treetop platforms and observation towers was set up throughout the study area to track parrots, but readings were also taken from the ground level as needed (Figure 2). Birds were tracked every other day. When tracking suggested that an individual had not moved in several days, a search was conducted to determine if it was dead or alive.

I report weekly survival and cumulative survival rates. The survival function (S[t]) is the probability of a given animal in a population surviving t units of time from

12

the beginning of the study. I was able to monitor birds for 40 weeks, but used 37 weeks (9 months) as the cutoff point to conduct analysis and the best approximation for estimating first-year survival. I selected this cut-off point because the number of readings was low past 37 weeks (i.e., high number of censored/undetected birds), inflating precision levels, and I also suspected that some batteries were failing. Battery life of transmitters used in this study was expected to be 9-11 mo. I assumed that survival was 1 for the next 3 months. I did not record any additional mortality during that period for those birds which still had active transmitters and for whom environmental conditions (e.g., food abundance) became more favorable (see FAI values for May below). Finally, this method assumes that survival probabilities were independent among birds. This assumption may not be valid due to the species being gregarious and being found in flocks, it is not known by how much this assumption could narrow precision levels around our survival estimates (K. Pollock, pers. comm., NCSU).

As I tracked juveniles, I recorded the approximate location of their occurrence from my GPS-referenced position. In most cases, I recorded direction and approximate distance from my position. I used these data to describe their distribution and gain insights on their movements through 37 weeks. I created "areas" where the birds were likely to be, bounded by the farthest distance a bird could be detected from my position (i.e., ca. 2 km), and overlaid these on a map of the study area (Map 2-4). Although the resultant "areas" where birds could occur were large, my aim was simply to detect their distributions and movements over large areas, particularly in light of patterns of food availability (see below).

Plant Phenology and Fruit Availability

Vegetation surveys were conducted in June, July, August (summer) and December 2003, and May 2004. Thirty points in coppice and 22 points in pine were randomly selected from point count stations used for population estimation. Once at the station, I randomly selected whether to sample to the left or right of the road. The sampling plot had a radius of 11.2 m (Martin and Guepel 1993) and was established 5 m from the road. The plot was divided into four quadrants, and two opposite quadrants were randomly selected for sampling. At each quadrant, I recorded the presence or absence of 24 plant species known to be used by Parrots (Gnam 1990 and 1991). In addition, I noted which plants where in fruits, and estimated a fruit availability index adopting the scale used by Carlo et al. (2003). The scale was: 0 (no fruits),1 (1-10 fruits), 2 (11-50 fruits), 3 (51-100 fruits), 4 (101-500 fruits), 5 (501-1000 fruits), 6 (1001-5000 fruits), 7 (5001-10,000 fruits) and 8 (10,001+ fruits). I report the total number of fruits and pine cones found per plot for each sampling period. The food availability index in this case was defined as the sum of the mid-points per plant species per plot, summed over all species. For the summer months, values were averaged. The plot-specific values were depicted on a map of the study area. Size of the circle denotes the amount of fruit available per month, and corresponds to the food availability index scale. Pines were not included in the above fruit estimate. Pines cone availability is limited to April – September while cones are maturing (green cones). The number of pines within each plot was also documented along with the DBH and number of mature cones on each tree.

The relationship between the number of mature cones and pine dbh was examined using regression analysis.

Results

I made 51 detections of parrot singles and clusters in 199 points surveyed in 2004 (total surveyed area: $k\pi r^2 = 199 \times 3.14159\ldots \times 440^2 \div 10,000 = 12,103.45$ ha). Detection probability was 0.22 and the cluster size was 2.3 (Table 1; Table 2). Effective detection radius was 135m and I truncated data at 290m (Table 1). The half normal function provided the best fit to the data ($AIC_c = 557$; next best model AIC =559). Other parameters of interest stemming from the analyses are summarized in table 2.

The population density in 2004 was 0.102 parrots/ha (Table 1), for a population size of 2,600 parrots (SE = 656.08; 95% CI = 1,593 – 4,242) (Table 2). The 2004 density estimate was slightly higher than those obtained in 2002 and 2003, but not significantly so (Z tests, P > 0.05) (Table 1). Density estimates from Inagua were higher than any recorded in Abaco, albeit more variable (Table 1). Only the estimate from Abaco in 2002 differed significantly from the 2003 (Z = 2.39, P = 0.01) and 2004 (Z = 2.09, P = 0.02) Inagua density estimates.

In May 2005 I surveyed 144 stations (8,758 ha surveyed) and recorded only 13 detections of singles and clusters (Table 2). A population density of .031 parrots/ha was estimated with a Coefficient of Variation of 49%. This density results in a population size of 788 (SE = 387; 95% CI = 302 - 2053). A lower number of stations were sampled, as compared to previous years, because hurricane damage prevented access. The 2005 survey can be placed in another quantitative context when it is considered that a detection

of at least a bird was made in only 9% of the stations sampled as compared to an average

of 29% of the stations sampled (n = 177) in surveys between 2002 and 2004 (Table 3).

At the frequency of detection recorded in previous years, one would have expected to

detect a bird in at least 42 stations in 2005.

I monitored 38 nests during the 2003 breeding season and 77 in 2004. The first

nests were found late May of 2003 and first week in May of 2004. Breeding productivity

in 2003 was 1.23 (SE 0.22) fledglings per nest attempt. In 2004, breeding productivity

was 0.8 (SE 0.13). The 0.8 value is a conservative estimate based on the assumption that

all unfledged chicks that were still alive on September 1, 2005 (n = 43) died in the

aftermath of hurricanes Frances (September 3, 2004; Category 4 at landfall on Abaco)

and Jeanne (September 25, 2004; strong category 3 at landfall on Abaco) due to one or a

combination of drowning, death of parents, and lack of food. If it is assumed that all

fledged, then, breeding productivity would have been 1.23 (SE 0.15). Most of the 43

chicks were 1 to 7 days away from fledging. Unfortunately, nests could not be monitored

after the hurricanes to ascertain their fate.

In 2004, I monitored the nest cavities used in 2003. Of 38 nests, 20 were

successful (Figure 3). Of these, 15 were reused in 2004. Of the 18 unsuccessful nests of

2003, only 3 were reused in 2004. Additional insights on reuse of nesting cavities were

gained from 6 banded and instrumented adults, all from different nests. Of these, 3

reused the same cavity as in 2003. A fourth adult nested close (ca. 100 m) but not on the

same cavity as in 2003. Of the remaining two adults, one was confirmed dead and the

other was not observed during the 2004 breeding season. The cavity used by the pair of

the dead bird in 2003, however, was used again in 2004.

16

Of the 77 nests monitored in 2004, 49 (64%) occurred within the Park. Seventeen nests were predated in 2004, and of these, 14 (82%) occurred within the Park. The daily survival probability of any given nest in 2004 was 0.9923 (SE 0.0013). The nest success (survival for the nesting cycle) was 0.5 (95% CI = 0.40 - 0.62; Table 4). Daily survival probability did not differ between areas classified as high density (0.025 nests/ha) when compared to all other nests occurring in lower density areas (0.008 nests/ha; $Z = 1.00$, $P > 0.05$). The incidence of predation was not associated with density (Chi-square = 2.21, d.f. = 1, $P = 0.14$). Daily nest survival rates in the Park were significantly lower than rates occurring outside the Park boundaries ($Z = 2.32$, $P = 0.01$, Table 4). Nest success for the entire nest cycle was 0.38 (95% CI = 0.26 – 0.56) in the Park and 0.65 (95% CI = 0.51 -0.83) outside its boundaries. On 10 July 2004, lightning ignited a fire that burned over 1,850 m^2 of the study area (Figure 2). Twenty-two nests were in the path of the fire, but none were lost to its immediate impact. Daily survival probabilities for nests that occurred in areas burned did not differ significantly from those that occurred on non-burned areas ($Z = 0.25$, $P > 0.05$; Table 4).

The probability of finding a nest in 2004 was 0.67 (SE = 0.026). After adjusting for detection probability, nest density estimates ranged from 0.006/ha to 0.025/ha (Table 5). The total estimated number of nests in the study area was 289 (SE = 85). This meant that about 578 (95% CI = 238-918) birds were breeding in 2004, or 22% of the estimated population size (i.e., 2,600).

Survival of breeding adults during the nesting cycle was estimated under three scenarios (Table 6). If females were the only member of the pair exposed, survival was 0.82 (95% CI = 0.73 - 0.93). If both members of the pair were equally exposed, their

survival probability was of 0.88 (95% CI = 0.83 – 0.94) for each adult in the breeding pair. And finally, if both members of the pair were differentially exposed, with females carrying the heavier burden, survival for female breeders was 0.87 (0.80 - 0.94), whereas for males it was 0.92 (95% CI = 0.88 - 0.97). Estimates of adult survival are few in psittacines; however, given that Amazons are long-lived, it is believed to be around 0.91-0.93 (Snyder et al. 1987, Muiznieks 2003, Wiley et al. 2004). Using 0.93 as the baseline value for non-breeders (and non-breeding period), and the various period survival estimates for breeders in 2004, annual survival for adult breeders in Abaco could range from 0.76 to 0.85.

Thirty-one nestlings where fitted with radio transmitters in 2003, of which 3 died after climbing out of the nest. The remaining 28 left the nest area, and constitute the cohort of juveniles monitored for 37 weeks. Four deaths were recorded during the study period, all occurring between November 2003 and January 2004. The estimated survival probability for that period was 0.76 (0.53 - 0.99) (Figure 4).

The distribution of occurrences for all instrumented parrots (28 juveniles, 5 adults) is summarized by trimester in Map 2. Movements occurred mostly in flocks of 2- 200 individuals. I monitored 5 juvenile-adult groups. Three of these groups remained together until late fall winter (November - December). Afterward the juveniles became independent. Two distinct patterns emerged in this study. First, post-fledging distribution encompassed the park and areas north of the study area. Second, winter occurrences were more scattered but many were recorded in the south-western portion of the study area (i.e., Sandy Point). Seasonal patterns of occurrences were consistent for adults and juveniles (Maps 3 and 4).

During June, July and August, food was available throughout the study area and areas north of it (e.g., privately owned lands; Map 5). From April through September, pine cones are an important component of the food resources available to parrots. I found that the availability of pine cones, the number of cones per tree, was positively and significantly correlated with pine dbh (F = 43.75, df = 1, 227, P < 0.0001). At this time, the distribution of occurrences was mostly concentrated in northern portion of the study area. By December 2004, food resources had become patchy (Map 6). Food was particularly scarce in the core nesting area. Bird occurrences had also become very segregated, many occurring in areas where plots had the highest food levels (e.g., Sandy Point sector). Parrot feeding activity in the pine forest at this time was associated with the presence of microstroboli of mature pine trees. Resources were substantially higher in May 2005, just prior to the onset of the breeding season (Map 7). Occurrences became more concentrated, particularly towards the northern third of the study area. These sectors included the core nesting area.

Discussion

Population numbers of the Bahama Parrot in Abaco ranged from 1578 to 2600 from 2002 to 2004. The size of the population in Inagua was almost twice as large as the one in Abaco (Rivera-Milán et al. 2005). Population levels from either island were considerably higher than for most other *Amazona* in the West Indies (Wiley et al. 2004). For example, the population of the Cayman Brac Parrot (*Amazona leucocephala hesterna*) is estimated at 300 – 430 parrots. The Imperial Parrot (*Amazona imperialis*) and Red-necked Parrot from (*Amazona arausiaca*) from Dominica have estimated

population sizes of 150 and 800, respectively. The St. Vincent Amazon (*Amazona guildingii*) is estimated at 519 parrots. Only populations of the Hispaniolan Parrot (*Amazona ventralis*), Cayman Amazon (*Amazona leucocephala caymanensis*) and Cuban Parrot (*Amazona leucocephala leucocephala*) are believed to have population levels as high as those reported for Abaco or Inagua (Wiley et al. 2004).

Population levels recorded during this study were encouraging because, as a locally endangered species, recovery efforts would be less likely to confront problems faced by other endangered *Amazona*. For example, the population size of the Puerto Rican Parrot (*A. vittata*) is less than 35 individuals. Problems range from highly variable reproductive rates to low number of breeding pairs (Snyder et al. 1987). Genetic diversity in the captive population does not been lost (Haig et al. 2004). The demographic inertia (e.g., stagnant growth rates) exhibited by the species for nearly 35 years prompted the US Fish and Wildlife Service to implement a release program in 2000 to bolster numbers of the wild population (White et al. 2005a). Excluding genetic considerations, my study suggested that these considerations or recovery measures were not an immediate concern or necessary for parrots in Abaco, particularly if the factors influencing the vital parameters discussed below do not worsen.

The 2004 hurricane season exposed the inherent vulnerability of avian populations in the Caribbean to such catastrophic events (see Wiley and Wunderle 1993). Two major hurricanes (category ≥ 3) hit Abaco in September 2004. Due to practical limitations (e.g., logistics, time) I could not fully assess their impact. The strongest indication of their impact was the marked reduction in population size for southern Abaco during a post-hurricane survey in May 2005. However, the low population size

from the southern Abaco surveys could be explained by birds being alive but elsewhere. Thus, an estimate of the severity hurricanes on survival, as well as reproduction, one year post-hurricanes was not estimable. The impact of hurricanes, however, can be devastating (Wiley and Wunderle 1993) and their impact on population persistence substantial (Chapter 2). In stochastic simulations, population persistence dropped from 0.99 to 0.85 by increasing the impact of hurricanes on survival and reproduction from 0.9 (or 10% impact on both vital parameters) to 0.7. The relationship between population size and the risks of extinction are exemplified by the Puerto Rican Parrot. In 1989 hurricane Hugo hit the only wild population, reducing its size from 47 to 23 individuals (FWS 1999, Wiley et al. 2004). The longer term impacts of hurricanes are more difficult to measure, but they are equally important (Wiley and Wunderle 1993). Collazo et al. (2003) documented a drop of 23% survival in just 8 weeks post-hurricane, largely associated with depleted food resources as a result of hurricane damage. To cope with degraded habitat, birds increased their foraging range by 3 times, from 4,884 to 15,490 ha (White et al. 2005b). Reproductive success in Abaco is being monitored in 2005, paying particular attention to the extent of cavity reuse. My findings suggest that this could be high, particularly for successful pair (75%). A low number of reused cavities could be construed as indicative of lower habitat quality (e.g., lower food availability), preventing meeting pre-breeding requirements, contributing to mortality, or both (Wiley and Wunderle 1993; Collazo et al. 2003). This kind of monitoring is important because, for species like the Puerto Rican Parrot, a reduction in the number of breeding pairs and of reproductive output was noted for as many as 2-3 years after the hurricane (Muiznieks

2003). Such a possibility is important to appropriately model the full impact of

hurricanes on the species population dynamics and persistence.

The 2005 hurricanes also underscored a characteristic of the Bahama Parrot that

could be viewed both as a strength and as a weakness. Inagua, 400 miles to the south,

was hit by tropical storm Jeanne in 2005 and Hurricane Frances passed off shore.

Population surveys showed that population numbers have remained around the same

levels as in 2003 and 2004 (ca. 5,280 birds, Frank Rivera-Milan pers. comm.). Thus,

while the benefits of multiple, isolated populations were evident in this case, marked

isolation not only hinders gene flow, but in the aftermath of a catastrophic event, it also

undermines the possibility of "rescue effects" (Brown and Kodric-Brown 1977);

Akcakaya and Atwood 1997).

My study strongly suggested that persistence, and likely the immediate recovery

of a post-hurricane population, could be hampered by the insidious presence of

mammalian predation. Predation curtailed breeding productivity, affecting 22% of the

nests. Breeding productivity would have been 1.17 instead of 0.8 when cat predated nest

where not removed from estimates. Predation, however, had another serious

demographic consequence—it reduced the period survival of the breeding segment of the

adult population. The reduction was substantial no matter which scenario was used to

evaluate exposure. Because annual survival for breeders is the product of breeding

season survival (0.82 - 0.92) and annual survival during the non-breeding period (0.93),

predation could dramatically decrease adult annual survival rates. This possibility has

major conservation implications because life history theory suggests that long-lived

species are very susceptible to minor changes in annual survival. Indeed, the greater

sensitivity to changes in adult survival, vis-à-vis changes in juvenile survival, has been shown for the Puerto Rican Parrot (Muiznieks 2003, Thompson 2004). My study suggested that 22% of the population bred in 2004, but I could not ascertain what proportion of the estimated population in Abaco was adult (4 years or older). Clearly, the full consequences of lower adult survival will vary as a function of the proportion of adult breeders each year. Finally, these results bring to bear another conservation implication. If Abaco parrots are not capable of breeding in tree cavities, then their value for translocations is compromised. Tree nesters are less vulnerable to predation (e.g., Snyder et al. 1987, Wiley et al. 2004), placing the Inagua population on the forefront of translocation initiatives.

Fire is a striking, yet essential element that molds the vegetation community in southern Abaco ecosystem (TNC 2002). Burns foster regeneration of plant trees (e.g., pines) and also make nutrients available to plants in a limestone dominated landscape (see Lugo et al. 2001). These benefits notwithstanding, my interest in this natural phenomenon was to ascertain its potential influence on the reproductive ecology of the parrot. I examined this role asking two questions. First, I was interested in assessing its direct, immediate impact—would it burn the nests and its contents. Second, I hypothesized that loss of vegetation cover (e.g., horizontal) would make nests more easily detectable by ground predators as members of the pair flew to and from the nest cavity. Although I did not assess the role of floristics and vegetation cover on nest site selection, the vast literature on the subject suggested that it was a reasonable hypothesis (Martin 1988b, Martin and Ropper 1988, Martin 1996). My results in the aftermath of a natural fire suggested that there was no evidence of direct damage—no nests were lost to

the passage of fire. In this sense, fires diverge from hurricanes even though both have the potential to alter vegetation structure and composition. Second, my results also showed that there was no evidence to support my working hypothesis. Nests in burned areas did not have lower nest success than those in unburned areas. If vegetation structure plays a role in nest site selection, it might be early in the season, when vegetation features might be part of the criteria to select sites (e.g., perching options for displaying males). Cavity quality (e.g., depth, access) might be more important selection features. This is not to say that fire could not have an influence on parrot demography. One scenario under which this possibility could occur would be if the extent of burned areas was large enough to undermine the carrying capacity of the system, reducing food resources, at least in the short-term. This could happen if habitat for parrots is reduced by human encroachment and the quality of the alternative, suitable habitat for parrots is undermined by extensive fires or frequency of fires (e.g., human-caused).

Many studies have shown that nest density can influence nest success, particularly mediated by predation rates (Martin 1988, 1996). Predators can develop search images, and these can be reinforced if encounter probabilities are enhanced by a high density of nests. My work demonstrated that there were specific sites of nest concentration in some sectors of the study area. The highest concentrations occurred within the Abaco National Park and adjacent sectors to the west (Figure 1). Whether this was a function of social interactions among parrots, or an artifact of the availability of holes on the ground is not known. The latter possibility is being examined (Gina Mori, pers. comm. UM). Regardless of the reason, I did not find differences in daily survival probabilities between high and lower nest density areas however this relationship may need to be examined

further. My result indicated that there was not association between the incidence of predation and nest density. Incidence of predation might be more related to intrinsic characteristics of the predators (e.g., home range, distribution, abundance), than to nest density (Martin 1996), or nest site characteristics (e.g., Filliater et al. 1994).

The nest density patterns recorded in this study, in concert with post-fledging occurrences, provided a quantitative basis to evaluate the role of the park in meeting annual habitat requirements. My findings affirmed the value of the park during the breeding season. The park protects the physical integrity of the nesting habitat, insuring its availability over time. The park harbored 64% of the nests during the study. Its functional role is strengthened by the fact that pairs, especially successful ones, will reuse cavities in subsequent years. Of course, this is only a political designation and did not translate into better nest success—daily survival probabilities were significantly lower in the Park than outside its boundaries. The average production of chicks per nest reflected this fact. Breeding productivity in 2004 was 0.67 ± 0.16 within the park as compared to 0.96 ± 0.20 outside the park. The high number of nests and interannual variability in breeding productivity likely affirms the value of this protected area in supporting the population in the long-run. For example, in 2003, breeding productivity was similar (statistically) between the park (1.46 ± 0.41) and areas outside its boundaires (1.1 ± 0.26).

The park, however, did not provide habitat to meet year round requirements. Birds used other areas of southern Abaco, some fairly consistently. The two most notable examples were the sector adjacent to Sandy Point and areas north of Crossing Rock. The same birds did not remain in each of these areas consistently although the areas remained high in parrot activity. Parrot flocks moved seasonally from the Northern ridge (Bahama

Palm shores to Long Beach) to Sandy Point and the Park. Parrot flock sizes were largest in these areas during winter months as indicated by winter surveys. The pattern of occurrences was not accidental. Patterns of food availability indicated that food resources were more abundant in those areas during fall, winter and early spring, prior to the availability of green cones in the pine forest. Those areas stand out as having a greater availability of food resources associated with coppice. Caribbean Pines, and plants in the understory, are important sources of food for parrots, but not during the non-breeding season. My results provided evidence to justify and develop a rationale for a more comprehensive habitat protection strategy. The most notable deficiency at present is the lack of coppice habitat away from core nesting areas.

In this study, juvenile survival was estimated at 76%. Comparative survival data on psittacines are scarce, and recently, most come from release projects (Sanz and Grajal 1998, Collazo et al. 2003, Brightsmith et al. 2004, White et al. 2005a). The survival estimates recorded in this study were in the upper range of reported values. Estimates for wild, juvenile birds ranged from 41 to 67% for Puerto Rican Parrots (Snyder et al. 1987, White et al. 2005a). Survival estimates for captive-reared juveniles of Hispaniolan (*A. ventralis*) and Puerto Rican Parrots ranged from 29% to 41% (Collazo et al. 2003, White et al. 2005a). If the reported values in this study were a good indication of inter-annual survival rates, then, juveniles in Abaco do not appear to face threats such as those faced by the Puerto Rican Parrot, where the major source of juvenile mortality are Red-tailed Hawks (*Buteo jamaicensis*; Snyder et al. 1987, White et al. 2005a). The reported levels of juvenile survival are also encouraging because recovery efforts can be focused on the

vital parameters most compromised by the pervasive conservation threat in Abaco—

mammalian predation and its influence on breeding productivity and adult survival rates.

The distribution of post-fledging occurrences was indicative of substantial

movements on the part of juveniles and adults. In one instance, a juvenile (bird # 5)

traveled 12 km in just one day. The wide-spread distribution of occurrences was

consistent with birds tracking patchy and seasonally available resources. Ultimately, the

ability to track those resources (mobility) likely had a positive influence on survival rates.

Collazo et al. (2003) documented a positive relationship between the probability of

survival of captive-reared Hispaniolan Parrots and a dispersion index, a measure of

movements. The fact that juveniles remained with at least a member of their parents for

up to 6 months likely contributed to better survival as adults are more familiar with the

landscape and resource distribution. Deaths in this study were recorded during winter

months, when resource levels were at their lowest and most scattered. The pattern of

adult-juvenile and mobility in this study parallels the results reported by Collazo et al.

(2003). Released Hispaniolan Parrots with higher likelihood of survival were those with

greater mobility and those that associated with wild birds, presumably adults.

The IUCN published a number of quantitative criteria to help establish the status

of wild birds (Collar 1992, IUCN 2001). Criteria range from population size to patterns

of distribution (e.g., fragmented populations). They also include measures regarding the

likelihood that a population decline patterns and quantitative persistence estimates where

available. On the basis of these criteria, and the demographic information made available

by my study and Gnam (1991), I believe that at present the Bahama Parrot is

"vulnerable" to extinction. The species, at least in Abaco, is not in imminent threat of

extinction (Chapter 2). This assertion stems primarily the fact that the species enjoys the benefits of having 2 large, geographically isolated populations. At present levels of mammalian predation, the Abaco population would persist over the next 100 years, albeit the population would decline in numbers from the current level of about 2,600 to a projected 996 (Chapter 2). In Abaco, initiatives to protect non-breeding habitat and curb nest predation rates are necessary to improve the species' outlook and recovery (e.g., upgrade to non-vulnerable). In the case of the Inagua population, studies building upon the work by Rivera-Milan et al. (2005), such as assessing its demographic vigor, are necessary. As a whole, translocations continue to be central to the conservation of the species as purported by Snyder et al. (1982). At our current level of knowledge, the Inagua population is the preferred source of birds for translocations. This is because of its tree-nesting habit, one that offers a mechanism to deal with the threat of mammalian predation at reintroduction sites. Translocations initiatives should be supported, not only by sound demographic data, but also by a genetic assessment that would identify ways to maintain maximum genetic diversity of the species and its multiple populations.

Literature Cited

Akcakaya, H. R. and J. L. Atwood. 1997. A habitat-based metapopulation model of the California Gnatcatcher. Conservation Biology 11:422-434.

Bessinger,S.R. and N.F.R. Snyder. 1992. New World Parrots in Crisis: Solutions from Conservation Biology. Smithsonian Institute Press. Washington. p288

Bond, J. 1947. Field guide to birds of the West Indies; a guide to all the species of birds known from the Greater Antilles, Lesser Antilles and Bahama Islands.

Bond, J. 1956(a). Check-list of birds of the West Indies. Philadelphia, Academy of Natural Sciences of Philadelphia. p 214.

Bond, J. 1956(b). Supplement to the Check-list of birds of the West Indies. Philadelphia, Academy of Natural Sciences of Philadelphia.

Brightsmith, D., J. Hilburn, del- A. Campo, J. Boyd, M. Frisius, R. Frisius, D. Janik, F. Guillen. 2005. The use of hand raised psittacines for reintroduction: a case study of scarlet macaw (*Ara macao*) in Peru and Costa Rica. Biological Conservation 121(3):465-472.

Brown, J.H. and A Kodric-Brown. 1977. Turnover rates in insular biogeography: effect of immigration on extinction. Ecology 58:445-449.

Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake. 1993. Distance sampling. Chapman and Hall, NY.

Carlo, T. A., J. A. Collazo and M. J. Groom. 2003. Avian fruit preference and seed dispersal effectiveness: A view of landscape variation of bird-plant interactions. Oecologia 134:119-131.

CITES http://www.cites.org/eng/resources/species.html June 16,2004.

Collar, N.J. 1992. Threatened birds of the Americas: the ICBP/IUCN red data. Smithsonian Institute Press. Washington. 1150p.

Collazo, J. A., T. H. White, F. J. Vilella, and S. Guerrero. 2003. Survival of captive-reared Hispaniolan Parrots released in Parque Nacional del Este, Dominican Republic. Condor 105: 198-207.

Etterson, M.A. and R.S. Bennett. 2005. Including transition probabilities in nest survival estimation: A Mayfield Markov Chain. Ecology 86(6):1414-1421.

Filliater, T. S., R. Breitwisch, and P. M. Nealen. 1994. Predation on Northern cardinal nests: Does choice of nest site matter? Condor 96:761-768.

Gnam, R. 1990. Zur Brutbiologie der Bahama Amazone auf Great Inagua. Papageien 3:89-92.

Gnam, R. S., and A. E. Burchsted. 1991. Population estimates for the Bahama Parrot on Abaco Island, Bahamas. Journal of Field Ornithology 62:139-146.

Gnam, R. S., and R. F. Rockwell. 1991a. Reproductive potential and output of the Bahama Parrot *Amazona leucocephala bahamensis*. Ibis 133:400-405.

Gnam, R. S., and R. F. Rockwell. 1991b. Diet, foraging behavior, and nutrition of the Bahama Parrot (*Amazona leucocephala bahamensis*) on Abaco Island, Bahamas Islands. El Pitirre 4:6.

Haig, S. M., J. Collazo, H. Draheim, and S. Daniels. 2004. Population structure and pedigree definition in captive and wild Puerto Rican Parrots (*Amazona vittata*). Conservation Genetics. Report to USFWS-Rio Grande Field Office and the PR Department of Natural and Environmental Resources. 2 November. 30 pp.

Heisey, D.M. and T.K. Fuller. 1985. Evaluation of survival and cause specific mortality rates using telemetry data. Journal of Wildlife Management 49(3):668-674.

Hensler, G.L. and J.D. Nichols. 1981. The Mayfield Method of estimating nest success – A model, estimators and simulation results. Wilson Bulletin 93(1):42-53.

Heppell, S. S., H. Caswell, and L. B. Crowder. 2000. Life histories and elasticity patterns perturbation analysis for species with minimal demographic data. Ecology 81:654-665.

Hirzel, A., J. Hausser, D. Chessel, and N. Perrin. 2002. Ecological-niche factor analysis: How to compute habitat- suitability maps without absence data. Ecology. 83: 2027-2036.

Johnson, D. H. 1979. Estimating nesting success: the Mayfield method and an alternative. Auk 96:651-661.

IUCN. 2001. Red List Categories and Criteria version 3.1.

Laake, Thomas, L., J.L., Derry, J.F., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Strindberg, S., Hedley, S.L., Burt, M.L., Marques, F., Pollard, J.H. And Fewster, R.M. 1998. Distance 3.5. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK.

Lugo A., L. Miranda, A. Vale, T. Lopez, E. Hernandez, A. Garcia, A. Puente, A. Tossas, D. McFarlane, T. Miller, A. Rodriguez, J. Lundberg, J. Thomlinson, J. Colon, J. Schellekens, O. Ramos, and E. Helmer. 2001. Puerto Rican Karst – A vital resource.

US Department of Agriculture, US Forest Service. General Technical Report WO-65.
100 pp.

Martin, T. E. 1988a. On the advantage of being different: nest predation and the
coexistence of bird species. Proc. Natl. Acad. Sci. 85:2196-2199.

Martin, T. E. 1988b. Habitat and area effects on forest bird assemblages: is nest
predation an influence? Ecology 69:74-84.

Martin, T. E. and J. J. Roper. 1988. Nest predation and nest site selection of a western
population of Hermit Thrush. Condor 90:51-57.

Martin, T. E. 1993. Nest predation and nest sites: new perspectives on old patterns.
BioScience 43:523-532.

Martin, T. E. and G. R. Geupel. 1993. Protocols for nest monitoring: Locating nests,
monitoring success and measuring vegetation. J. Field Ornith. 64:510-519.

Martin, T. E. 1996. Fitness costs of resource overlap among coexisting bird species.
Nature 380:338-340.

Mayfield, H. 1975. Suggestions for calculating nest success. Wilson Bulletin. 87:456-
466.

Meyers, J. M., W. J. Arendt, and G. D. Lindsey. 1996. Survival of radio-collared nesting
Puerto Rican Parrots. Wilson Bulletin 108:159-163.

Muiznieks, B. D. 2003. Population viability analysis of the Puerto Rican Parrot: an
evaluation of its current status and prognosis for recovery. M.S. Thesis, North
Carolina State University. 88 pp. (http://www.lib.ncsu.edu/ETD-db/ETD-
browse/browse).

Olson, S.L. and W.B. Hilgartner. 1982. Fossil and subfossil birds from the Bahamas. Pp
22-60. *in* S. Olson (ed) Fossil vertebrates from the Bahamas. Smithsonian
Institute Press, Washington, D.C.

Pollock K.H., S.R. Winterstein, C.M. Bunck. 1989. Survival analysis in telemetry
studies – the staggered entry design. Journal of Wildlife Management 53(1):7-15

Rivera-Milan ,Frank F; J.A. Collazo; C. Stahala; W.J. Moore; A. Davis; G. Herring; R.
Pagliaro; J.L. Thompson; W. Bracey. Estimation of density and population size
and recommendations for monitoring trends of Bahama parrots on Great Abaco
and Great Inagua. Wildlife Society Bulletin. 2005. In press.

Sanz, V. and A. Grajal. 1998. Successful reintroduction of captive-raised yellow-
shouldered amazon parrots on Margarita Island, Venezuela. Conservation
Biology 12:430-441.

Snyder, N. F. R.,W. B. King, and C. B. Kepler. 1982. Biology and conservation of the Bahama Parrot. Living Bird 19:91-114.

Snyder, N., P. McGowan, J. Gilardi and A. Grajal (eds.). 2000. Parrots. Status survey and Conservation Action Plan 2000-2004. UICN, Gland, Switzerland and Cambridge, UK. 180 pp.

Snyder, N. F. R., J. W. Wiley, and C. B. Kepler. 1987. The parrots of Luquillo. West. Found. Vert. Zool., Los Angeles.

Steele, R.G.D., J.H. Torrie, D.A. Dickey. 1997. Principles and Procedures of Statistics a Biometric approach. McGraw-Hill, Inc. p666.

Thompson, J. J. 2004. An age-structured population model of the Puerto Rican Parrot (Amazona vittata). Ornitologia Neotropical 15:289-297.

TNC. 2002. The Ecological Role and Management of Fire in Caribbean and Central American Pineland Ecosystems.

US Fish and Wildlife June 14, 1976. Endangered Status for 159 Taxa of Animals; 41 Federal Register 24062 24067

U.S. Fish and Wildlife Service. 1999. Technical/Agency Draft Revised Recovery Plan for the Puerto Rican Parrot (*Amazona vittata*). Atlanta, Georgia. 77 pp.

Wiley, J. W. and J. Wunderle 1993. Hurricane effects on bird populations in general. Bird Conservation International 3:319-349.

Wiley, J. W., R. S. Gnam, S. E. Koenig, A. Dornelly, X. Galvez, P. E. Bradley, T. White, M. Zamore, P. Reillo, and D. Anthony. 2004. Status and conservation of the family Psittacidae in the West Indies. J. Caribbean Ornithology (Special Issue Honoring Nedra Klein) :94-154.

White, T. H., Jr., J. A. Collazo, and F. J. Vilella. 2005a. Survival of captive-reared Puerto Rican Parrots released in the Caribbean National Forest. Condor 107:426-434.

White, T. H., Jr., F. J. Vilella, J. A. Collazo, and S. A. Guerrero. 2005b. Effects of Hurricane George on habitat use by captive-reared Hispaniolan Parrots released in the Dominican Republic. Ornitologia Neotropical.16(3): 000-000

Williams, B. K., J. D. Nichols, and M. J. Conroy. 2001. Analysis and Management of Animal Populations. Academic Press, San Diego, CA. 817 pp.

Table 1. Component percentages of variance for estimated density ($\hat{D}$) of Bahama parrots on Abaco and Inagua, Bahamas. (CV) Coefficient of Variation, Dispersion parameter estimate ($\hat{b}$), number of point transects surveyed (k), number of detections after data truncation (n).

Island (month–year)	CV	$\hat{b}$ [a]	k	n	$\bar{s}$ [b]	SE	μ [c]
Abaco (05–02)	0.10	2.39	174	49	1.35	0.10	851
	0.15	2.39	174	49	1.35	0.10	378
	0.20	2.39	174	49	1.35	0.10	213
Abaco (05–03)	0.10	2.13	194	47	1.98	0.16	882
	0.15	2.13	194	47	1.98	0.16	391
	0.20	2.13	194	47	1.98	0.16	221
Inagua (05–03)	0.10	3.15	144	44	1.86	0.14	1032
	0.15	3.15	144	44	1.86	0.14	459
	0.20	3.15	144	44	1.86	0.14	258
Inagua (05–04)	0.10	4.06	159	39	1.54	0.14	1659
	0.15	4.06	159	39	1.54	0.14	737
	0.20	4.06	159	39	1.54	0.14	415
Abaco '04 Combined	0.25		199	51	2.67	0.35	
Abaco '04 AM	0.32		115	25	2.48	0.27	
Abaco '04 PM	0.44		84	26	2.85	0.63	
Abaco '05	0.49		144	13	2.23	0.17	

[a]Dispersion parameter was computed as: $\hat{b} = n \times (\mathrm{CV}[\hat{D}])^2$, where observed CV$= \mathrm{SE}(\hat{D})/\hat{D}$ (Buckland et al. 2001: 243).
[b]Mean cluster size was used in the absence of size bias and expected cluster size was used if cluster detection was size biased.

Table 2. Estimated density ($\hat{D}$), detection probability ($\hat{P}_a$), effective detection radius in meters ($\hat{ERD}$), and bootstrapped standard error (SE) from point–transect survey data of Bahama parrots collected on Abaco and Inagua, Bahamas.

Island (month–year)	$\hat{D}$	SE	N	SE	$\hat{P}_a$ [a]	SE	$\hat{ERD}$ [b]	SE	n [c]	k
Abaco (05–02)	0.061	0.013	1586	304	0.34	0.03	140.72	6.78	49	174
Abaco (05–03)	0.085	0.018	2583	530	0.31	0.02	134.20	4.79	47	194
Abaco '04	0.102	0.026	2600	656	0.22	0.034	135	10.55	51	199
Abaco '05	0.031	0.015	788	387	0.46	0.19	136	27.79	13	144
Inagua (05–03)	0.183	0.049	5,344	1836	0.30	0.05	99.47	9.02	44	144
Inagua (05–04)	0.153	0.042	4,450	1921	0.22	0.04	88.74	7.87	39	159

[a] $\hat{ERD} = \sqrt{2/\hat{h}(0)}$ (Buckland et al. 2001:159–161).

[b] $\hat{P}_a = \dfrac{2}{w^2} \int_0^w r g(r) dr$ (Buckland et al. 2001:39–41).

[c] Encounter rate = n/k after data truncation at distance w (Buckland et al. 2001:78–80).

Table 3. Component percentages of variation for estimated density ($\hat{D}$) made up of Encounter rate, detection probability and cluster size on Abaco and Inagua January 2002-2004.

	Percentage		
Island (month–year)	Encounter rate	Detection probability	Cluster size
Abaco (05–02)	65	22	12
Abaco (01–03)	14	16	70
Abaco (05–03)	73	15	12
Inagua (05–03)	49	42	8
Inagua (05–04)	47	42	11
Abaco '04 Combined	49	38	12
Abaco '04 AM	57	35	7
Abaco '04 PM	35	38	25
Abaco '05	29	69	2

Table 4: Daily and nesting cycle survival probabilities of Bahama Parrot nests in southern Abaco in 2004. An overall estimate as well as estimates under different conditions, namely, burned areas, nest density and whether they occurred within the Abaco National Park. Survival probabilities were calculated using the Mayfield Method. Nesting cycle duration was 90 days. A successful nest fledged at least one young.

	Probability of survival (breeding season)			Probability of survival (daily)		
	mean	95% CI		mean	SE	95% CI
NEST	0.5	0.40 - 0.625		0.9923	0.0013	0.9898 - 0.9948
Burned	0.47	0.28 - 0.79		0.9917	0.0029	0.9861 - 0.9974
Unburned	0.51	0.395 - .657		0.9925	0.0014	0.9897 - 0.9953
Outside Park	0.651	0.505 - 0.835		0.9952	0.0014	0.9924 - 0.9980
Park	0.383	0.264 - 0.557		0.9894	0.0021	0.9853 - 0.9935
High Density	0.46	0.36 - .62		0.9918	0.0015	0.9889 - 0.9947
Lower Density	0.614	0.40 - 0.94		0.9946	0.0024	0.9899 - 0.9993

Table 5. Nest density estimates in southern Abaco in 2004. Estimates were calculated for 4 strata using a stratified random sampling scheme, namely, high use, mid use, low use, unknown use.

Values per Strata					
Strata	High Nest Density	Mid Nest Density	Low Nest Density	No Nest Density	Total
Total Number of Quads in Strata	346	141	150	232	
Number of Quads Sampled	73	33	27	35	
Number of Nests found in Strata	28	3	4	4	
Nests per Quad (unadjusted for detectability)	0.378	0.091	0.148	0.114	
SE (unadjusted for detectability)	0.127	0.101	0.155	0.102	
Number of Nests per Strata	132.51	12.83	22.2	26.44	193.98
Values for Study Area (Adjusted for detectability)					
Nest per hectare	0.025	0.006	0.01	0.0075	
Total number of Nests	197.7	19.15	33.13	39.46	289.44
Detectability	0.67				

Table 6. Period survival (nesting cycle) of adult Bahama Parrots in southern Abaco in 2004. Survival probabilities were calculated using the Mayfield Method and were calculated for three scenarios that varied by the time males and female breeders were exposed. These scenarios were: both sexes were equally exposed, females were there the only breeder exposed, and females and males were differentially expose.

	Probability of survival (breeding season)		Probability of survival (daily)		
	mean	95% CI	mean	SE	95% CI
Male exposure for 50 days during nestling stage/ Female exposure during entire nesting period (90 days)					
Males	0.92	0.88 - 0.97	0.9984	0.00048	0.9975 - 0.9994
Females	0.87	0.80 - 0.94	0.9984	0.00048	0.9975 - 0.9994
Only females exposed during nesting period					
Females	0.82	0.73 - 0.93	0.9978	0.0007	0.9965 - 0.9992
Males and females equally exposed during entire nesting period (90 days)					
Breeding Adult	0.88	0.83 - 0.94	0.9986	0.00036	0.9979 - 0.9993

Figure 1 Map of Southern Abaco study area with delineated park and nesting boundaries. Orange boundaries indicate areas of high nesting activity and green boundaries indicate peripheral or lower nesting activity,
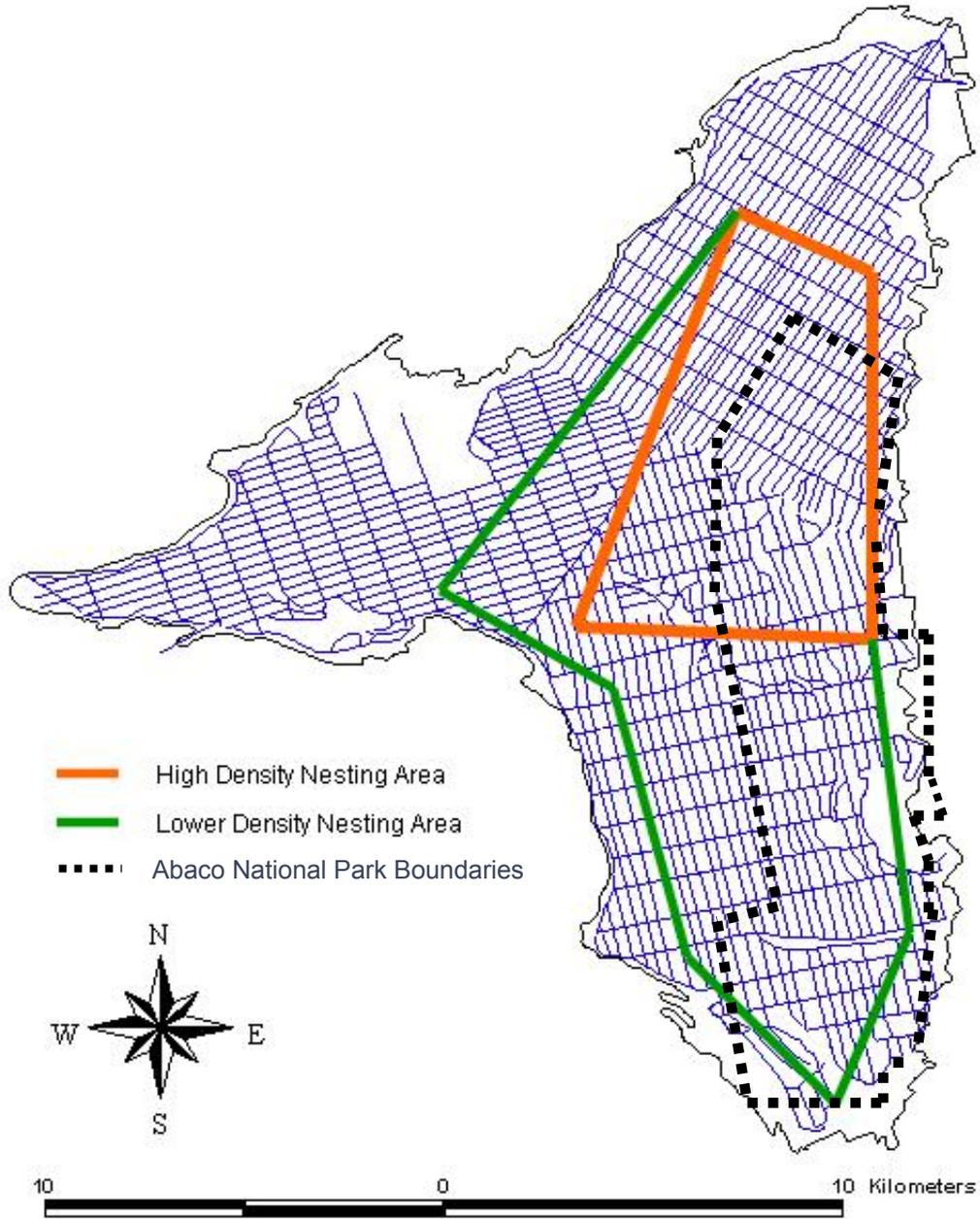
Figure 2 Map of Abaco National Park (black dash) and fire footprint of area in southern Abaco which burned July 10-13, 2004. Black squares represent array of towers used for telemetry.

Bahama Palm
Shores Fire Tower

Schooner Bay

———— July 10, 2004 Fire Footprint

▪ ▪ ▪ ▪ Abaco National Park Boundaries

■ Telemetry Platform
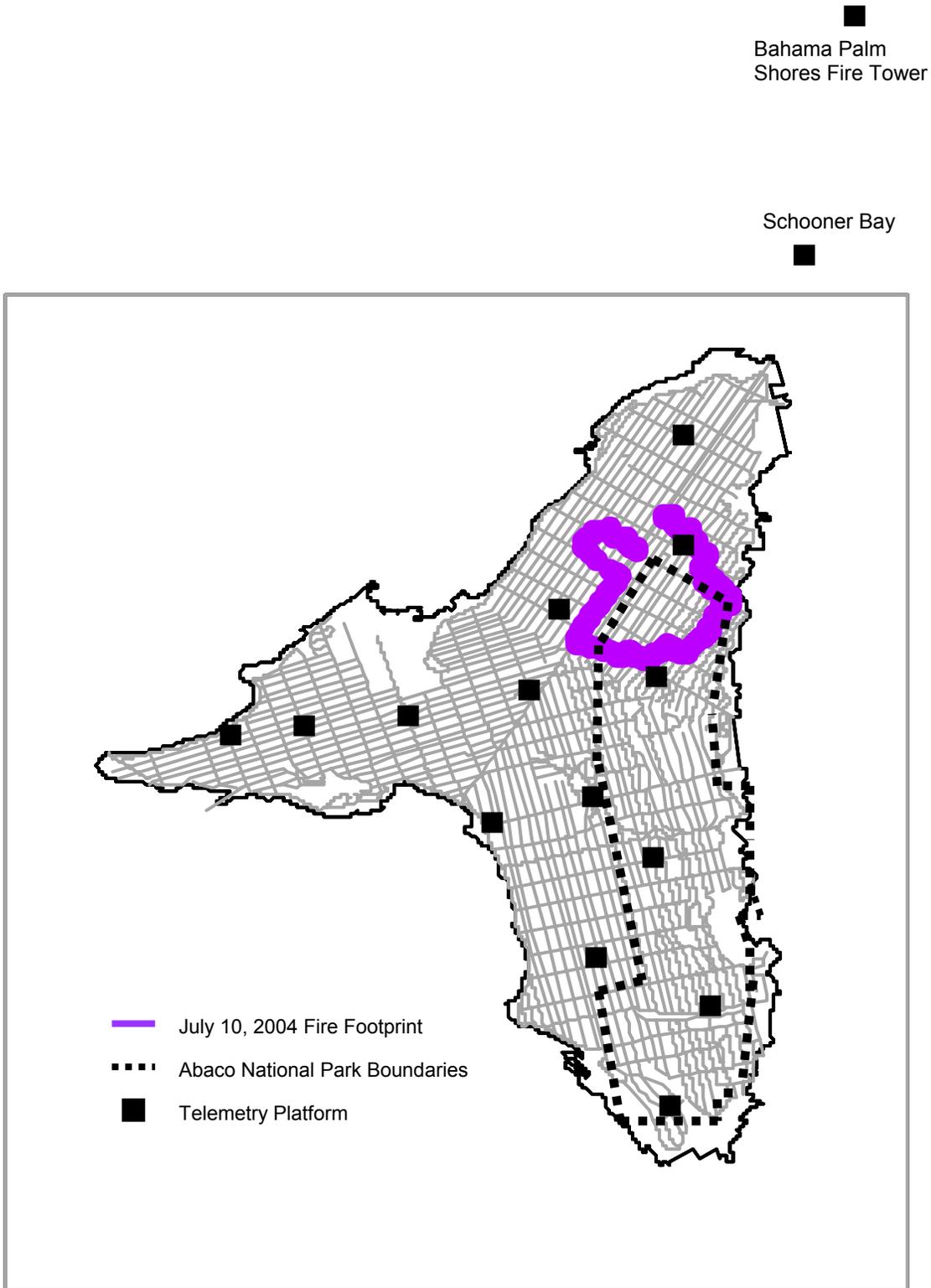
Figure 3: Fate of 38 nests found in 2003 in southern Abaco. Nests were followed through the 2004 breeding season, noting whether the nests were reused.

'03 Fate of Nest   '04 Status   '04 Fate of Nest

Successful (6)

Used
(15)   Active with feathered chicks
                    at time of Hurricane (3)

Successful
(20)   Unsuccessful (6)

Not Used
(5)

Successful (2)

Used
(3)   Active with Feathered chicks at
                    time of Hurricane (0)

Unsuccessful
(18)   Unsuccessful (1)

Not Used
(15)
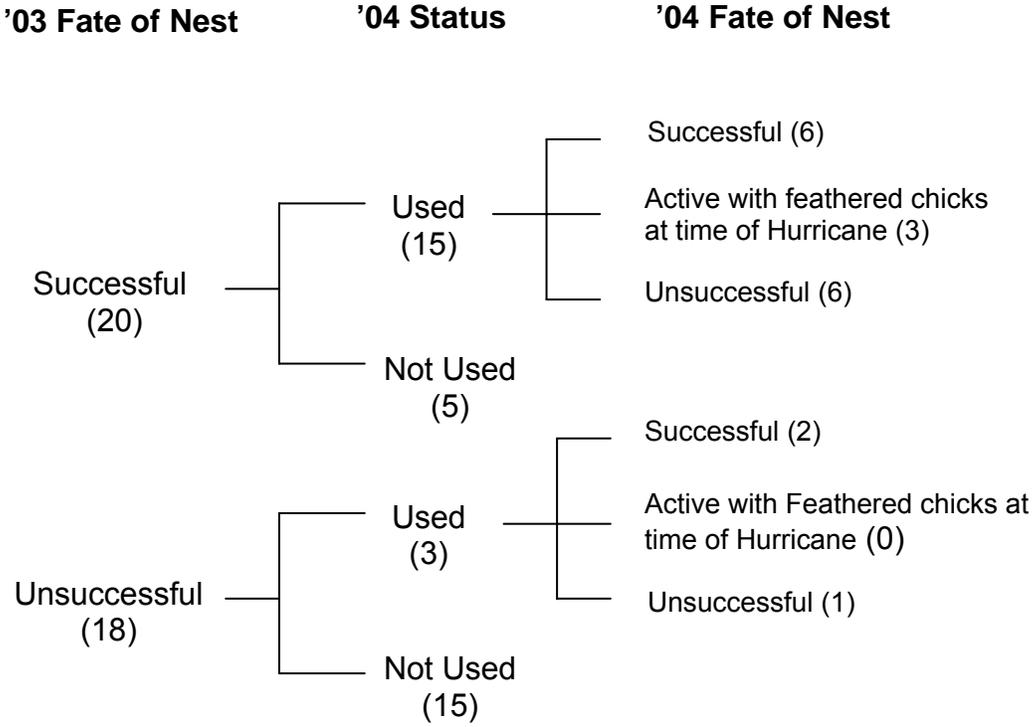
Figure 4: Kaplan-Meyer cumulative survival rates of 28 juvenile Bahama Parrots monitored over a 37 week period. Upper and lower confidence intervals are included.
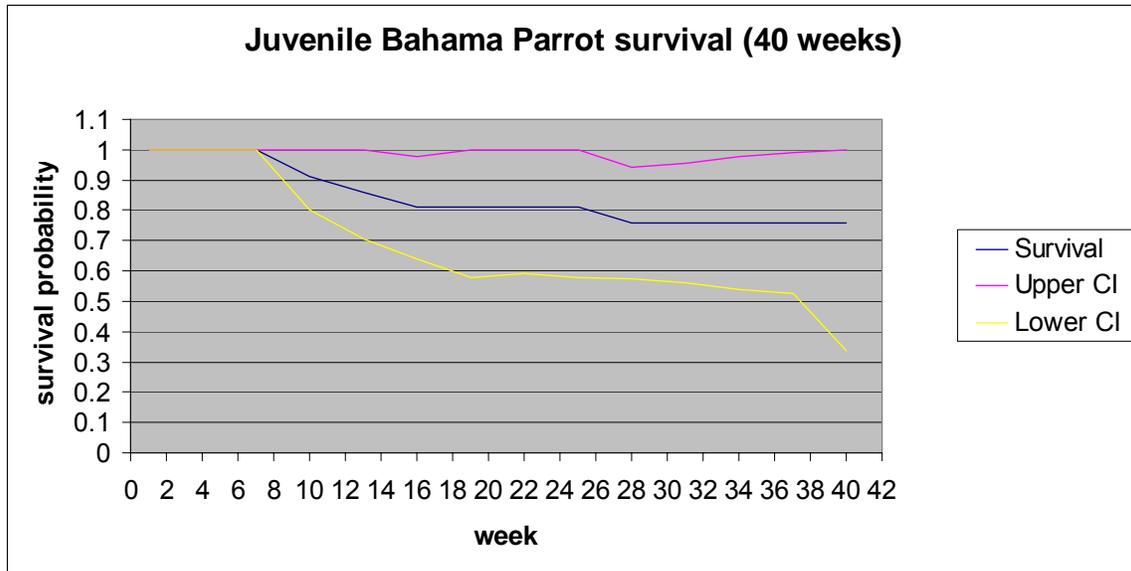
Map 1. Map of the Bahama Islands with insets of Abaco Island and the southern Abaco study area with the lattice logging roads.

A) The Bahamas

B) Abaco Island

Crossing Rocks

Sandy Point

Hole-in-the-Wall
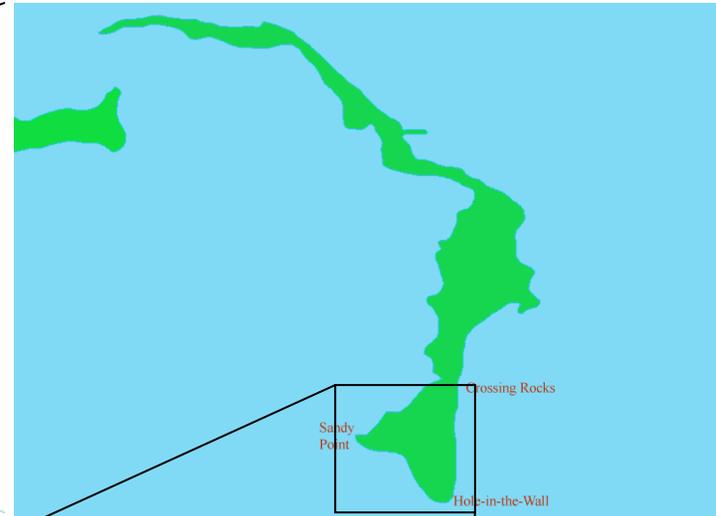
Great Inagua Island

C) Southern Abaco Study Area

Crossing Rocks

Sandy Point

Hole-in-the-Wall
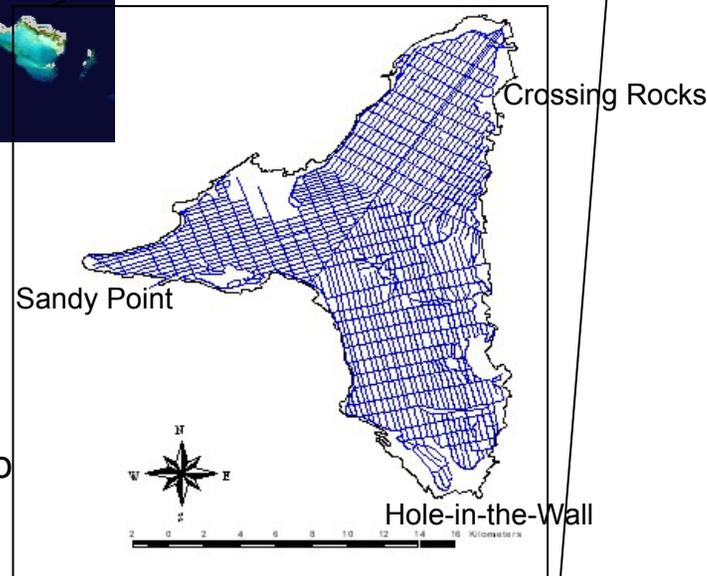
Map 2. Locations of 5 instrumented adults and 28 juveniles recorded from August 2004 to July 2005 in southern Abaco. Occurrences were grouped by trimesters. The boundary of the Abaco National Park is depicted on the map.

Purple – Nov, Dec, Jan
Green – Feb, March, April
Blue – May, June, July
Red – Aug, Sept, Oct
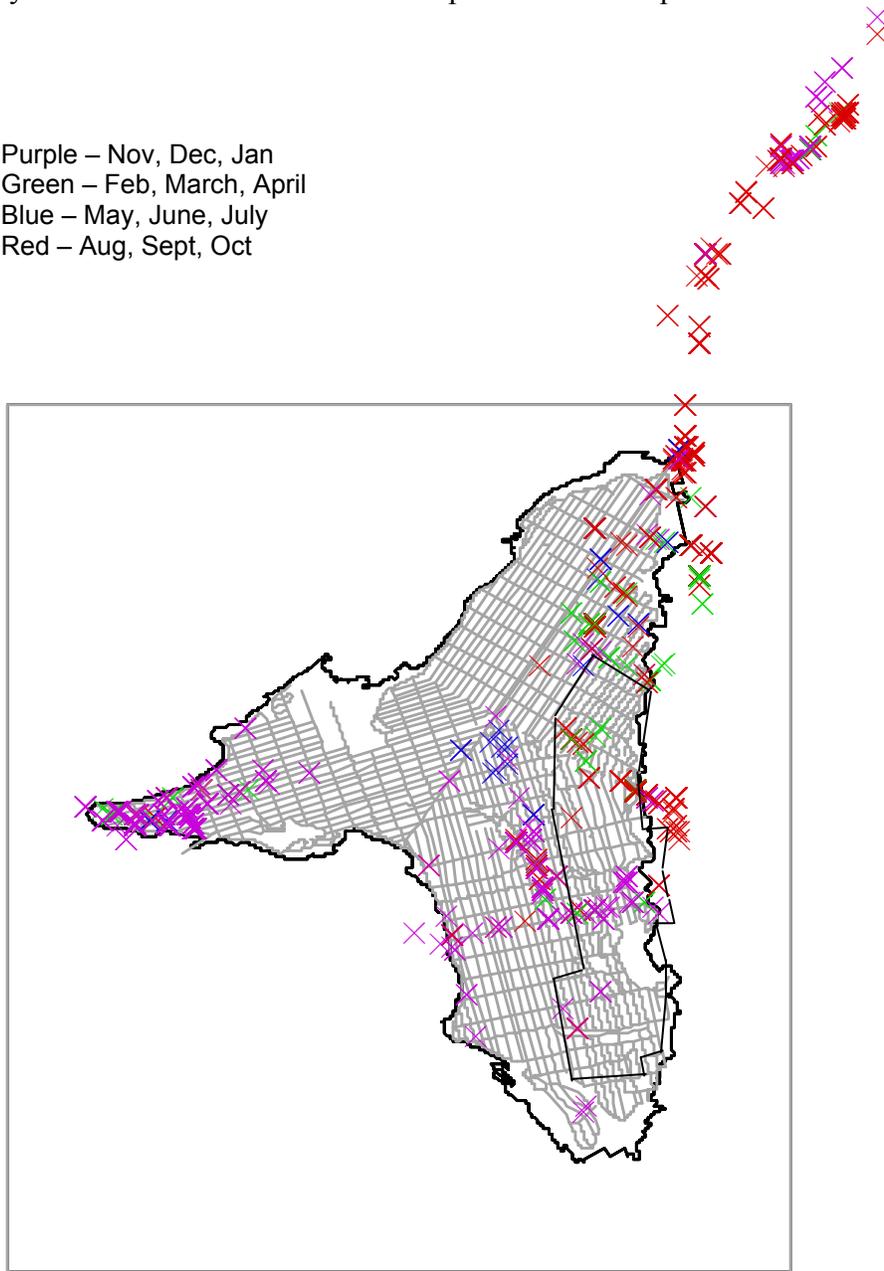
Map 3. Locations of 5 instrumented adults recorded from August 2004 to July 2005 in southern Abaco. Occurrences were grouped by trimesters. The boundary of the Abaco National Park is depicted on the map.

Purple – Nov, Dec, Jan
Green – Feb, March, April
Blue – May, June, July
Red – Aug, Sept, Oct
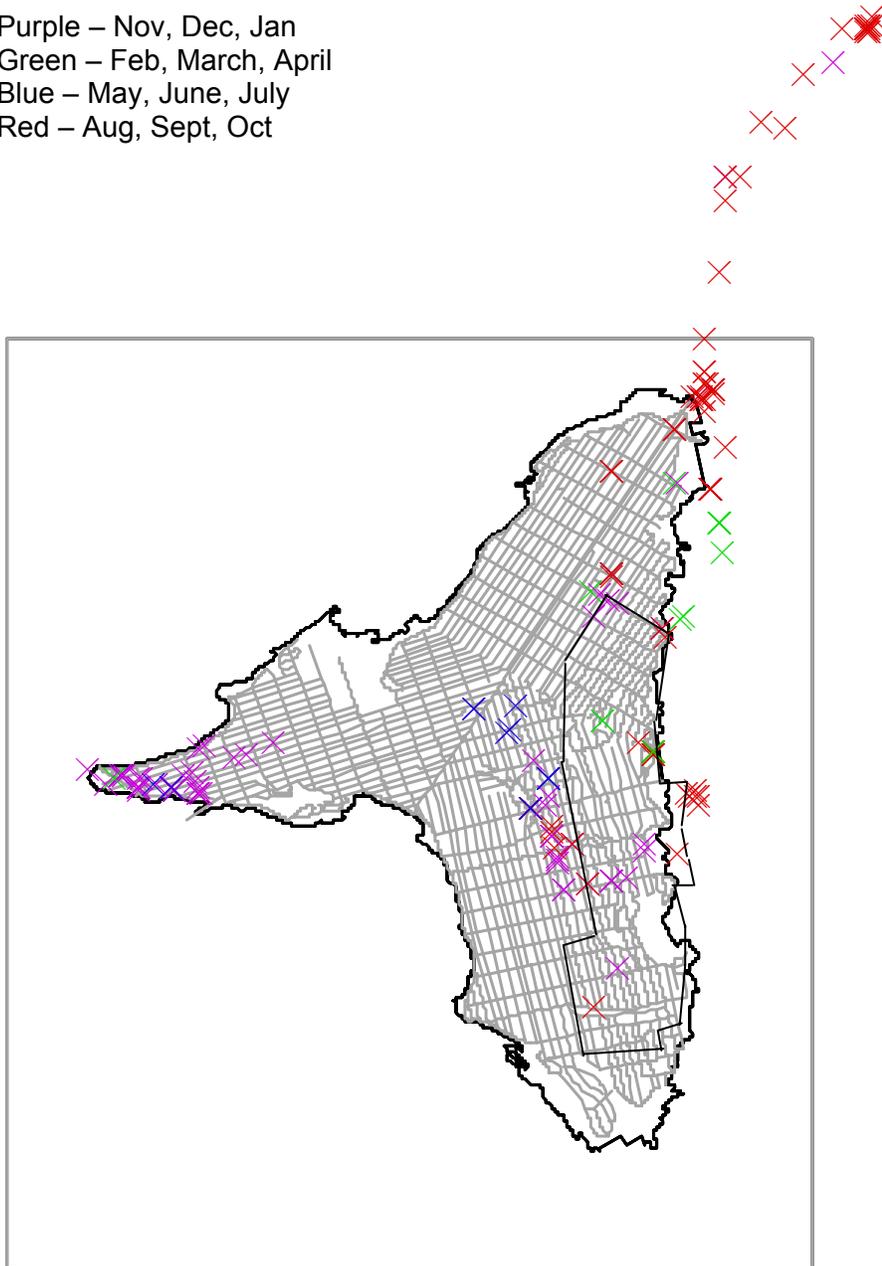
Map 4. Locations of 28 instrumented juveniles recorded from August 2004 to July 2005 in southern Abaco. Occurrences were grouped by trimesters. The boundary of the Abaco National Park is depicted on the map.

Purple – Nov, Dec, Jan
Green – Feb, March, April
Blue – May, June, July
Red – Aug, Sept, Oct
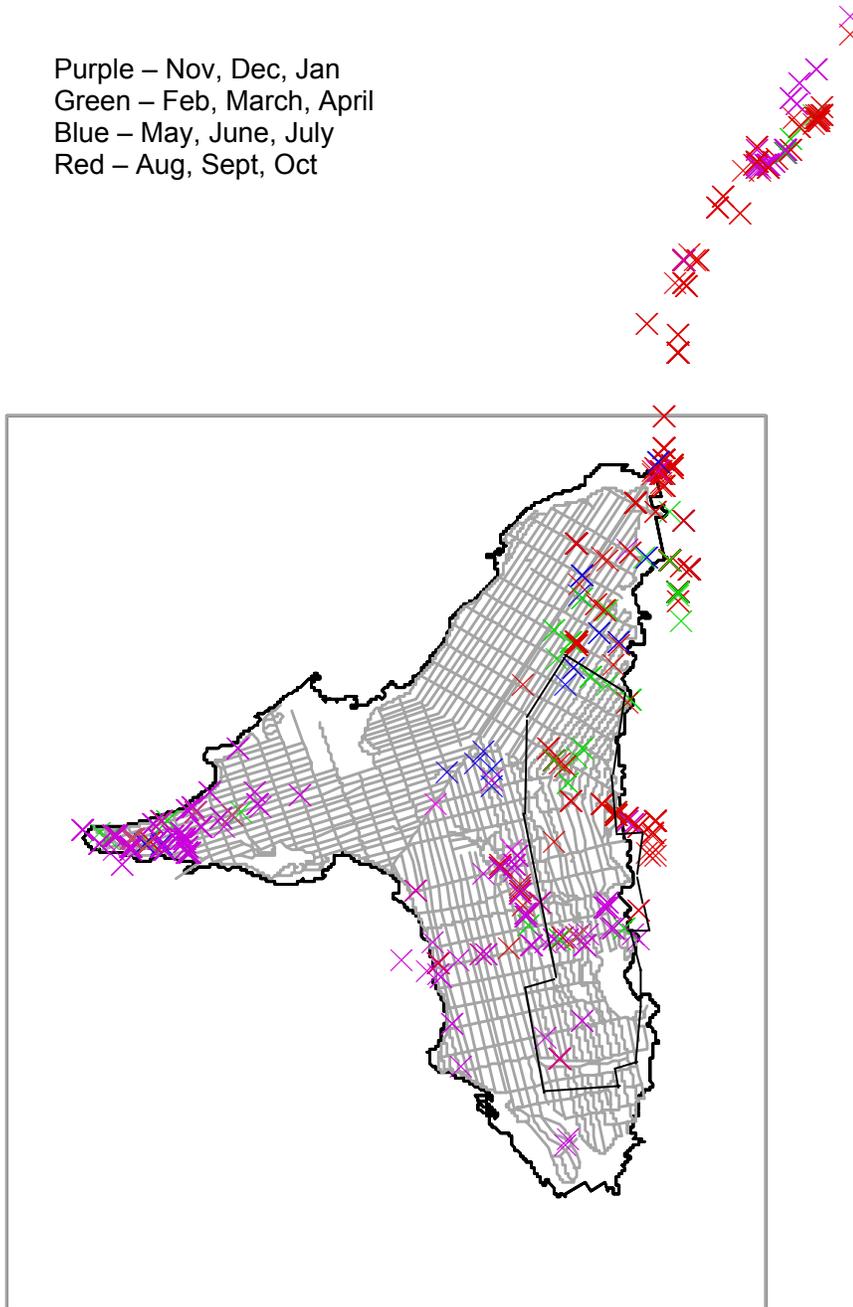
Map 5. Distribution pattern of instrumented Bahama Parrots (adults and juveniles) with respect to a fruit availability index over southern Abaco for June, July and August, 2004. I created "areas" where the birds were likely to be, bounded by the farthest distance a bird could be detected from my position (i.e., ca. 2 km). The food availability index follows an abundance scale from 0 to 10. Data were collected at 52 vegetation plots randomly selected across the study area. North ridge only depicted by location points of vegetation transects.

Pine
Number of fruits per .04 ha
- 0 - 5000
- 5001 - 25000
- 25001 - 100000
- 100001 - 500000
- 500001 - 1000000
- 1000001 - 2000000

Coppice
Number of fruits per .04 ha
- 0 - 5000
- 5001 - 25000
- 25001 - 100000
- 100001 - 500000
- 500001 - 1000000
- 1000001 - 2000000

····· Abaco National Park Boundary

2km radius of detected instrumented parrot

5   0   5   1 0   1 5   2 0   K i l o m e t e r s
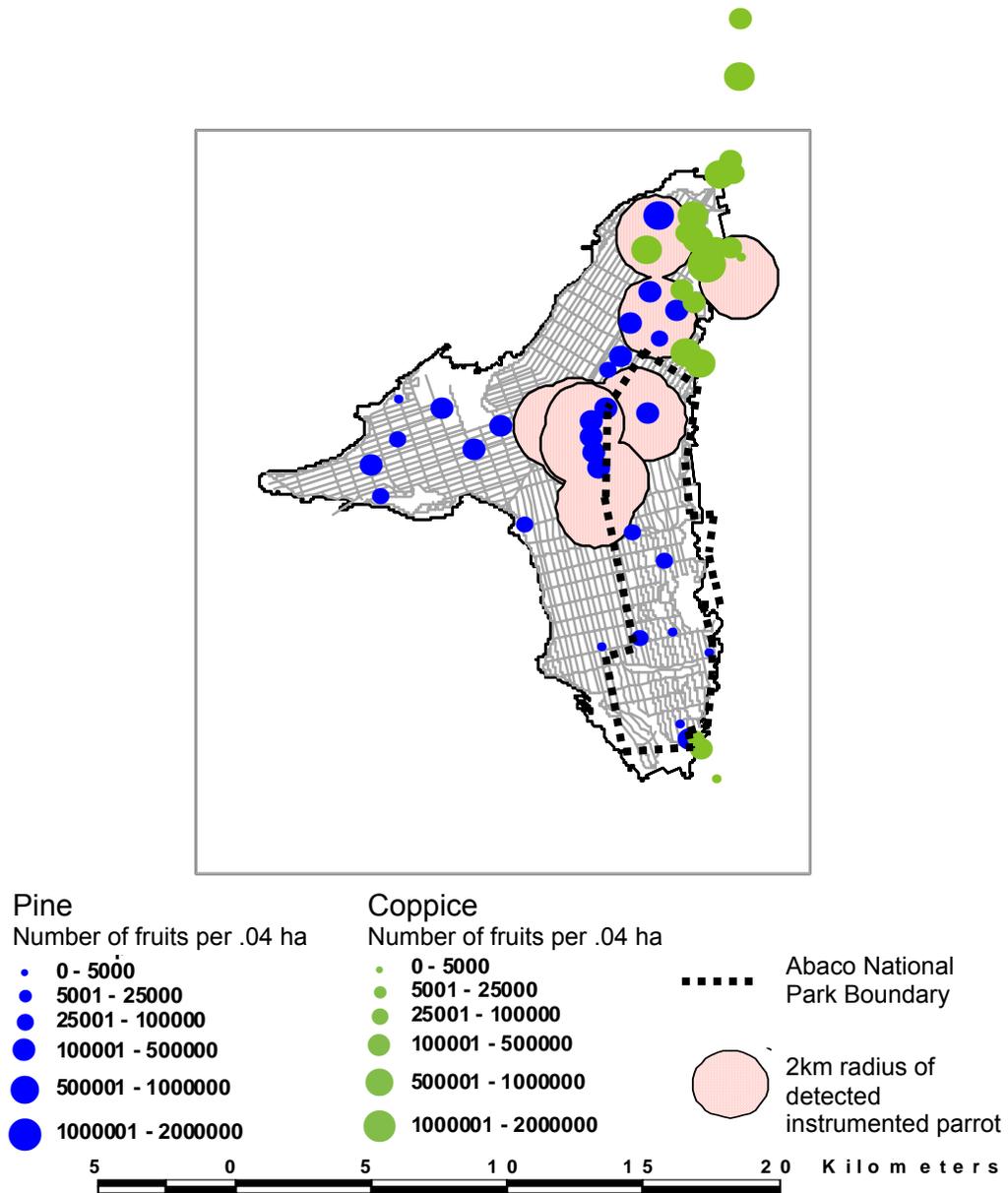
Map 6. Distribution pattern of instrumented Bahama Parrots (adults and juveniles) with respect to a fruit availability index over southern Abaco for December 2004. I created "areas" where the birds were likely to be, bounded by the farthest distance a bird could be detected from my position (i.e., ca. 2 km). The food availability index follows an abundance scale from 0 to 10. Data were collected at 52 vegetation plots randomly selected across the study area. North ridge only depicted by location points of vegetation transects.

Pine
Number of fruits per .04 ha
- 0 - 5000
- 5001 - 25000
- 25001 - 100000
- 100001 - 500000
- 500001 - 1000000
- 1000001 - 2000000

Coppice
Number of fruits per .04 ha
- 0 - 5000
- 5001 - 25000
- 25001 - 100000
- 100001 - 500000
- 500001 - 1000000
- 1000001 - 2000000

- - - - - Abaco National Park Boundary

2km radius of detected instrumented parrot

5   0   5   10   15   20   Kilometers

Map 7. Distribution pattern of instrumented Bahama Parrots (adults and juveniles) with respect to a fruit availability index over southern Abaco for May 2005. I created "areas" where the birds were likely to be, bounded by the farthest distance a bird could be detected from my position (i.e., ca. 2 km). The food availability index follows An abundance scale from 0 to 10. Data were collected at 52 vegetation plots randomly selected across the study area. North Ridge only depicted by location points of vegetation transects.

Pine
Number of fruits per .04 ha
- 0 - 5000
- 5001 - 25000
- 25001 - 100000
- 100001 - 500000
- 500001 - 1000000
- 1000001 - 2000000

Coppice
Number of fruits per .04 ha
- 0 - 5000
- 5001 - 25000
- 25001 - 100000
- 100001 - 500000
- 500001 - 1000000
- 1000001 - 2000000

..... Abaco National Park Boundary

2km radius of detected instrumented parrot

5   0   5   1 0   1 5   2 0   K i l o m e t e r s

Appendix I

Rivera-Milan ,Frank F; J.A. Collazo; C. Stahala; W.J. Moore; A. Davis; G. Herring; R. Pagliaro; J.L. Thompson; W. Bracey. Estimation of density and population size and recommendations for monitoring trends of Bahama parrots on Great Abaco and Great Inagua. Wildlife Society Bulletin. 2005. In press.

Estimation of density and population size and recommendations for monitoring trends of

Bahama parrots on Great Abaco and Great Inagua

Wildlife Society Bulletin

The Bahama parrot (*Amazona leucocephala bahamensis*) once was abundant and widely distributed in the Bahamas but is now restricted to Great Abaco and Great Inagua. Among the threats to these geographically isolated populations are hurricanes, fires, development, and predators. Parrots nest in tree cavities on Inagua and in the ground in limestone solution cavities on Abaco, where cats (*Felis silvestris*) and other predators can kill nestlings and nesting females (Gnam and Rockwell 1991). The introduction of raccoons (*Procyon lotor*) on Abaco in the 1990s (D. Knowles, Department of Agriculture, personal communication) has the potential of increasing predation, and concerns about this possibility prompted the initiation of a demographic study (C. Stahala, North Carolina State University, unpublished data). Raccoons have not been introduced on Inagua (H. Nixon, Bahamas National Trust, personal communication).

Previous researchers considered the Abaco population to be smaller than the Inagua population (Snyder et al. 1982, Gnam 1990), but density and population size were not estimated. Gnam and Burchsted (1991) reported counts of 860–1,317 parrots at roosts and along flight paths to and from roosting areas in central and

southern Abaco in January 1988 and 1989. These counts, however, were not adjusted for differences in the detection probability of parrot singles and clusters, which is needed to estimate density, population size, and trend over time and space (Buckland et al. 2001). Unadjusted counts confound abundance and detectability and do not provide a valid index of population change unless detection remains constant across samples (i.e., constant-proportion index; Lancia et al. 1996). Moreover, although Gnam and Burchsted (1991) considered their searching effort thorough enough to doubt missing any major parrot concentration in the study area, it was unlikely that small and large roosts were equally detectable (Casagrande and Beissinger 1997) and had the same chance of being sampled to allow valid inferences about the population (Thompson et al. 1998).

Survey data are lacking for Inagua, but locals claim observing as many as 3,000 parrots eating kinep (*Melicoccus bijugatus*) and tamarind (*Tamarindus indica*) at Mathew Town in the 1990s (H. Nixon, Bahamas National Trust, personal communication). Although parrots can be observed throughout Inagua, particularly in areas with trees providing food and shelter, their distribution seems rather limited on Abaco. They are commonly observed in pine and mixed broadleaf coppice in central and southern Abaco but are rare or absent in areas with similar vegetation in the northern part of the island (Gnam and Burchsted 1991; F. F. Rivera-Milán, Division of International Conservation, unpublished data).

Here we report results of point-transect surveys (a type of distance sampling; Buckland et al. 2001) and make recommendations for estimating density and population size as part of an integrated monitoring strategy for Bahama parrots. Surveys were

51

conducted on Abaco in May 2002 and January and May 2003. Surveys also were

conducted on Inagua in May 2003 and 2004 because not much is known about the parrot

population (Snyder et al. 1982, Gnam 1990) and because we wanted to compare the

densities of both islands. Distance sampling is based on estimation of a detection

function, $\hat{g}(r)$ in the case of point transects, which decreases with distance (r) and is

needed to estimate the probability of detection of parrots in the surveyed area ($\hat{P}_a$). By

definition, $\hat{g}(r)$ is the conditional probability of detecting a parrot single or cluster, given

that it is located at radial distance r from a random point (i.e., $P\{\text{detection} \mid r\}$).

Study Areas

Little Abaco and Great Abaco were connected by a land bridge and together

covered an area of about 168,100 ha in the northernmost part of the Bahamas. Ridges

reached a maximum elevation of 37 m; soils were composed of limestone, and the

vegetation was characterized by species such as Caribbean pine (*Pinus caribaea*), pond

top palm (*Sabal palmetto*), cocoplum (*Chrysobalanus icaco*), poisonwood (*Metopium

toxiferum*), gumbo limbo (*Bursera simaruba*), and doveplum (*Coccoloba diversifolia*).

Great Inagua had an area of about 155,100 ha but a saltwater lagoon (Lake Rosa)

covered about 21,200 ha in the western side of the island. Inagua and Abaco had similar

geography but the former was drier than the latter (Snyder et al. 1982). Inagua had no

Caribbean pine but trees such as black-olive (*Bucida buceras*), lignumvitae (*Guaiacum

sanctum*), buttonwood (*Conocarpus erectus*), poisonwood, gumbo limbo, and doveplum

were common. Most of Inagua was uninhabited by humans (<1,000 people at or near

Mathew Town) and a national park covered about 74,415 ha. In contrast, the national

park on Abaco covered about 8,302 ha, and the demands of a rapidly increasing human

population (>10,000 people at Marsh Harbour and other developing areas) were causing

environmental problems that could jeopardize the viability of the parrot population

(Snyder et al. 1982, Gnam 1990; for more information about these islands, also see

Campbell 1978 and Sealey and Burrows 1982).

Methods

Point-transect surveys

In May 2002 and January and May 2003, 41 points (counting stations) were

surveyed in central Abaco (26°08'N, 77°11'W–26°32'N, 77°12'W) and 167 points in

southern Abaco (26°07'N, 77°12'W–25°52'N, 77°11'W). We surveyed 144 points

throughout Inagua (20°95'N, 73°60'W–21°04'N, 73°27'W) in May 2003 and 159 points

in May 2004. Using global positioning system (GPS) and geographical information

system (GIS), forestry and topographic maps, and aerial photographs, we placed points

on and off (≥200 m) secondary (paved) and tertiary (unpaved) roads and forest interior

trails. The first point on and off a road or trail was placed randomly (resulting in 102

random starts on Abaco and 82 random starts on Inagua) and others systematically at

intervals of 800 m or 1,600 m to provide representative coverage of study areas and

minimize the chance of double-counting parrots between points (Rivera-Milán et al.

2003a). Distance sampling is robust to violation of the assumption of independent

detections (i.e., recording the same parrot or cluster of parrots from more than one point;

Buckland et al. 2001).

Two-observer teams surveyed the points, with 1 observer recording the data and

the other measuring detection distances. To meet the basic assumptions of distance

sampling (i.e., parrots at point centers are not missed, singles or clusters are detected at

initial locations, and distances are measured accurately; Buckland et al. 2001:29–35), the observers remained side by side for 6 min at each point and concentrated on securing detections at short distances (0–180 m), recording any responsive movements, and carefully measuring distances to singles and geometric center of clusters. Six minutes provided an adequate snapshot of each point, decreased the chance of movement in the survey area, increased detectability of silent parrots in the forest understory or canopy, and allowed us to collect supplementary data (Marsden 1999, Buckland et al. 2001, Rivera-Milán et al. 2003a).

We used laser rangefinders and fiberglass tapes to measure exact distances from points to parrots detected singly or the center of flocks (i.e., clusters ≥ 2 parrots). We recorded detections beyond 440 m but they were not used for density estimation. Because a network of old logging roads and trails form a grid on Abaco, we easily reached points or approached them by car and we conducted surveys during 0600–1030 hours. However, because road and trail access was limited on Inagua, we walked to points in the interior of the island and for logistical reasons conducted surveys during 0600–1130 and 1500–1930 hours.

When cluster detection was size independent, we estimated density as

$$\hat{D} = n\,\hat{h}\,(0)\,\bar{s}\,/2\pi k,$$

where $\hat{D}$ = the number of parrots/ha; n = the number parrots detected as singles or clusters; $\hat{h}\,(0)$ = the slope of the probability density function of radial distances (r), estimated at $r = 0$; $\bar{s}$ = the sample mean used as an unbiased estimator of average cluster size; and k = the number of points surveyed. When cluster detection was size biased (i.e., we detected large clusters at longer distances than small clusters; $\alpha = 0.15$), regressed

54

$\log_e(s_i)$ on $\hat{g}(y_i)$ to estimate $E(s)$ where $\hat{g}(y_i) = 1$ (Buckland et al. 2001:171), and estimated density using $\hat{E}(s)$ instead of $\bar{s}$.

We estimated population size by extrapolating density estimates to the area covered by the surveys, which was defined as the area from which points were randomly selected (i.e., $\hat{N} = \hat{D} \times A$; where $A = 26{,}154$ ha in southern Abaco in May 2002; 28,222 ha in central and southern Abaco in January 2003; 28,162 ha in central and southern Abaco in May 2003; and 29,174 ha on Inagua, excluding Lake Rosa and other areas considered nonhabitat for parrots in May 2003 and 2004). We estimated effective radius of detection ($\hat{ERD}$) and probability of detection in the surveyed area of each point ($\hat{P}_a$) after data truncation at distance w. We grouped and truncated data to remove outliers, improve model fit, and reduce size-bias effect (Buckland et al. 2001).

Program Distance (Thomas et al. 2002) version 4.1 was used for the analysis of ungrouped data. The fit of detection models (uniform, half-normal, and hazard-rate key functions with cosine and polynomial adjustment terms) to data was evaluated with χ^2 goodness-of-fit tests. In addition to conventional distance sampling analysis, we included cluster size, team, and time of day as covariates in the half-normal and hazard-rate key functions (Thomas et al. 2002). Following the principle of parsimony, we based the model selection on minimization of Akaike's Information Criterion (AIC_c; Buckland et al. 2001:69–70). We considered models with differences in AIC_c values ≤ 2 equally parsimonious. We used nonparametric bootstrapping on points for robust estimation of variance and confidence interval and to account for model selection uncertainty through model averaging ($B = 999$; Buckland et al. 2001: 82–84).

We used conventional distance sampling analysis for the data of each year and conventional and multiple covariates distance sampling analysis for the data of all years combined. We computed the Z statistic to determine if parrot density differed on Abaco in May 2002 and 2003, Inagua in May 2003 and 2004, and Abaco and Inagua in May 2003 and 2002–2004 (Buckland et al. 2001:84–86). Based on survey data collected in January 2003 and May 2002–2004, we calculated the number of points (μ) that would be needed to obtain a CV of 10–20% for estimated density (Buckland et al. 2001:245–246).

Results

Point-transect surveys on Abaco

We made 64 detections of parrot singles and clusters in 174 points surveyed on Abaco in May 2002 (total surveyed area: $k\pi r^2 = 174 \times 3.14159\ldots \times 440^2 \div 10{,}000 = 10{,}582.90$ ha). Maximum detection distance was 390 m and we truncated data at 240 m. The uniform key function with 1 cosine adjustment term ($\chi^2_5 = 1.53$, $P = 0.91$; $AIC_c = 182.62$; Figure 1a) and half-normal key function with 1 cosine adjustment term ($\chi^2_5 = 1.65$, $P = 0.89$; $AIC_c = 182.70$) provided the best fit to the data. Probability of detection in the surveyed area of each point was 34% and the effective radius of detection was 140.72 m (Table 1). Estimated density was 0.061 parrots/ha and population size was 1,600 (SE = 354, log-normal 95% CI = 1,041–2,460) parrots in 26,154 ha. Cluster detection was size biased ($r = -0.30$, df = 47, $P = 0.02$), but factors affecting encounter rate and detection probability explained 65% and 22% of the variance of estimated density, respectively, and factors affecting the detection of different cluster sizes explained 12% ($\bar{s} = 1.71$, SE = 0.15; $\hat{E}(s) = 1.35$, SE = 0.18; Table 2). Parrot

distribution was clumped ($\hat{b}$ = 2.39) and we would need to survey 213–851 points to obtain a CV of 10–20% for estimated density in May 2002 (Table 3).

We made only 24 detections of parrot singles and clusters in 208 points surveyed in central and southern Abaco in January 2003 ($k\pi r^2$ = 12,650.82 ha). Maximum detection distance was 390 m and we did not truncate data due to small sample size. We selected the hazard-rate key function with 2 cosine adjustment terms as the best fitting model for the data (χ^2_2 = 1.38, P = 0.50). Probability of detection in the surveyed area of each point was 19% and the effective radius of detection was 169.75 m (Table 1). Estimated density was 0.078 parrots/ha but precision was low (CV = 73%), resulting in a population size of 2,208 (SE = 1,606 and log-normal 95% CI = 594–8,210) parrots in 28,222 ha. Cluster detection was size independent (r = 0.07, df = 22, P = 0.63) but, contrasting with surveys conducted in May, surveys conducted in January were affected by an increase in clumping and clustering and its variability ($\bar{s}$ = 6.17, SE = 3.23), and cluster size explained 70% of the variance of estimated density (Table 2). Parrot distribution was highly clumped ($\hat{b}$ = 12.69) and we would need to survey >2,800 points to obtain a CV of 20% for estimated density in January 2003.

We made 49 detections of parrot singles and clusters in 194 points surveyed in central and southern Abaco in May 2003 ($k\pi r^2$ = 11,799.32 ha). Maximum detection distance was 335 m and we truncated data at 240 m. The uniform key function with 1 cosine adjustment term (χ^2_3 = 2.87, P = 0.41; AIC$_c$ = 153.15; Figure 1b) and half-normal key function with 1 cosine adjustment term (χ^2_2 = 1.36, P = 0.51; AIC$_c$ = 153.25) provided the best fit to the data. Probability of detection in the surveyed area of each point was 31% and the effective radius of detection was 134.20 m (Table 1). Estimated

density was 0.085 parrots/ha and population size was 2,386 (SE = 508 and log-transformed 95% CI = 1,576–3,612) parrots in 28,162 ha. Size did not influence cluster detection ($r = -0.12$, df = 44, $P = 0.22$) but factors affecting encounter rate and detection probability explained 73% and 15% of the variance of estimated density, respectively, and factors affecting cluster detection explained 12% ($\bar{s}$ = 1.98, SE = 0.16; Table 2).

Because parrot distribution remained clumped ($\hat{b}$ = 2.13), we would need to survey 221–882 points to obtain a CV of 10–20% for estimated density in May 2003 (Table 3). Density differed on Abaco in May 2002 and 2003 ($Z = 1.97$, $P = 0.04$).

Based on results obtained in May 2002 and 2003, we conducted model averaging using the uniform and half-normal key functions without covariates and with size-bias adjustment and used the half-normal key function for multiple covariates analysis. Among the covariates, cluster size ($AIC_c = 315.75$) was the more important one, followed by time of day ($\Delta AIC_c = 1.66$) and team ($\Delta AIC_c = 2.87$). Thus, to be consistent with the analysis conducted for each year, we selected the average of the uniform ($AIC_c = 317.22$) and half-normal ($AIC_c = 317.69$) models without covariates and with size-bias adjustment (Figure 1c). Probability of detection in the surveyed area of each point was 32% and the effective radius of detection was 136.11 m (Table 1). Estimated density was 0.072 parrots/ha and population size was 2,021 (SE = 513 and log-transformed 95% CI = 1,236–3,305) parrots in 28,162 ha. Size influenced cluster detection ($r = -0.20$, df = 95, $P = 0.02$) and factors affecting encounter rate and detection probability explained 71% and 15% of the variance of estimated density, respectively, and factors affecting cluster detection explained 14% ($\bar{s}$ = 1.87, SE = 0.11; $\hat{E}(s)$ = 1.60, SE = 0.09).

Point-transect surveys on Inagua

We made 50 detections of parrot singles and clusters in 144 points surveyed on Inagua in May 2003 ($k\pi r^2$ = 8,758.26 ha). Maximum detection distance was 290 m and we truncated data at 180 m. The half-normal key function with 1 cosine adjustment term (χ^2_4 = 0.19, P = 1.00; AIC_c = 152.01; Figure 2a) and the uniform key function with 1 cosine adjustment term (χ^2_4 = 0.37, P = 0.98; AIC_c = 152.19) provided the best fit to the data. Probability of detection in the surveyed area of each point was 30% and the effective radius of detection was 99.47 m (Table 1). Estimated density was 0.183 parrots/ha and population size was 5,344 (SE = 1,431 and log-normal 95% CI = 3,178–8,987) parrots in 29,174 ha. Detection was independent of cluster size (r = –0.07, df = 42, P = 0.33) and factors affecting encounter rate and detection probability explained 49% and 42% of the variance of estimated density, respectively, and factors affecting cluster detectability explained 8% ($\bar{s}$ = 1.86, SE = 0.14; Table 2). Parrot distribution was clumped ($\hat{b}$ = 3.15) and we would need to survey 258–1,032 points to obtain a CV of 10–20% for estimated density in May 2003 (Table 3).

We made 45 detections of parrot singles and clusters in 159 points surveyed on Inagua in May 2004 ($k\pi r^2$ = 9,670.58 ha). Maximum detection distance was 250 m and we truncated data at 180 m. The half-normal key function with 1 cosine adjustment term provided the best fit to the data (χ^2_4 = 1.70, P = 0.79; AIC_c = 144.72; Figure 2b), followed by the hazard-rate key function with 2 cosine adjustment terms (χ^2_4 = 0.03, P = 0.99; AIC_c = 144.98), and the uniform key function with 1 cosine adjustment term (χ^2_4 = 0.66, P = 0.96; AIC_c = 145.61). Probability of detection in the surveyed area of each point was 22% and the effective radius of detection was 88.74 m (Table 1). Estimated density was 0.153 parrots/ha and population size was 4,450 (SE = 1,435 and log-normal

95% CI = 2,391–8,283) parrots in 29,174 ha. Detection was not cluster-size dependent (r = –0.04, df = 37, P = 0.41) and factors affecting encounter rate and detection probability explained 47% and 42% of the variance of estimated density, respectively, and factors affecting cluster detection explained 11% ($\bar{s}$ = 1.54, SE = 0.14; Table 2). Parrot distribution was clumped ($\hat{b}$ = 4.06) and we would need to survey 415–1,659 points to obtain a CV of 10–20% for estimated density in May 2004 (Table 3). Density did not differ on Inagua in May 2003 and 2004 (Z = 1.20, P = 0.23).

Based on results obtained in May 2003 and 2004, we compared the fit of the half-normal, hazard-rate, and uniform key functions without covariates and the half-normal key function with 1–3 covariates. The half-normal key function without covariates (AIC_c = 306.36) and with 1 covariate (cluster size: ΔAIC_c = 1.07; and time of day: ΔAIC_c = 1.99) best fitted the data. These models produced similar results. Thus, to be consistent with the analysis conducted for each year, we selected the half-normal model with 1 cosine adjustment term (no covariates; Figure 2c). Probability of detection in the surveyed area of each point was 25% and the effective radius of detection was 93.46 m (Table 1). Estimated density was 0.172 parrots/ha and population size was 5,110 (SE = 1,002 and log-transformed 95% CI = 3,486–7,490) parrots in 29,174 ha. Cluster detection was not size biased (r = –0.09, df = 81, P = 0.20) and factors affecting encounter rate and detection probability explained 47% and 42% of the variance of estimated density, respectively, and factors affecting cluster detection explained 11% ($\bar{s}$ = 1.72, SE = 0.16). Density differed on Abaco and Inagua in May 2003 (Z = 2.16, P = 0.03) and 2002–2004 (Z = 3.51, P < 0.001).

Discussion

Point-transect surveys on Abaco

A seasonal change in the flocking behavior of Bahama parrots affected the dispersion parameter and variance components of density. Because we conducted surveys in late May 2002, when parrots were nesting or selecting nesting sites, most of the detections were of singles and pairs, clumping decreased and encounter rate was the most important variance component of density. Nesting ended in September (Gnam and Rockwell 1991; C. Stahala, North Carolina State University, unpublished data), clumping increased and large clusters were detected, which made cluster size the most important variance component of density in January 2003. We conducted surveys in early May 2003, when parrots were pairing or selecting nesting sites, and, as in May 2002, clumping decreased and encounter rate was the most important variance component of density. Although further research is needed, we suggest that increased clumping and clustering are the result of behavioral adaptations and strategies (e.g., social facilitation, nomadic roosting, and flock switching) of parrots to exchange information about foraging habitats and cope with food scarcity and patchiness in wintertime (Stephens and Krebs 1986, Bucher 1992). Pine cones, poisonwood fruits, and other important food sources are relatively abundant and widely distributed in springtime, and clumping and clustering decreases as parrots spend less time searching for food and more time in nesting activities.

The onset of nesting may explain, at least in part, the density difference detected in May 2002 and 2003. Because surveys were conducted later in May 2002 than in 2003, we were unable to determine if the density change reflected a population increase (i.e., births > deaths) or if more females were attending nests and not available for sampling

61

(Bailey et al. 2004). Moreover, parrots tend to have high survival and low reproductive rates (Beissinger and Bucher 1992), and we do not know if the proportion of nesting pairs remained constant or changed in the population. Survey, telemetry, and nest monitoring data are needed to better understand the population dynamics of Bahama parrots (Gnam and Rockwell 1991, Collazo et al. 2003, Rivera-Milán et al. 2003*b*).

We recommend conducting point-transect surveys before egglaying to decrease the variance component of density related to cluster size to 15% or less, and increasing survey effort by using 3 2-observer teams and counting parrots during 0600–1130 and 1500–1930 hours. Surveying a minimum of 213 points would be needed for a CV $\hat{D}$ of 20%, but we recommend surveying 300–400 points to obtain a CV $\hat{D}$ of 15–20%. With an encounter rate of 25%, this survey effort should generate 75–100 detections/year, which is desirable for estimation of the detection function and density (Buckland et al. 2001).

Histograms of distance data had shoulders in which detectability was near 100% within 60 m and remained above 30% up to 160 m from point centers. The fit of models with uniform and half-normal key functions and 1 cosine adjustment term was excellent and histograms of distance data did not reveal major problems, such as measurement error and evasive movement prior to detection (Buckland et al. 2001). Cluster detection was size biased in May 2002, but the regression method generated an estimate of expected cluster size from the area around the point in which detectability was 100% and eliminated the bias associated with the detection of clusters far from point centers.

The increase in cluster size and its variability and clumping made point-transect surveys imprecise and cost ineffective in winter. Telemetry is providing information

about the flocking and roosting behavior of parrots after reproduction (C. Stahala, North

Carolina State University, unpublished data) and further development of roost surveys

and its estimators may explore the combination of extensive and intensive sampling

methods to estimate population parameters and provide answers to research and

management questions (Casagrande and Beissinger 1997, Nichols et al. 2000, Bart and

Earnst 2002, Cougill and Marsden 2004).

In distance sampling, multipliers can be used to account for repeated surveys

(e.g., $c = 2$ for each point after pooling data collected in late April and early May;

Buckland et al. 2001). Because parrot distribution was clumped, survey data were

characterized by many points with zero counts and few points with singles or clusters,

and repeated surveys may be needed to generate adequate sample sizes each year and

incorporate environment (e.g., habitat), observer (e.g., experience), and species (e.g.,

behavior) variables into the detection function through stratification and multiple

covariates analysis (Buckland et al. 2001, Thomas et al. 2002).

Point-transect surveys on Inagua

Our survey data showed that parrot density was higher on Inagua than Abaco in

May 2003 and 2002–2004. Density did not differ on Inagua in May 2003 and 2004,

which was surprising given a prolonged period of dryness and food scarcity (rainfall in

Jan–Apr 2003 = 13.03 cm and Jan–Apr 2004 = 3.61 cm; H. Nixon, Bahamas National

Trust, personal communication). Food may be less abundant and more dispersed on

Inagua than Abaco, and moving parrots may have better chances of finding food and

surviving under stressful environmental conditions (Collazo et al. 2003). This may

explain why parrots are widely distributed and attracted to Matthew Town and nearby

areas, where they have available the fleshy fruits of introduced trees found nowhere else on the island. Additionally, nesting parrots may be exposed to lower predation pressure from mammals and have higher reproductive success on Inagua than Abaco (Snyder et al. 1982, Gnam 1990). Although these are plausible explanations, detailed demographic and habitat data are lacking and we cannot single out the factors and mechanisms behind the observed differences in abundance and distribution.

Detection probability of parrot singles and clusters decreased more markedly with distance from point centers on Inagua than Abaco. Because fires are frequent on Abaco, the understory of pine forest is open and parrots can be detected far from points. In contrast, there are no pines and fires are rare on Inagua, and parrots can be difficult to detect at short distances in dense vegetation. Yet, detection probability was near 100% within 50 m from points, and histograms of distance data showed little evidence of evasive movement and measurement error. The half-normal and hazard-rate key functions fitted the distance data better than the uniform key function due to the marked decrease in detectability beyond 50 m from points (Buckland et al. 2001).

Because parrot distribution was clumped and detection decreased markedly with distance, encounter rate and detection probability were almost equally important variance components of density, and cluster size was relatively unimportant in May 2003 and 2004. A minimum of 262–415 points would need to be surveyed for a CV $\hat{D}$ of 20%. With an encounter rate of 28–35%, this survey effort should generate an adequate sample size for estimation of the detection function and density (Buckland et al. 2001). However, it seemed logistically feasible for 3 2-observer teams to survey 400–500 points/year and obtain a CV $\hat{D}$ of 15–20%. As recommended for Abaco, surveys should

be conducted during 0600–1130 and 1500–1930 hours, and repeated before reproduction to increase sample size and minimize the effects of nesting females not being available for sampling and clustering and clumping after reproduction.

Our knowledge of the ecology of the Bahama parrot on Inagua is meager. For example, because Inagua is drier than Abaco, parrots may have higher variation in the timing of nesting on the former than the latter and respond faster to rainfall and the production of fruits of key plant species (Grant and Grant 1989, Bancroft et al. 2000, Rivera-Milán 2001). Some pairs may lay eggs as early as March (Snyder et al. 1982; F. F. Rivera-Milán, United States Fish and Wildlife Service, unpublished data). Therefore, we recommend repeating point-transect surveys yearly (e.g., Feb, May, Aug) as part of an integrated, cost effective monitoring strategy, linked to research and management goals (Walters and Green 1997, Gibbs et al 1999, Boyce 2001). Estimates of density and other key demographic parameters (Clobert and Lebreton 1993, Sandercock et al. 2000) are needed to better understand the life-history traits and elucidate the mechanisms by which biological and environmental factors influence the dynamics of parrot populations occupying the northern and southern ends of the Bahamas.

of the Bahamas, Friends of the Environment, Bahamas National Trust, United States

Geological Survey's Biological Resources Division, and United States Fish and Wildlife

Service's Division of International Conservation.

Literature cited

Bailey, L. L., T. R. Simons, and K. H. Pollock. 2004. Estimating detection probability

parameters for *Plethodon* salamanders using the robust capture–recapture design.

Journal of Wildlife Management 68: 1–13.

Bancroft, G. T., R. Bowman, and R. J. Sawicki. 2000. Rainfall, fruiting phenology, and

the nesting season of White-crowned Pigeons in the upper Florida Keys. Auk 117:

615–626.

Bart, J., and S. Earnst. 2002. Double sampling to estimate density and population trends

in birds. Auk 119: 36–45.

Beissinger, S. R., and E. H. Bucher. 1992. Can parrots be conserved through sustainable

harvesting. Bioscience 42: 164–173.

Boyce, M. S. 2001. Population viability analysis: development, interpretation, and

application. Pages 123–136 *in* T. M. Shenk and A. B. Franklin, editors.

Modeling in natural resource management. Island Press, Washington, D.C., USA.

Bucher, E. H. 1992. The causes of extinction of the Passenger Pigeon. Current

Ornithology 9: 1–36.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L.

Thomas. 2001. Introduction to distance sampling. Oxford University Press, New

York, New York, USA.

Campbell, D. G. 1978. The ephemeral islands: a natural history of the Bahamas. Macmillan, London, United Kingdom.

Casagrande, D. G., and S. B. Beissinger. 1997. Evaluation of four methods for estimating parrot population size. Condor 99: 445–457.

Clobert, J., and J. D. Lebreton. 1993. Estimation of demographic parameters in bird populations. Pages 75–104 *in* C. M. Perrins, J. D. Lebreton, and G. J. M. Hirons, editors. Bird population studies. Oxford University Press, New York, New York, USA.

Collazo, J. A., T. H. White, Jr., F. J. Vilella, and S. A. Guerrero. 2003. Survival of captive-reared Hispaniolan Parrots released in Parque Nacional del Este, Dominican Republic. Condor 105: 198–207.

Cougill, S., and S. J. Marsden. 2004. Variability in roost size in an *Amazona* parrot: implications for roost monitoring. Journal of Field Ornithology 75: 67–73.

Gibbs, J. P., H. L. Snell, and C. E. Causton. 1999. Effective monitoring for adaptive wildlife management: lessons from the Galápagos islands. Journal of Wildlife Management 63: 1055–1065.

Gnam, R. 1990. Conservation of the Bahama Parrot. American Birds 44:32–36.

Gnam, R., and A. Burchsted. 1991. Population estimates for the Bahama Parrot on Abaco Island, Bahamas. Journal of Field Ornithology 62: 139–146.

Gnam, R., and R. F. Rockwell. 1991. Reproductive potential and output of the Bahama Parrot *Amazona leucocephala bahamensis*. Ibis 133: 400–405.

Grant, B. R., and P. R. Grant. 1989. Evolutionary dynamics of a natural population. University of Chicago Press, Chicago, Illinois, USA.

Lancia, R. A., J. D. Nichols, and K. H. Pollock. 1996. Estimating the number of animals in wildlife populations. Pages 215–253 *in* T. A. Bookhout, editor. Research and management techniques for wildlife and habitats. Allen Press, Lawrence, Kansas, USA.

Marsden, J. S. 1999. Estimation of parrot and hornbill densities using a point count distance sampling. Ibis 141: 377–390.

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk 117: 393–408.

Rivera-Milán, F. F. 2001. Transect surveys of columbid nests on Puerto Rico, Vieques, and Culebra islands. Condor 103: 332–342.

Rivera-Milán, F. F., C. R. Ruiz, J. A. Cruz, M. Vázquez, and A. J. Martínez. 2003*a*. Population monitoring of Plain Pigeons in Puerto Rico. Wilson Bulletin 115: 45–51.

Rivera-Milán, F. F., C. R. Ruiz, J. A. Cruz, M. Vázquez, and J. A. Sustache. 2003*b*. Reproduction of Plain Pigeons (*Columba inornata wetmorei*) in east–central Puerto Rico. Auk 120: 466–480.

Sandercock, B. T., S. R. Beissinger, S. H. Stoleson, R. R. Melland, and C. R. Hughes. 2000. Survival rates of a neotropical parrot: implications for latitudinal comparisons of avian demography. Ecology 81: 1351–1370.

Sealey, N., and E. J. Burrows. 1982. School atlas for the Commonwealth of the Bahamas. Longman House, Essex, United Kingdom.

Snyder, N. F. R., W. B. King, and C. B. Kepler. 1982. Biology and conservation of the

Bahama Parrot. Living Bird 19: 91–114.

Stephens, D. W., and J. R. Krebs. 1986. Foraging theory. Princeton University Press,

Princeton, New Jersey, USA.

Thomas, L., J. L. Laake, S. Strindberg, F. F. C. Marques, S. T. Buckland, D. L. Borchers,

D. R. Anderson, K. P. Burnham, S. L. Hedley, and J. H. Pollard. 2002. Distance

4.0 Release 1. Research Unit for Wildlife Population Assessment, University of

St. Andrews, St. Andrews, United Kingdom.

Thompson, W. L., G. C. White, and C. Gowan. 1998. Monitoring vertebrate

populations. Academic Press, San Diego, California, USA.

Walters, C. J., and R. Green. 1997. Valuation of experimental management options for

ecological systems. Journal of Wildlife Management 61: 987–1006.

Table 1. Estimated density ($\hat{D}$), detection probability ($\hat{P}_a$), effective detection radius in meters ($\hat{ERD}$), and bootstrapped standard error (SE) from point-transect survey data of Bahama parrots collected on Abaco and Inagua, Bahamas, in January and May 2002-2004.

Island (month-year)	$\hat{D}$ [a]	SE	$\hat{P}_a$ [b]	SE	$\hat{ERD}$ [c]	SE	n [d]	k [e]
Abaco (05-02)	0.061	0.013	0.34	0.03	140.72	6.78	49	174
Abaco (01-03)	0.078	0.057	0.19	0.05	169.75	20.95	24	208
Abaco (05-03)	0.085	0.018	0.31	0.02	134.20	4.79	47	194
Abaco (05-02/03)	0.072	0.018	0.32	0.02	136.11	3.82	97	194[f]
Inagua (05-03)	0.183	0.049	0.30	0.05	99.47	9.02	44	144
Inagua (05-04)	0.153	0.042	0.22	0.04	88.74	7.87	39	159
Inagua (05-03/04)	0.172	0.032	0.25	0.03	93.46	5.82	83	159[g]

[a] $\hat{D}$ = **number of individuals/ha.**
[b] $\hat{ERD} = \sqrt{2/\hat{h}(0)}$ **(Buckland et al. 2001:159–161**

Table 1 (continued)

[c] $\hat{P}_a = \dfrac{2}{w^2} \displaystyle\int_0^w rg(r)dr$ **(Buckland et al. 2001:39–41).**

[d]**Encounter rate = n/k after data truncation at distance w (Buckland et al. 2001:78–80**

[e]**We surveyed 174 points in central ($k = 9$) and southern ($k = 165$) Abaco in May 2002; the same 174 plus 34 additional points were surveyed in January 2003; and 194 of 208 points were surveyed in May 2003. We surveyed 144 points throughout Inagua in May 2003; the same 144 plus 15 additional points were surveyed in May 2004.**

[f]**Survey effort (K) = 368 (i.e., 174 points surveyed twice and 20 points surveyed once in May 2002 and 2003).**
[g]**Survey effort (K) = 303 (i.e., 144 points surveyed twice and 15 points surveyed once in May 2003 and 2004)**

Table 2. Component percentages of variance for estimated density ($\hat{D}$) of Bahama parrots on Abaco and Inagua, Bahamas, January and May 2002-2004.

Island (month-year)	Percentage		
	Encounter rate	Detection probability	Cluster size
Abaco (05-02)	65	22	12
Abaco (01-03)	14	16	70
Abaco (05-03)	73	15	12
Inagua (05-03)	49	42	8
Inagua (05-04)	47	42	11

Table 3. Dispersion parameter estimate ($\hat{b}$), number of point transects surveyed (k), number of detections after data truncation (n), and number of point transects (μ) that would be needed to obtain a coefficient of variation (CV) of 10–20% for the estimated density ($\hat{D}$) of Bahama parrots on Abaco and Inagua, Bahamas, in January and May 2002-2004.

Island (month-year)	CV	$\hat{b}$ [a]	k	n	$\bar{s}$ [b]	SE	μ [c]
Abaco (05-02)	0.10	2.39	174	49	1.35	0.10	851
	0.15	2.39	174	49	1.35	0.10	378
	0.20	2.39	174	49	1.35	0.10	213
Abaco (05-03)	0.10	2.13	194	47	1.98	0.16	882
	0.15	2.13	194	47	1.98	0.16	391
	0.20	2.13	194	47	1.98	0.16	221
Inagua (05-03)	0.10	3.15	144	44	1.86	0.14	1032
	0.15	3.15	144	44	1.86	0.14	459
	0.20	3.15	144	44	1.86	0.14	258
Inagua (05-04)	0.10	4.06	159	39	1.54	0.14	1659
	0.15	4.06	159	39	1.54	0.14	737
	0.20	4.06	159	39	1.54	0.14	415

[a]Dispersion parameter was computed as: $\hat{b} = n \times (CV[\hat{D}])^2$, where observed CV = SE($\hat{D}$)/$\hat{D}$ (Buckland et al. 2001: 243).

[b]Mean cluster size was used in the absence of size bias and expected cluster size was used if cluster detection was size biased.

Table 3 (continued)

[c]Number of point transects was computed as: $\mu = k(\hat{b} + [\mathrm{sd}\{s\}/\bar{s}\,]^2)/n \times \mathrm{CV}^2$, where

desired CV = 0.20 (Buckland et al. 2001: 246).

Figures

Figure 1. Histograms of radial distance and detection probability of Bahama parrots, showing the fit of the model with a uniform key function and 1 cosine adjustment term to the distance data collected on Abaco in May 2002 (A), 2003 (B), and 2002-2003 (C). $n =$ 64 before data truncation in May 2002, and $n = 49$ before data truncation in May 2003. Data truncation distance was 240 m in both years (see Table 1 for sample sizes after data truncation).

Figure 2. Histogram of radial distance and detection probability of Bahama parrots, showing the fit of the model with a half-normal key function and 1 cosine adjustment term to the distance data collected on Inagua in May 2003 (A), 2004 (B), and 2003-2004 (C). $n = 50$ before data truncation in May 2003, and $n = 45$ before data truncation in May 2004. Data truncation distance was 180 m in both years (see Table 1 for sample sizes after data truncation).
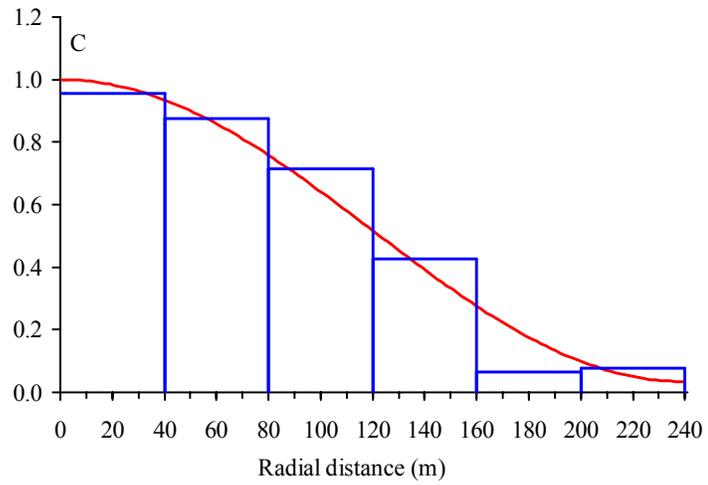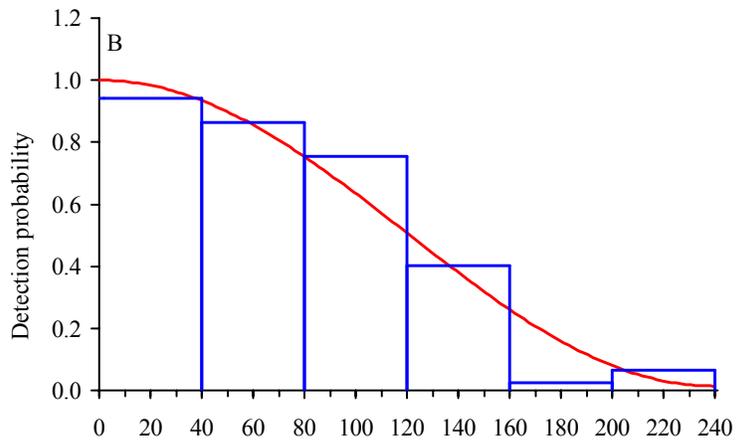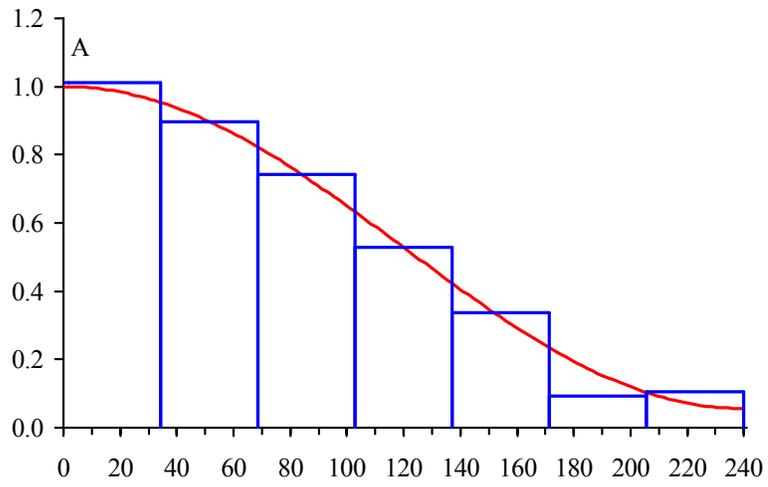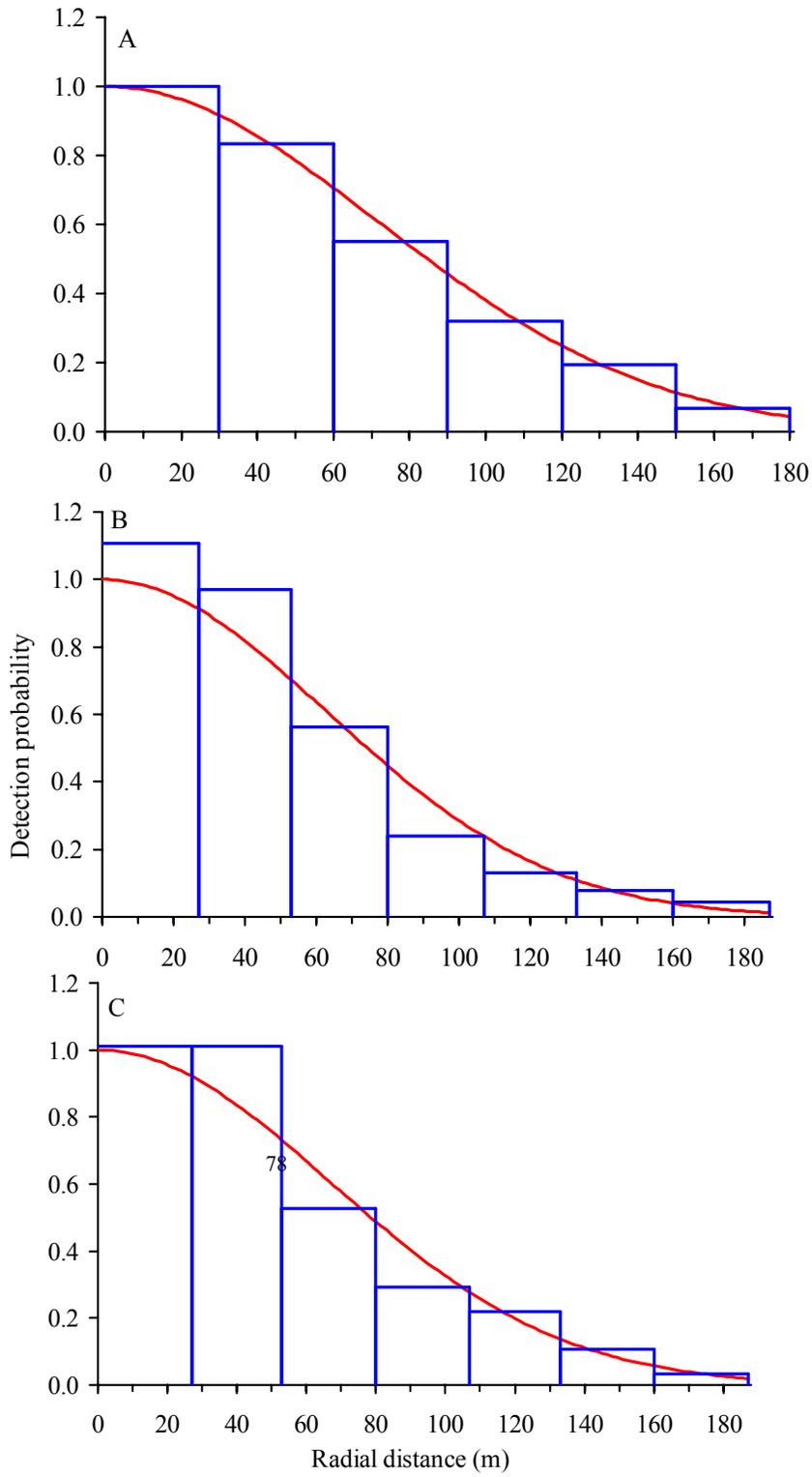
Chapter 2

Population Viability Analysis of the Abaco Population
of the Bahama Parrot.

Introduction

The Bahama Parrot (*Amazona leucocephala bahamensis*) was listed as an

endangered species in 1976 (USFWS 1976). The designation was prompted by concerns

about mammalian predation on nests of the Abaco population and disjunct distribution

(Snyder et al. 1982). The second extant population occurs in Great Inagua Island, about

400 miles south of Abaco. It is believed that the species occurred throughout the

archipelago, and as recent as 1950, it was reported on Ackland island (Bond 1947, 1956a,

1956b; Olson and Hilgarten 1982). Currently there is no evidence of dispersal between

the two remaining populations. It is not surprising that the two conservation

recommendations advanced by Snyder et al. (1982) to recover the species were to curb

the impact of predation and reintroduce the species to portions of its former range.

Progress towards meeting those recommendations has been slow to non existent

particularly on Abcao Island where parrots exhibit an underground nesting behavior and

which was the focus of this study. Implementing an effective predator control program is

costly and requires knowledge about the predators (e.g., density, home range), data that

are not available for southern Abaco. This limitation has not prevented the

implementation of *ad hoc* predator removal, but none have been implemented for extended periods of time, nor has their effectiveness in terms of curbing nest predation rates reported. On the other hand, lack of information, per se, does not impede the implementation of a translocation project as proposed by Snyder et al. (1982). However, it precludes framing a scheme that will facilitate its implementation without hampering the source population(s) and that will maximize the success of the reintroduction effort.

From 2003 to 2004, I collected data on selected demographic parameters to set a more comprehensive foundation upon which to assess the status of the Bahama Parrot, paying particular attention to the status of the Abaco population, and translocation schemes that would foster the persistence of the species (i.e., 95% survival probability over 100 years). From these data, and using the standardized criteria used to establish status by IUCN (2001), I concluded that the Bahama Parrot at present is vulnerable to extinction (Chapter 1). Fortunately the Bahama Parrot exhibits population sizes which are among the highest reported for *Amazona* throughout the Caribbean (Wiley et al. 2004). One of the benefits of a multi-population complex was illustrated during the 2004 hurricane season. Abaco and Inagua were hit by hurricanes in 2004, but Abaco was hit by stronger storms ($\geq$ category 3). The population in the Abaco study area appears to have been affected, unlike Inagua, where population numbers have remained about the same for the last three years (Chapter 1).

At the local scale, nest predation and its effects upon adult breeder survival rates was perhaps the most serious threat to the continued existence of the Abaco population. In 2004 22% of nests incurred predation. Predation occurred mostly within the Abaco National Park, created in 1994 to protect the core nesting area of parrots. Of primary

concern is predation on breeding adults. The results of my work suggested that adult survival rates could decrease by 5 to 11%, depending on how much each member of the pair was exposed (Chapter 1). The population in Abaco was also exposed to other natural threats such as fire and avian predation, but these did not result in adverse effects and were not as important as for other Amazons. I also documented that the passage of fire did not destroy any nest, and nest success in burned areas did not differ statistically from success in unburned areas (Chapter 1).

The vulnerability of the Abaco population to nest predation, coupled with the poor vagility that typifies Amazons (Snyder et al 1987), affirmed the importance of implementing a translocation program to insure the species' persistence. It also underscored the need to understand how the various factors impinging upon the Abaco's population influence its likelihood to persist. In this chapter, I evaluated the basis for sensitivity to extinction of the Abaco population, and through sensitivity analyses, provided additional insights on the importance of selected parameters on their population dynamics. Also, as a precursor to a translocation program, I evaluated the pros and cons of several components of such a program based on similar efforts with other Amazons (e.g., Collazo et al. 2003, White et al. 2005).

I used program VORTEX, a program designed to simulate population dynamics and stochastic events, to determine population persistence (Miller and Lacy 1999, 2003a and 2003b), to conduct the assessments, and to serve as a basis to discuss their conservation implications. With regards to the Abaco population, I asked the following questions:

1) what is the long-term outlook viability of the Abaco population?

2) By how much do predation and hurricanes undermine the persistence of the

Abaco population?;

3) Could a hypothetical population associated to the Abaco National Park, by

itself, sustain a viable population?

4) what is the combination of lowest values for selected vital parameters that

would lead to a growing, persistent population? The latter I called the vital parameter

space for the Abaco population. With regards to a translocation strategy, I asked the

following questions:

1) if Abaco birds were used as a source population how many birds can be safely

removed to establish a new population?

2) are removals for translocations limited to a specific age class?

3) what are the benefits in terms of persistence for the species?

Methods

I used program *Vortex* to assess the status of the species (e.g., probability of

survival over 100 years) and various conservation scenarios, and conduct a sensitivity

analysis to assess the relative importance of selected parameters in the demography of the

Abaco population. *Vortex* program is designed to simulate the effects of deterministic

forces as well as demographic, environmental and genetic stochastic events on wildlife

populations (Miller and Lacy 1999). Miller and Lacy (1999, check also

http://www.vortex9.org/vortex.html) described the computer program in detail (e.g.,

source codes, algorithms); however, the following are excerpts from their description of

the program aimed at providing the reader a better understanding of how it works.

In its attempt to model many of the extinction vortices that can threaten persistence of populations, Vortex models population dynamics as discrete, sequential events that occur according to probabilities that are random variables following user-specified distributions. Vortex simulates a population by stepping through a series of events that describe an annual cycle of a typical sexually reproducing, diploid organism: mate selection, reproduction, mortality, increment of age by one year, migration among populations, removals, supplementation, and then truncation (if necessary) to the carrying capacity. Vortex is an individual-based model. It creates a representation of each animal in its memory and follows the fate of the animal through each year of its life time. Vortex keeps track of the sex, age, and parentage of each animal. Demographic events (birth, sex determination, mating, dispersal, and death) are modeled by determining for each animal in each year of the simulation whether any of the events occur.

Vortex models demographic stochasticity by determining the occurrence of probabilistic events (e.g., reproduction, litter size, death) with a pseudo-random number generator. For each life event, if the random value sampled from a specified distribution falls above the user-specified probability, the event is deemed to have occurred, thereby simulating a binomial process. Demographic stochasticity is therefore a consequence of the uncertainty regarding whether each demographic event occurs for any given animal. To model annual fluctuations in natality or death rates, or carrying capacity that might result from environmental variation, *Vortex* assigns each demographic parameter to a distribution with a mean and standard deviation specified by the modeler. Fluctuations in probabilities of reproduction and mortality are modeled as binomial distributions. Environmental variation in carrying capacity is modeled as a normal distribution. A

catastrophe will occur if a randomly generated number between 0 and 1 is less than the probability of occurrence.

Because *Vortex* is a stochastic program it is important to note the distinction between demographic stochasticity and environmental variability (Miller and Lacy 1999). Demographic stochasticity is the variation in the observed rate of some demographic variable (e.g., birth rate, death rate) due to the sampling variation that is inherent whatever each individual (an observation) is an independent and random sample from a population with a given mean or probability. Hence, it is the variation in sample means ($\bar{x}$) around a fixed population mean (μ). Environmental variation, on the other hand, is variation (due to extrinsic factors that vary over time) in the population mean itself (e.g., μ is different each year). From this it follows that variation across years in the frequencies of birds and deaths, both in real and the simulated *Vortex* populations, will have two components. One is the demographic variation resulting from binomial sampling around the mean for each year, and additional fluctuations due to the environmental variability. Catastrophic events also contribute to the overall observed variation across many years of data, but they are treated separately in *Vortex* from the standard annual environmental variability.

I used a 25% coefficient of variation for all parameters (EV in models). This is the recommended default value when reliable estimates of variance are not available (Miller and Lacy 1999). I used this conservative value because my database consisted of only 1 or 2 field seasons and insights and calculations about the relative contribution of each source of variance (DS, EV) was therefore limited. Miller and Lacy (1999) provide guidelines to calculate the relative contributions that demographic stochasticity (DS) and

environmental variability (EV) make on the total observed variance. Miller and Lacy (1999) indicate, however, that *Vortex* generates an estimate of demographic stochasticity (DS) automatically as it determines whether each individual lives, whether it breeds, and what sex it is.

The status assessment and persistence was assessed by creating a BASE model. The BASE model also facilitated interpretation of results (e.g., other scenarios). The BASE model reflected the current understanding of vital parameters and factors influencing the Bahama Parrot (Chapter 1, Table 1). When values for input parameters were not available, they were adopted from other Amazon species in the Caribbean (Chapter 1, Snyder et al. 1982, Snyder et al. 1987, Lacy et al 1989, Gnam 1991, Collazo et al 2000, Wiley et al. 2004). I assumed that there were no density-dependent effects on reproduction (Chapter 1 provides some support for this assumption), or inbreeding depression in the population. I report the mean population size of extant and extinct populations (SD), mean stochastic rate of growth (SD), and persistence probability at the end of 100 years. Estimates were obtained by running each simulation 1000 times (i.e., iterations).

The following is a breakdown of values for selected input parameters for the BASE model, and when appropriate, I provide a rationale to justify them (Table 1). The Bahama Parrot is a long-lived species with a monogamous mating systems, as most *Amazona* parrots are (Lacy et al 1989; Forshaw 1989). Estimates of life span for Amazons in the wild range from 15-20 years. I used 18 years in my simulations (sensu Lacy et al. 1989). Initial population size was set at 2,600 individuals, survival of juveniles at 76% and breeding productivity at 1.2 chicks/ nest attempt. These values

84

were obtained from studies conducted on Abaco in 2003-2004 (Chapter 1). Annual

survival of females and males was adjusted by estimates of period survival during the

nesting cycle. The Bahama Parrot nests in underground cavities and is subject to

mortality as a result of mammalian predation (Chapter 1). It is estimated that adult

survival for Amazons is $\geq$0.90, and in the case of the Puerto Rican Parrot, around 91-93%

(Snyder et al. 1987, Muiznieks 2003). I used a 88% and 86% annual survival estimate

for adult males and females, respectively. This estimate reflected the differential

vulnerability of females to predation and was the result of the product of nest cycle

period survival and 0.93. Sub-adult survival was set at 0.85, as documented for the

Puerto Rican Parrot ((Snyder et al. 1987, Muiznieks 2003). Likewise, on the basis of the

Puerto Rican, age of first breeding was set at 4 years of age, and the proportion of adults

breeding at 60% (Beissinger 2000). The severity of hurricanes on survival and

reproduction could not be ascertained. Over the past 100 years 11 category 3 or higher

hurricanes have hit Abaco Island so I set hurricane probability equal to 0.1. The impacts

of the 2004 hurricanes are not certain but preliminary indications are that it had an impact

on the population. Thus I assessed an impact of 10% (0.9 input value), a conservative

level to reflect that fact that hurricanes invariably have an effects on avian populations,

be it directly (e.g., immediate impact) or indirectly (e.g., depleted food base; Wiley and

Wunderle 1993).

I also used *Vortex* to gain insights on 4 major scenario categories of conservation

interest. Below I list them and provide a brief rationale for each.

Sensitivity Analysis – This analysis was used to gain insights about the importance of

selected parameters on the population dynamics. Interest was placed on adult and

juvenile survival estimates and two elements of productivity—proportion of adult

breeding and nesting success. I had reasonable or empirical estimates for most the

parameters, some affected by predation, a factor evaluated during my study. I evaluated

the 4 parameters using 700 permutations. Values for adult survival ranged from 0.92, the

maximum value available in the literature (Snyder et al. 1987), to 0.82). Intervals

between values were of 2%. Juvenile survival ranged from 0.76 (Chapter 1) to 0.66,

breeding productivity ranged from 1.4 to 0.6, including 1.2 (observed value), and the

proportion of adults breeding ranged from 0.8 to 0.5. Sensitivity was expressed as the

mean stochastic growth rate for a given parameter. The estimate was obtained by sorting

by the parameter of interest, and then, averaging across all possible permutations or

model scenarios.

Predation and Hurricanes – These parameters represent the two natural threats that

appear to have the greatest impact on the Abaco population (Chapter 1). Of the two,

management can only be implemented to mitigate the effects of predation. I modeled

population persistence and growth in the absence of predation, presumably the conditions

prior to the introduction of exotic mammals (i.e., cats, raccoons). In this case, adult

survival was set at 0.93 for both sexes, and breeding productivity at 1.6 chicks/nest

attempt. Obviously, any reduction in predation rates would move population trajectory

towards the outcome of this scenario. Conversely, worsening conditions would move it

away from the current conditions as illustrated by the BASE model. I also modeled the

impacts of hurricane on reproduction and survival (I did not make a distinction between

the two in the models) and population persistence and growth. Although I have

circumstantial evidence indicating that hurricanes in September had an impact on the

population, I could not ascertain its severity. Thus, I evaluated scenarios that went from

10% (0.9 in model) to 30% (0.7) impact on survival and reproduction, evident the year

after the hurricane but maintaining hurricane frequency at 0.1. The severity of hurricanes

on either parameter can be steep as documented for the Puerto Rican Parrot (Muiznieks

2003). Impact on survival and breeding ranged from 50 to 60%.

Abaco National Park – I evaluated population persistence and growth within the Park,

with and without a complementary population outside the Park. Each population had its

own breeding productivity values, based on my study (Chapter 1), and the population size

was 1,300, or half of the estimated 2,600 in southern Abaco. There were no restrictions

on dispersal and survival of birds moving between populations. Three scenarios were

evaluated: 1) the base model consisted of running the model for both population without

any constraints; 2) a model whose carrying capacity "outside the park" population

arbitrarily decreased by 5% for 30 years, and 3) a model in which breeding productivity

of the "outside the park" population was zero. In the case of the second model (carrying

capacity), I modeled loss of habitat quality (e.g., foraging, nesting cavities), that might be

the result of human encroachment. In the case of the third model a source and sink

population, I modeled the effects of two populations that interacted but could only breed

in the park. In this case, nesting habitat is lost outside the park, but parrots are still able

to roam and forage opportunistically on remnant habitat much like in the urban areas

north of Crossing Rock (Figure 1, Chapter 1).

Translocations – I explored several scenarios aimed at evaluating the demographic and

persistence consequences of removing (e.g., capturing) 20 individuals, adults, and all

other age classes, from the Abaco population (source) for release in a pre-determine

reintroduction site as proposed by Snyder et al. (1982). Removals were conducted only

yearly, on 3 consecutive years, and over 5 consecutive years, and over 5 years with half

the source population composed of age 1-3 individuals and the other half adults. Sex

ration of removed birds was 50:50. I used 20 as the number to remove because it is the

same number of Puerto Rican Parrots that will be released during each of 3 years to

establish a second wild population in Puerto Rican (T. H. White, FWS, pers. comm.).

Benefits from such a group size include anti-predator behavior, locating foraging

resources, and statistically, a better means to obtain a reliable post-release survival

estimate (Collazo et al. 2000, White et al. 2005). Reintroduction efforts are notoriously

difficult (Wiley et al. 1992, Snyder et al. 2000), thus the chances of success are increased

by multiple releases (i.e., multiple removals from the source population) and releasing

adults from the wild (Snyder et al. 1994). The latter option is always dependent on

capturing adults at roost sites. Otherwise, captures might have to occur at nests. If so,

captures would likely include juveniles.

Results

The BASE model indicated the Abaco population has a 0.997 probability of

surviving over a 100 years, based on my best assessment of vital parameters and factors

impinging upon the population at present. The stochastic r, however, was negative or

indicative of a declining population (-0.012; Table 2; Figure 1). The population began at

2,600 parrots and dropped to 919 over 100 years.

The average stochastic r obtained from the permutations assess during the

sensitivity analysis was negative for all parameters, regardless of its value, with the

exception of breeding productivity. Breeding productivity of 1.4 or higher was the only value that resulted in a growing population (Figure 2). However, patterns in stochastic-r increased for all parameters, indicating a progression towards maintenance with higher values of each parameter. For juveniles, the increase over 10% survival was of 0.02 (Figure 3), where as for adults it was of 0.074 (Figure 4). The increase in stochastic r with increasing proportion of breeders was 0.06 (Figure 5). A summary of the results of the sensitivity analysis is presented in Appendix II.

The range of values yielding positive stochastic growth (i.e., Vital Parameters Space) is depicted in Figure 6. The minimum values to obtain a positive growth rate for the 4 parameters of interest was 84% for adult survival, 66% for juvenile survival, a breeding productivity of 1.0 chicks/nest attempts, and 60% was the minimum for the proportion of adults engaged in reproduction. As a parameters value changes, the values of the other parameters change as well to meet a positive growth rate. For example, if adult survival is 84%, then values must be 74% juvenile survival, a breeding productivity of 1.4 chicks/nest attempt, and 70% of the population breeding to maintain a positive growth rate.

Removing predation pressure from breeding productivity and adult survival yielded a positive stochastic r (0.062). Accordingly, the population size projection increased substantially, particularly when compared to the population trajectory of the BASE model (Figure 7). In response to hurricanes, population growth decreased from –0.012 (severity of 10% due to hurricanes) to –0.049 (severity of 30%; Table 1; Figure 8). Population survival over the next hundred years went from 0.997 (10% severity) and 0.984 (20% severity) to 0.788 with a 30% severity.

The persistence of the metapopulation model, with no constraints (base model), indicates a persistence of 0.986 over 100 years. As the carrying capacity (model 2 – decrease of 5% a year for 30 years) of the "neighboring" population of the Abaco National Park decreased, so did the persistence for the park population (0.862, Figure 9). Similarly, the scenario restricting reproduction only to the park yielded a probability of survival of 0.858 over 100 years (Figure 9). Population size for the metapopulation (sum of both populations) without constraints was 157. The metapopulation size for the model with a gradual decrease in carrying capacity was 32. The metapopulation size for the model with no reproduction outside the park was 34 (Figure 10).

Removing 20 adults or 20 mixed aged birds from the Abaco population did not result in marked decreases in stochastic r or survival probability from the BASE model (Figure 11). Removing adults only yielded a persistence probability of 0.999 and a stochastic rate of increase of -0.013 (Table 1). Removing adults for 3 consecutive years yielded a survival probability of 0.996 and a stochastic r of -0.013. Removing birds for 5 consecutive years yielded a persistence probability of 0.995 and a growth rate of -0.014. Removing adults and juveniles over a 5 year period yielded a -0.013 stochastic r and a persistence probability of 0.996 (Table 1).

Discussion

Criteria available through IUCN stipulate that a species should be considered endangered if it has a 20% probability of going extinct in 20 years or five generations (IUCN 2001). The results of my simulations suggest that, at least locally, the Abaco population was not in an imminent threat of extinction. The population had a 0.997 probability of surviving over 100 years. The population, however, decreased in numbers

consistently throughout that period (stoch. r = -0.012). The simulations began with a

population of 2,600 and finished with 996 individuals. Clearly, the population was not

maintaining itself, supporting concerns expressed about its status (Snyder et al. 1982,

Gnam 1991, Wiley et al. 2004).

The persistence and growth projections obtained from my models stemmed from

the best available demographic and environmental information (i.e., BASE model). I

believe that inferences from this model, and its variants, were sound and should be

helpful in molding future conservation measures. Parameter values originated from

available data for the Abaco population (e.g., Snyder et al. 1982, Gnam 1991, this study),

or congeners in the Caribbean (e.g., Snyder et al. 1987, Wiley et al. 2004). If values were

adopted from other Amazons, I erred on the side of caution. Sensitivity models were

particularly useful in identifying parameters or factors that deserve further attention to

reduce model uncertainty or to focus conservation actions. Parameters with the greatest

impact on the average stochastic r were adult survival and two expressions of

reproductive effort, that is, proportion of the breeding adults and breeding productivity.

Actually, breeding productivity was the only parameter that yielded a positive average

stochastic r. The sensitivity of stochastic r to changes in adult survival was not surprising

and consistent with life-history theory (i.e., long-lived species; Muiznieks 2003,

Thompson 2005). Clearly, improvements in these parameters will result in the best

opportunity for population growth. In this sense, the vital parameter space provided

values that could help set goals and guide management actions. For example, the

combination of vital parameters with lowest values that would yield a positive growth

was when adult survival was 84%, juvenile survival 72%, breeding productivity was 1.4

chick/nesting attempt, and the proportion of adults that bred was 70%. Of the said parameters, adult survival and breeding productivity can be positively influenced by management (e.g., predator control program, Chapter 1), which were also the two parameters with the greatest impact on the average stochastic r. From the same exercise it can be surmised that obtaining, for example, estimates of adult survival rate and the proportion of adults breeding would improve model projections and their usefulness to guide conservation efforts.

The effects on population persistence and growth by predation and hurricanes were in concert with the findings reported in Chapter 1. They were the threats that had the greatest impact or potential for substantial impact in the population. In the case of predation, I did not have a basis to create worst-case scenarios, although insights from lower adult survival and breeding productivity can be gained from the vital parameter space summarization. Instead, I removed predation pressure to discern how much would be gained if a predator control program was successful in abating their impact. Gains were not discernable in terms of persistence (P ~ 1.0), but were marked in terms of population growth (stochastic-r improved from -0.012 to 0.06). While fully abating the impact of predation is not likely (Keedwell 2002), a carefully designed predator control program could yield values of adult survival and breeding productivity that lead to growth. For example, reducing nest predation rates from current levels (22% of all nests, Chapter 1) by 25% or 50% could yield improvements in breeding productivity estimates and adult breeder survival estimates. Gains in breeding productivity would go from 1.2 chicks/nest attempt (Chapter 1) to 1.34 and 1.47, respectively. If we use the scenario where only breeding females are exposed to predation, gains in adult female breeder

annual survival would go from 0.82 to 0.89 (25% reduction) and 0.91 (50% reduction).

These gains bring both parameters to levels that could yield maintenance or population

growth as illustrated in the Vital Parameters Space diagram.

Hurricanes are a natural threat to avian populations in the Caribbean (Wiley and

Wunderle 1993), and their effects can be devastating (Muiznieks 2003, Collazo et al.

2003). For example, Collazo et al. (2003) documented a drop of 23% in survival rates of

released Hispaniolan Parrots (*A. ventralis*) 2 months after the passage of hurricane

Georges. In the case of the Puerto Rican Parrot, population numbers were cut by nearly

50% as a result of the immediate impact of hurricane Hugo (Muieznicks 2003). In

September 2004, the Abaco population was hit by, not one, but two major hurricanes

within 3 weeks of each other (Frances and Jeanne). Due to practical limitations (e.g.,

logistics, time) I could not fully assess their impact. The strongest indication of their

impact was the marked reduction in number of stations (9%) in which at least a parrot

was detected during a post-hurricane survey in May 2005 (Chapter 1). However, the low

number of detections could be explained by birds being alive but elsewhere. Thus, an

estimate of the severity hurricanes on survival, as well as reproduction, one year post-

hurricanes was not available. For this reason I used values for severity that range from

conservative impacts (0.9 as in BASE model) to more substantial (0.7). Results indicated

that the probability that the population would persist over 100 years decreased from 0.99

to 0.85. It is entirely possible that persistence could be lower because some impacts (e.g.,

on reproduction) could ensue beyond the first-year post-hurricane. Empirical data

suggested that reproduction of Puerto Rican Parrots (e.g., number of breeding pairs and

breeding productivity) decreased by as much as 50-60% for up to 2-3 years post-

hurricane (Muiznieks 2003). These results underscored why a translocation program for the Bahama parrot is central to its recovery. The high frequency of strong hurricanes hitting Abaco every 100 years (11) also underscored the need to evaluate their impact (see below recommendations).

The Abaco National Park was created because it harbors the core of the breeding population. Although it represents a third of the available habitat in southern Abaco (8K/25K ha), 64% of nesting attempts occurred within its boundaries in 2004. The remaining 36% of nesting attempts took place in the area surrounding the park. This area does not have any sort of designation, thus, it is subject to human encroachment. I documented that the number of chicks per nesting attempt produced in both areas was similar (Chapter 1). The question of interest in this case was to evaluate the persistence of a hypothetical park in light of two scenarios, namely, losing the capacity to produce chicks outside the park and losing habitat quality, or carrying capacity. My results suggested that persistence probability dropped from 0.99 to 0.85, regardless of the scenario modeled. In other words, losing a hypothetical, neighboring population harmed the population of interest. I was particularly intrigued by the parallels between the implications derived from the distribution birds and resources (Chapter 1) and the results of the scenario in which the carrying capacity decreased over 30 years. I documented that the park was not used heavily by parrots beyond the breeding season, and that areas to the north (Crossing Rock) and to the southwest (Sandy Point) were more important during the non-breeding season. It follows that survival and reproduction could be compromised if habitat outside the park is lost or degraded. Admittedly, the "park" scenarios are oversimplifications and making specific suggestions about how much

habitat needs to be protected is beyond the intended use of the models. Conversely, the results of the models and those presented in Chapter 1 provided compelling reasons to formulate habitat protection initiatives to accommodate the annual requirements of the parrots in Abaco, and protect "essential" habitat.

The "park" scenarios also helped illustrate what has been established in the literature--multiple populations enhance persistence (Shaffer 1981). As such, my analyses lent additional support to the implementation of a translocation program to insure the long-term survival of the species in the archipelago as suggested by Snyder et al. (1982). A precursor of such a program has to be whether the Abaco population could serve as a source, that is, "losing" individuals for reintroduction. In addition, if birds could be trapped (removed), which age class resulted in the lowest impact to the source population? For example, Collazo et al. (2000) showed that removing birds from the wild population was not possible for the Puerto Rican Parrot (*A. vittata*) until the population was >125 individuals, and then removal needed to focus on juveniles, not adults.

The results of my "translocation" scenarios suggested that removing 20 individuals once or over a number of years did not reduce stochastic growth nor persistence markedly (Figure 11). This was the case whether birds were adults or a mix of age classes. Two important elements for a successful reintroduction can be gleaned from these results (Snyder et al. 1994, Snyder et al. 2000). First, adults can be removed without hampering the source population (Figure 11). Second, translocating wild birds, as opposed to captive-reared birds, offers many advantages for reintroduction (Derrickson and Snyder 1992, Snyder et al. 1994). The benefits of removing adults from

the wild include better survival skills (e.g., foraging and predator avoidance), and equally important, interactions with or dependence on humans. Removing up to 20 is desirable because birds benefit improved survival by means of group defense and location of food resources. A larger release group also facilitates estimating post-release survival (Collazo et al. 2003, White et al. 2005), a measure to assess success during the early stages of the program. From these simulations it can also be surmised that there is no need for a captive-propagation program to implement such a program. Such a program should be viewed as a last resort (Snyder et al. 2000). They are costly, management intensive, and generate a whole host of other challenges (e.g., imprinting, genetics, acclimation to wild conditions; Derrickson and Snyder 1992, Ford 2001, Haig et al. 2004, White et al. 2005).

I conclude that at present the Bahama Parrot is vulnerable to extinction based on estimates of vital parameters summarized in Chapter 1 and standardized IUCN criteria (2001). This conclusion extended to the local situation in Abaco based on the results of model scenarios evaluated in this chapter. Although the BASE model did not yield a worrisome extinction scenario, it depicted a population consistently decreasing in numbers over 100 years. The primary basis for vulnerability at the local level is predation and its adverse effects on breeding productivity and adult survival. Vulnerability is further compounded by hurricanes. Clearly, management opportunities can only be applied to predation. A carefully designed predator control program is a logical proposition. Another recovery avenue that should be explored is to determine whether birds in Abaco are facultative nesters. That is, could they be capable of nesting in tree cavities like the birds in Inagua? This could be tested using artificial structures set

96

up near underground cavities during nest site selection periods. If birds from Abaco are facultative nesters, it not only offers an alternative management opportunity to preserve the species in case predation pressure becomes unsustainable, but it also makes the Abaco parrot a suitable candidate for translocation. Clearly, in light of the threat posed by mammalian predation to population persistence, reintroduction efforts should be made in islands devoid of mammals. As a long-term insurance, birds capable of nesting in tree cavities should be given preference for release.

Finally, model uncertainty can be reduced not only by augmenting the number of parameters for which an estimate can be obtained, but also by improving the reliability of key parameters (Miller and Lacy 1999). Two parameters had a marked influence on stochastic growth, namely, breeding productivity and adult survival. Thus, future research should make a concerted effort to estimate adult survival rate as it is intimately related to the effects of predation, and minor changes have major implications for population health. In that same vein, it cannot be overemphasized the importance of long-term monitoring of breeding productivity and population numbers. Rivera-Milan et al. (2005) set the sampling and analytical foundation for monitoring population numbers. Likewise, my work has outlined the methods to estimate breeding productivity and parrot annual survival, and the relationship between the two. These parameters are essential to assess the status of the species, effects of hurricanes, and evaluate the success of recovery actions.

Literature Cited

Bond, James. 1947. Field guide to birds of the West Indies; a guide to all the species of birds known from the Greater Antilles, Lesser Antilles and Bahama Islands.

Bond, James. 1956(a). Check-list of birds of the West Indies. Philadelphia, Academy of Natural Sciences of Philadelphia. p 214.

Bond, James. 1956(b). Supplement to the Check-list of birds of the West Indies. Philadelphia, Academy of Natural Sciences of Philadelphia.

Collazo, J. A., T. H. White, F. J. Vilella, and S. Guerrero. 2003. Survival of captive-reared Hispaniolan Parrots released in Parque Nacional del Este, Dominican Republic. Condor 105: 198-207.

Derrickson, S. R. and N. F. R. Snyder 1992. Potentials and limits of captive breeding in parrot conservation. Pages 133-163 in S. R. Beissinger and N. F. R. Snyder (Eds.). New World parrots in crisis: solutions from conservation biology, Smithsonian Institution Press, Washington, D. C.

Ford, M. J. 2001. Selection in Captivity during supportive breeding may reduce fitness in the wild. Conservation Biology 16(3):815-825.

Forshaw, J.M. 1989. Parrots of the World. London : Blandford, 1989

Gnam, R. S., and A. E. Burchsted. 1991. Population estimates for the Bahama Parrot on Abaco Island, Bahamas. Journal of Field Ornithology 62:139-146.

Haig, S. M., J. Collazo, H. Draheim, and S. Daniels. 2004. Population structure and pedigree definition in captive and wild Puerto Rican Parrots (*Amazona vittata*). Conservation Genetics. Report to USFWS-Rio Grande Field Office and the PR Department of Natural and Environmental Resources. 2 November. 30 pp

IUCN. 2001. Red List Categories and Criteria version 3.1.

Keedwell, R.J., R.F. Maloney, D.P. Murray. 2002. Predator control for protecting kaki (Himantopus novaezelandiae): Lessons from 20 years of management. Biological Conservation 105(3):369-374

Miller, P. S. and R. C. Lacy. 1999. VORTEX Version 8 users manual. A stochastic simulation of the simulation process. Apple Valley, MN: Conservation Breeding Specialist Group (SSC/IUCN).

Miller, P.S., and R.C. Lacy. 2003a. Integrating the human dimension into endangered species risk assessment. Pages 41-63 in: F.R. Westley and P.S. Miller, eds.

Experiments in Consilience: Integrating Social and Scientific Responses to Save Endangered Species. Island Press, Washington, DC.

Miller, P.S., and R.C. Lacy. 2003b. Metamodels as a tool for risk assessment. Pages 333-351 in: F.R. Westley and P.S. Miller, eds. Experiments in Consilience: Integrating Social and Scientific Responses to Save Endangered Species. Island Press, Washington, DC.

Muiznieks, B. D. 2003. Population viability analysis of the Puerto Rican Parrot: an evaluation of its current status and prognosis for recovery. M.S. Thesis, North Carolina State University. 88 pp. (http://www.lib.ncsu.edu/ETD-db/ETD-browse/browse).

Olson, S.L. and W.B. Hilgartner. 1982. Fossil and subfossil birds from the Bahamas. Pp 22-60. in S. Olson (ed) Fossil vertebrates from the Bahamas. Smithsonian Institute Press, Washington, D.C.

Rivera-Milan ,Frank F; J.A. Collazo; C. Stahala; W.J. Moore; A. Davis; G. Herring; R. Pagliaro; J.L. Thompson; W. Bracey. Estimation of density and population size and recommendations for monitoring trends of Bahama parrots on Great Abaco and Great Inagua. Wildlife Society Bulletin. 2005. In press.

Sandercock, B.K., S.R. Beissinger, S.H. Stoleson, R.R. Melland, C.R. Hughes. 2000. Survival Raltes of a Neotropical Parrot: Implications for Latitudinal Comparisons of Avian Demography. Ecology 81(5):1351-1370.

Shaffer,M.L. 1981. Minimum population sizes for species conservation. BioScience 31:131-134.

Snyder, N. F. R.,W. B. King, and C. B. Kepler. 1982. Biology and conservation of the Bahamas Parrot. Living Bird 19:91-114.

Snyder, N. F. R., J. W. Wiley, and C. B. Kepler. 1987. The parrots of Luquillo. West. Found. Vert. Zool., Los Angeles.

Snyder, N., S. Koenig, J. Koschmann, H. Snyder y T. Johnson. 1994. Thick-billed parrot releases in Arizona. Condor. 96: 845-862.

Snyder, N., P. McGowan, J. Gilardi and A. Grajal (eds.). 2000. Parrots. Status survey and Conservation Action Plan 2000-2004. UICN, Gland, Switzerland and Cambridge, UK. 180 pp.

Thompson, J. J. 2004. An age-structured population model of the Puerto Rican Parrot (Amazona vittata). Ornitologia Neotropical 15:289-297.

US Fish and Wildlife June 14, 1976. Endangered Status for 159 Taxa of Animals; 41 Federal Register 24062 24067

Wiley, J. W., N. Snyder, and R. Gnam. 1992. Reintroduction as a conservation strategy for parrots. In: S. Beissinger and N. Snyder (eds.). New world parrots in crisis: solutions from conservation biology, 165-200 pp. Smithsonian Inst. Press, Washington, USA.

Wiley, J. W., R. S. Gnam, S. E. Koenig, A. Dornelly, X. Galvez, P. E. Bradley, T. White, M. Zamore, P. Reillo, and D. Anthony. 2004. Status and conservation of the family Psittacidae in the West Indies. J. Caribbean Ornithology (Special Issue Honoring Nedra Klein) :94-154.

White, T. H., Jr., J. A. Collazo, and F. J. Vilella. 2005a. Survival of captive-reared Puerto Rican Parrots released in the Caribbean National Forest. Condor 107:426-434.

White, T. H., Jr., F. J. Vilella, J. A. Collazo, and S. A. Guerrero. 2005b. Effects of Hurricane George on habitat use by captive-reared Hispaniolan Parrots released in the Dominican Republic. Ornitologia Neotropical.16(3): 000-000

Figure 1. Population size change over 100 years under BASE model scenario.

	BASE Model	BASE EV
Breeding System	Monogamous	
Age of first breeding	4	
Max age of reproduction	18	
% Adults reproducing	60%	15%
Breeding Productivity	1.2	0.3
Survival 0-1	76%	6%
Survival 1-2	85%	4%
Survival 2-3	85%	4%
Survival 3-4	85%	4%
Survival ≥4 (females)	86%	3.50%
Survival ≥4 (males)	88%	3%
Hurricane probability	0.11	
Impact of Hurricanes on survival	10%	
Impact of Hurricanes on breeding	10%	
Initial Population Size	2600	
Carrying Capacity	10000	2500

Table 2. Results for BASE, Hurricane 20%, Hurricane30%, No Predation, Harvest 5yrs,
Harvest 3yrs, Harvest 1 yr, Harvest 5 yrs Adult and Subadult scenario models. Stochastic
population growth rate (stoc-r), Standar deviation of stochastic growth rate (SD(r)), Mean
population size at end of 100 years for extant populations (N-extant), Standard deviation
of N-extant, mean population size of all 1000 iterations (N-all) and its standard deviation
(SD(Nall).

Scenario	stoc-r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)
Base Model	-0.012	0.068	0.003	922.61	635.64	919.84	636.69
Hurricane 20%	-0.03	0.101	0.016	230.13	251.61	226.47	251.24
Hurricane 30%	-0.049	0.148	0.222	87.26	155.1	68	141.47
No Predation	0.062	0.062	0.003	7293.16	1835.25	7271.28	1875.44
Harvest 5 yrs	-0.014	0.069	0.005	818.03	563.77	813.94	565.32
Harvest 3 yrs	-0.013	0.069	0.004	856.12	606.21	861.66	607.45
Harvest 1 yr	-0.013	0.068	0.001	843.42	597.68	842.57	597.98
Harvest 5 yrs Adults and Juveniles/Subadults	-0.013	0.069	0.004	861.91	588.73	858.46	590.07
Metapopulation Models							
base (no restrictions on population)							
park only	-0.043	0.085	0.014	85.86	71.78	84.67	71.96
total population	-0.045	0.076	0.008	158.66	132.27	157.41	132.48
5% reduction in K over 30 years							
park only	-0.053	0.095	0.138	37.47	39.13	32.46	38.43
total population	-0.042	0.094	0.138	37.47	39.13	32.46	38.43
No breeding outside protected park							
park only	-0.057	0.095	0.142	37.83	35.27	32.59	35.12
total population	-0.056	0.092	0.134	39.93	37.42	34.7	37.29

**Figure 1** BASE model Population Size Projection for 100 years
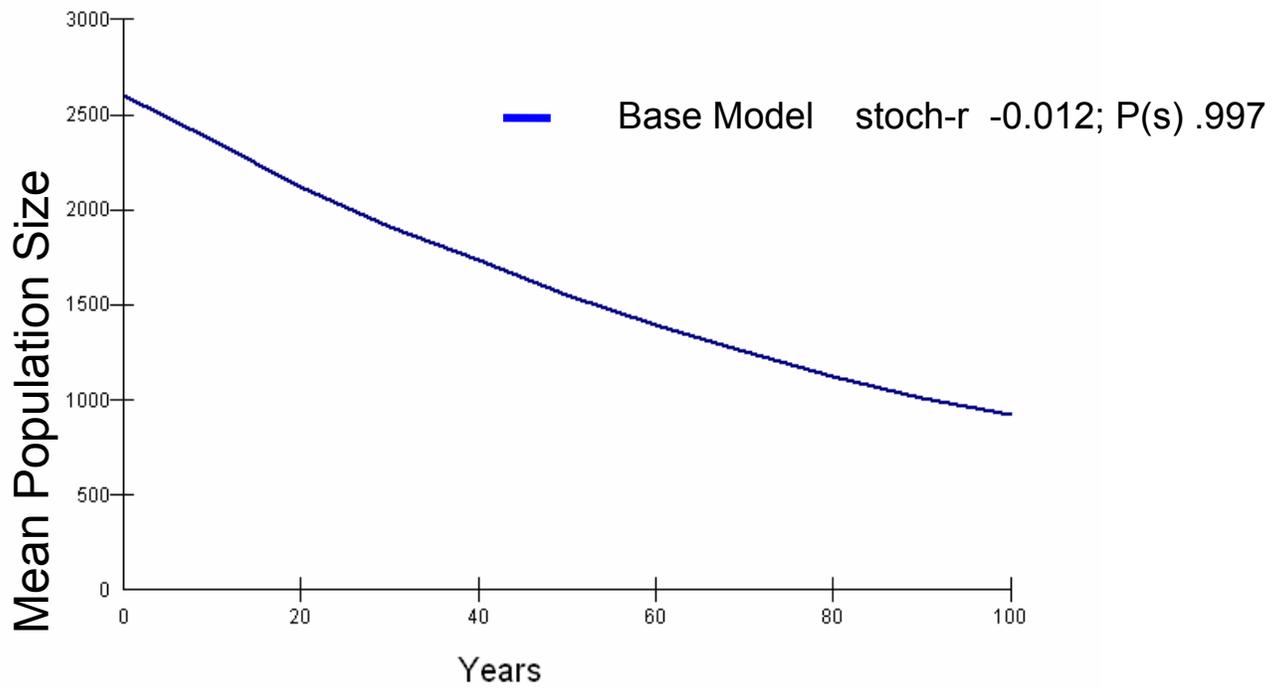
Figure 2 Sensitivity Analysis for Juvenile Survival showing the change in population growth rate with change in survival.
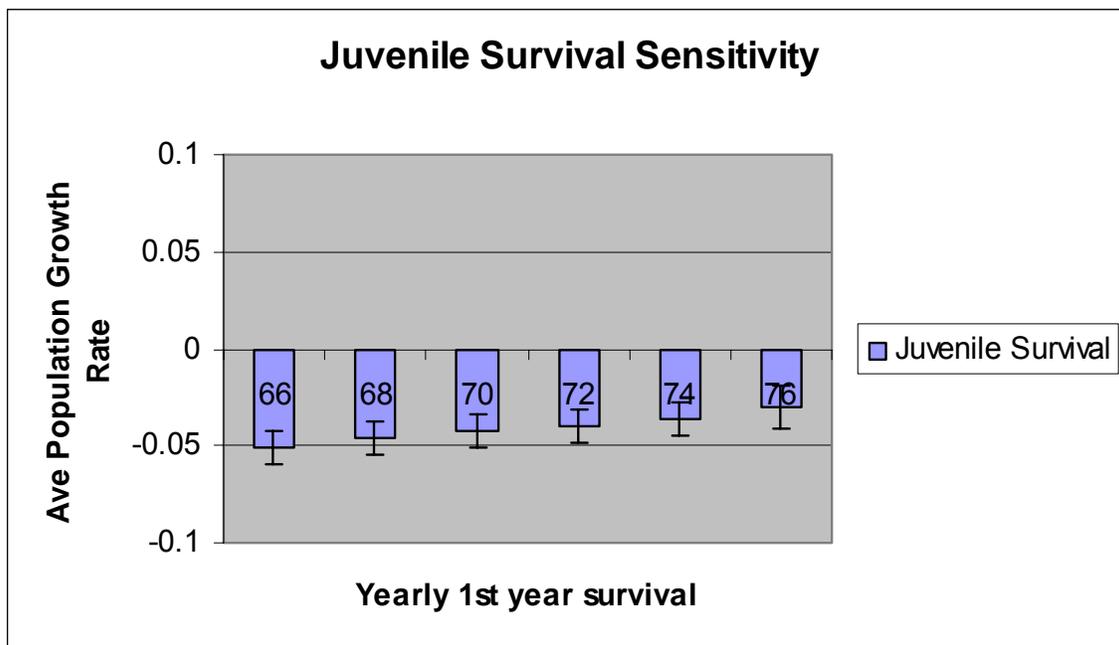
Figure 3 Sensitivity Analysis for Adult Survival showing the change in population growth rate with change in adult survival.
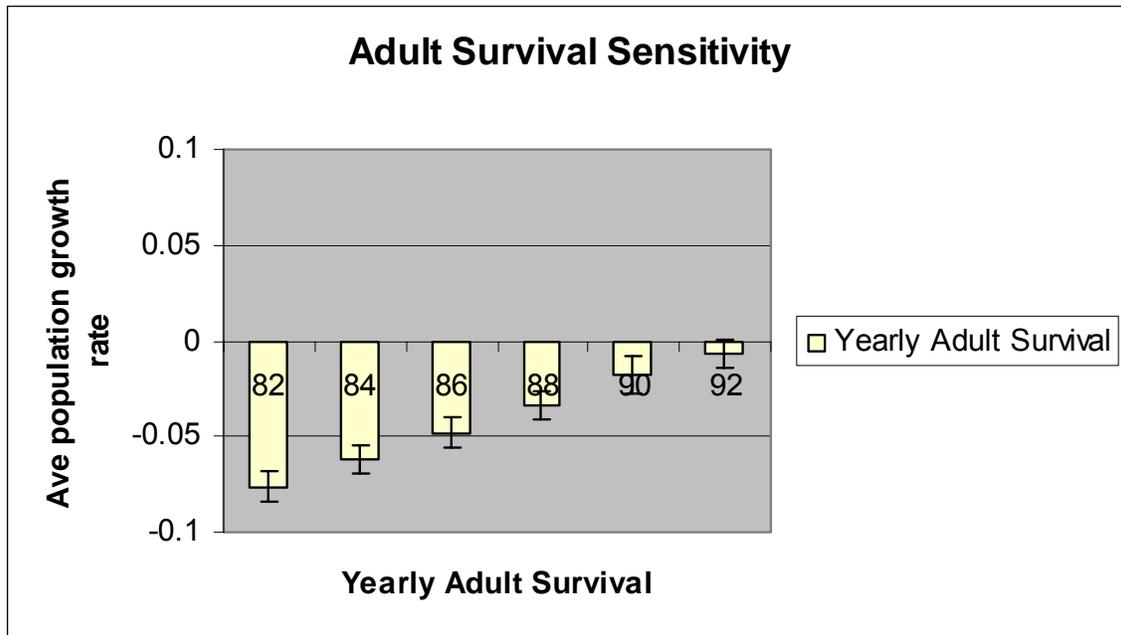
Figure 4 Sensitivity Analysis for percent adults breeding in the population showing the change in population growth rate with change in proportion of breeding adults.
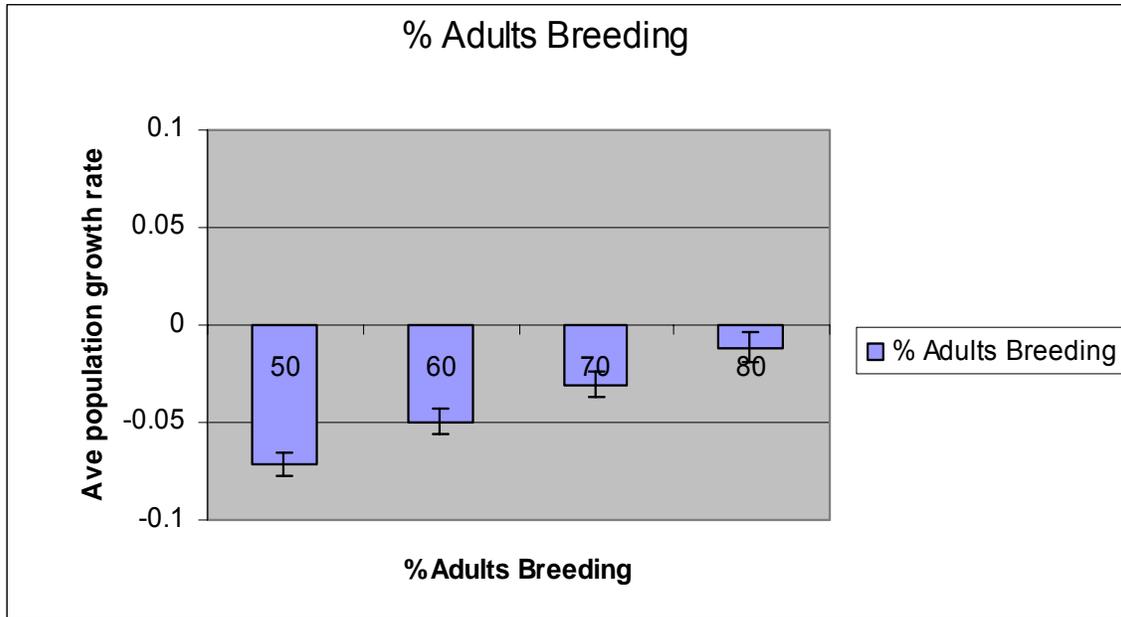
Figure 5 Sensitivity analysis for breeding productivity, showing the change in population growth rate with change in number of chicks fledged per nest initiated.
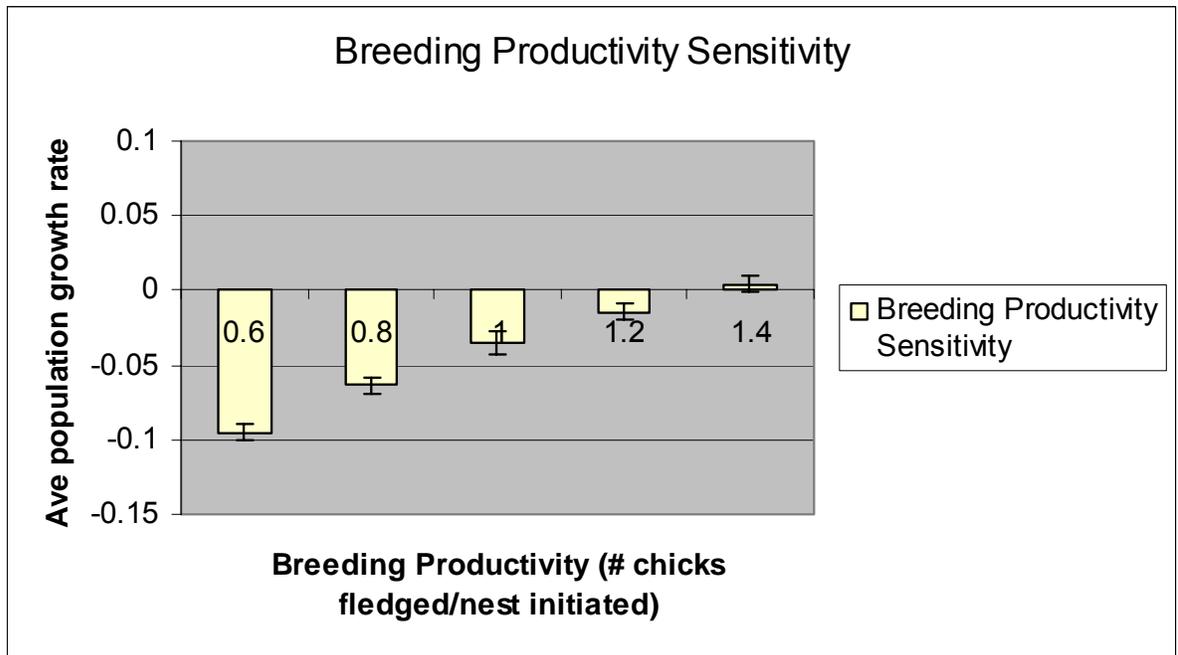
Figure 6 Vital Parameters Space depicting combinations (same color lines denote unique demographic combinations that yield positive growth rate) of adult survival, juvenile survival, breeding productivity and proportion of adults breeding to maintain a positive population growth rate.
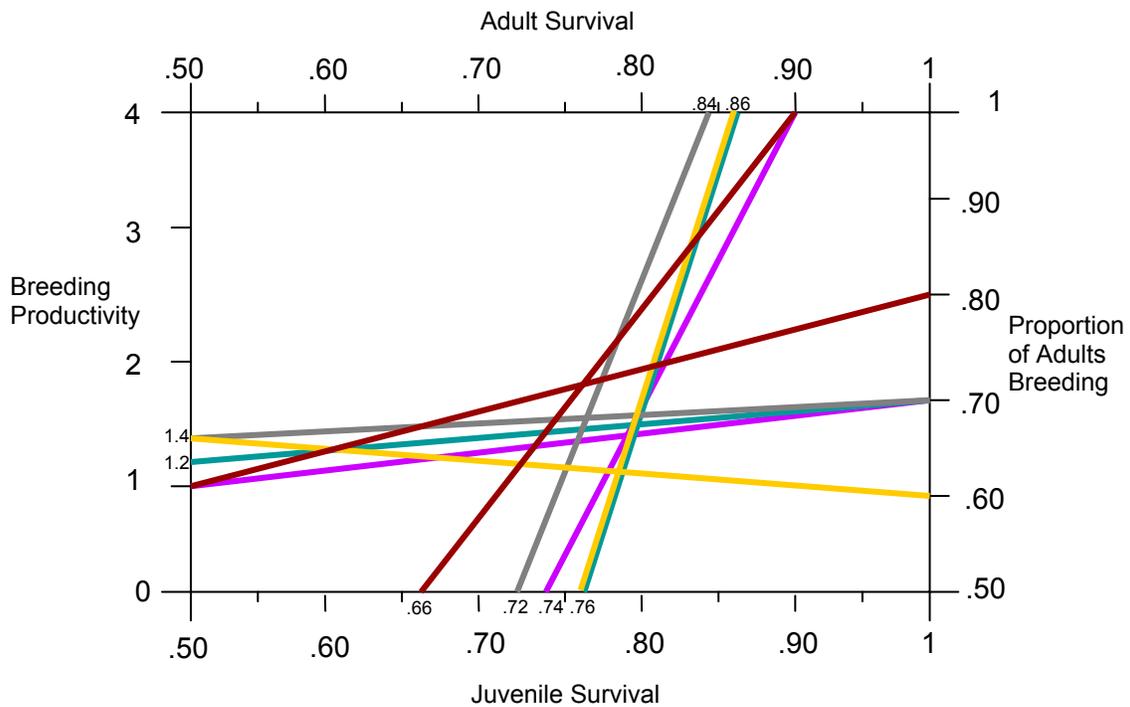
Figure 7 Population Size Projections over 100 years with no Cat Predation
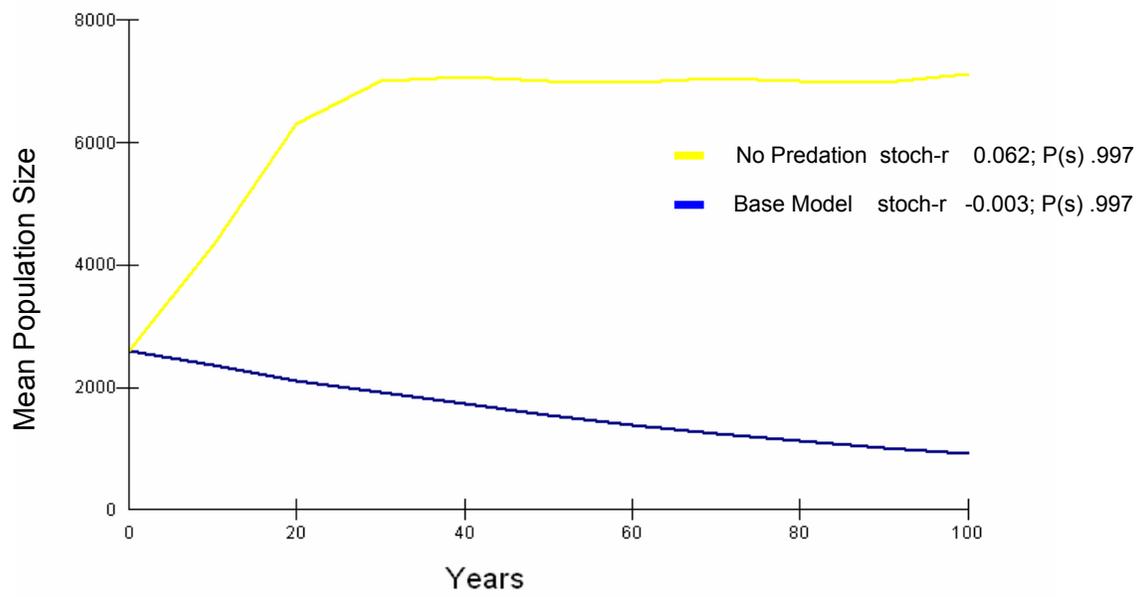
**Figure 8** Population Size Projections over 100 years under 10, 20 and 30% Hurricane impacts
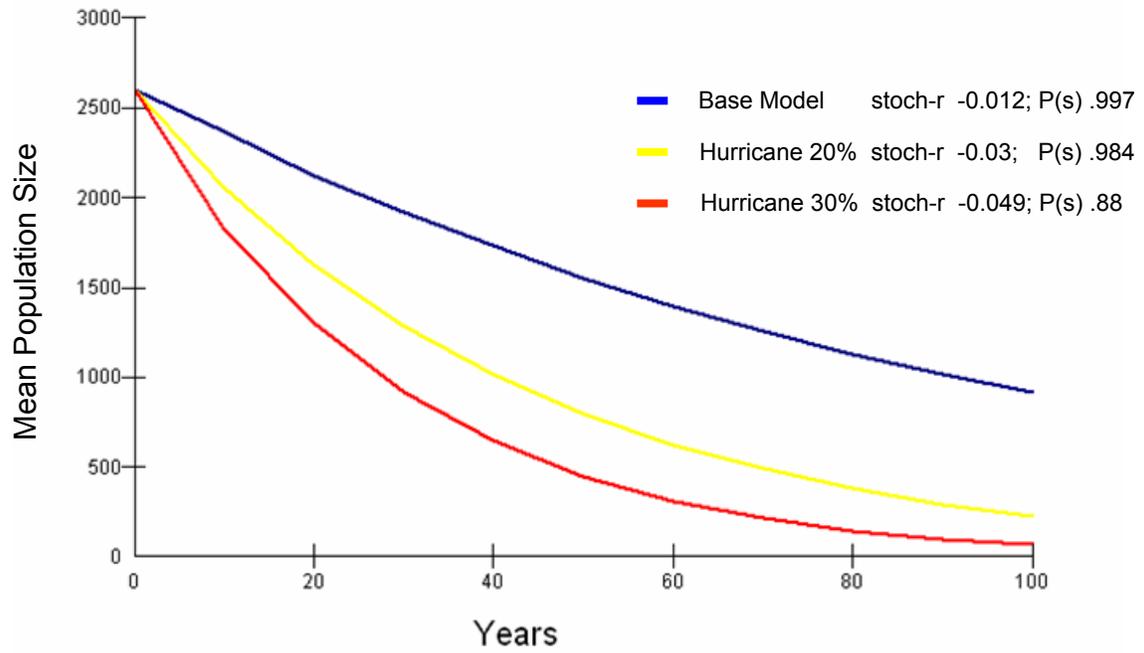
Figure 9 – Population Size of Park under various Metapopulation circumastances

Figure 10 Metapopulation Size (Park and Nonpark) under various
Metapopulation circumstances.
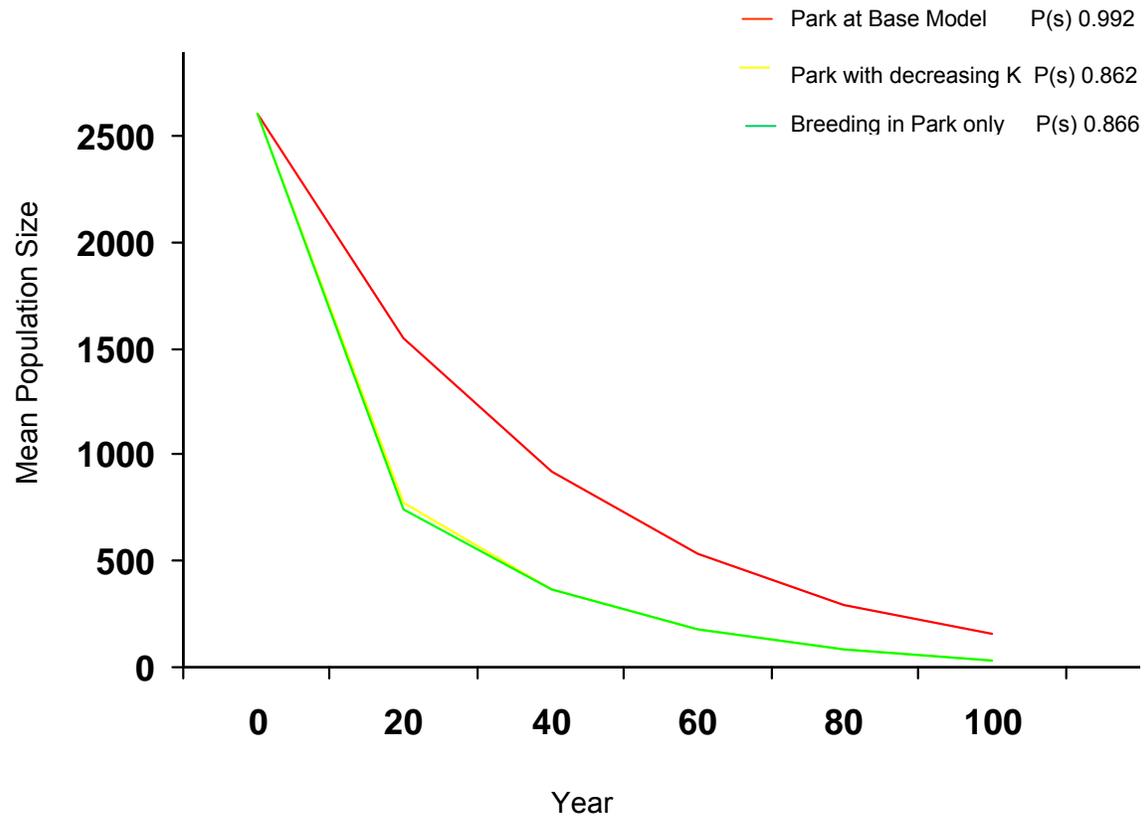
Figure 11 Population Size Projections over 100 years under various harvesting scenarios.