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Population viability analysis of monk parakeets in the United States and examination of alternative management strategies

Stephen Pruett-Jones, Department of Ecology and Evolution, University of Chicago, 1101 East 57th Street, Chicago, IL 60637, USA *pruett-jones@uchicago.edu*
James R. Newman, Pandion Systems, Inc., 5200 NW 43rd Street, Suite 102–314, Gainesville, FL 32606, USA
Christian M. Newman, Pandion Systems, Inc., 5200 NW 43rd Street, Suite 102–314, Gainesville, FL 32606, USA
Michael L. Avery, USDA Wildlife Services, National Wildlife Research Center, 2820 East University Avenue, Gainesville, FL 32641, USA
James R. Lindsay, Florida Power and Light Company, 700 Universe Boulevard, Juno Beach, FL 33408, USA

Abstract: In the United States, monk parakeets (*Myiopsitta monachus*) are expanding their geographical distribution, and their overall population size is growing exponentially. Monk parakeets are causing widespread economic damage in the United States by nesting on utility structures, which leads to electrical fires and power outages. Although few life history data are available for the species from North America, extensive data are available from the species' native range in South America. Incorporating data from South America into the population viability analysis program VORTEX, we simulated population growth in United States monk parakeets to determine whether it is likely that the United States population shows life history patterns similar to those in the native range. The answer was, no. The intrinsic rate of growth (r) of monk parakeets in the United States (r = 0.119 during the period 1976–2003) was almost double the rate of population growth (r = 0.064) for the simulated population. Modifying the South American data to allow for reduced mortality, higher fecundity, or a greater proportion of breeding females resulted in population growth rates similar to those in the United States. We extended the simulations to examine the effectiveness of alternative control measures on the monk parakeet population by using the modified life history data. Simulations revealed that it would be necessary to remove 20% of the adult population or to destroy 50% of the nests each year to reduce the population size of monk parakeets. In practical terms, such massive management efforts are unlikely to be sustainable. Instead, control of monk parakeets will likely require an integrated approach including removal of local problem nests on a case-by-case basis and long-term population reduction through trapping or chemical sterilization.

Key words: human–wildlife conflicts, management, monk parakeets, *Myiopsitta monachus*, parakeets, population viability analysis

The monk parakeet (*Myiopsitta monachus*) is now a common breeding species in many areas of the United States. An introduced species, the monk parakeet established self-sustaining breeding populations in the United States during the late 1960s and early 1970s (Spreyer and Bucher 1998). Since then, the species has both expanded its distribution and increased in population size. For example, on the National Audubon Society's 2002–2003 Christmas Bird Count, a total of 4,158 monk parakeets was recorded at 45 localities in 10 states (including count week records; Pruett-Jones et al. 2005). Across the United States generally and in specific states where analyses have been conducted, populations of monk parakeets are growing exponentially and currently double every 6 to 7 years (Van Bael and Pruett-Jones 1996, Pruett-Jones and Tarvin 1998, Pruett-Jones

Parakeets nesting in power transformer.

Table 1. Parameters of the VORTEX model used to simulate monk parakeet population growth and consideration of alternative management strategies. The default values are those that were used in the simulations. Default values in italics represent estimates due to a lack of data from the literature (# = number; EV = environmental variability; N/A = not applicable; F = female; M = male).

Variable	Explanation or notes	Default values
# of iterations	# of times the simulation is run	100
# of years	# of years the population is modeled	27 (1976–2003)
Extinction definition	How extinction is defined in the model	Only 1 sex remains
# of populations	# of populations to be modeled	1
Inbreeding depression	The level and effect of inbreeding depression	No inbreeding depression assumed
EV concordance of reproduction and survival	The concordance between reproduction and survival in different populations	N/A–only 1 population modeled
Dispersal rate	The rate of dispersal between populations	N/A–only 1 population modeled
Reproductive system	The mating system	Monogamy (Table 2)
Age of 1st reproduction in females	Age at which F begin breeding	2 (Table 2)
Age of 1st reproduction in males	Age at which M begin breeding	2 (Table 2)
Maximum age of reproduction	Age of F/M when breeding ceases	8 (Table 2)
Maximum # of progeny produced/year	Maximum # of offspring produced by F each year	6.0 (mean clutch size, see Table 2)
Sex ratio at birth	Sex ratio of offspring at hatching	1:1 (Table 2)
Density dependence in reproduction	The relationship between reproduction and population density	No relationship assumed
Proportion of adult F breeding	The percentage of adult F that breed each year	70% (Table 2)
EV in % breeding	EV in % of adult F breeding each year	10% set as default (10% variability in percentage of F breeding)
Distribution of # of offspring/female	Statistical distribution characterizing the # of offspring produced	Normal distribution
Mean # of offspring/F	Mean # of offspring produced by each F	2.0 for baseline simulation (Table 2)
SD in # of offspring/F	SD in number of offspring produced by each F	0.5
F mortality	Mortality rates of F, specified for three age classes (0–1, 1–2, and 2+) by mean and SD	For baseline: 0–1: 39%, 1–2: 19%, 2+: 19% (Table 2), SD set at 10% of mean as default
M mortality	Mortality rates of M, specified for 3 age classes (0–1, 1–2, and 2+) by mean and SD	Identical to F mortality
Catastrophe frequency	Frequency of catastrophes affecting the population (e.g., hurricanes)	5% (a catastrophe affects the population once every 20 years)
Catastrophe severity	Reduction in survivorship/reproduction as a result of the catastrophe	25% reduction in both survivorship and reproduction
Mate monopolization	% of adult M breeding/year	100%
Initial population size	The number of individuals at the beginning of the simulation	1,000
Age distribution of initial population	Distribution of individuals by age at the beginning of the simulation	Stable age distribution
Carrying capacity	The carrying capacity of the environment	20,000 for baseline simulation
Harvest	Whether individuals were removed from the population (F/M)	No harvest for baseline simulation (see text for harvest simulation)
Supplementation	Whether individuals were added to the population (F/M)	No supplementation assumed

et al. 2005). Similar population expansions have been observed in Europe, where the species is also established (Sol et al. 1997).

The monk parakeet is reportedly a significant agricultural pest in its native range (Bump 1971, Bucher and Bedano 1976, Bucher 1984) and the fear that it would become a pest species here led the U.S. Fish and Wildlife Service (USFWS) to institute a nationwide eradication program in the early 1970s. This program reduced the numbers of monk parakeets by approximately one-half at the time (Neidermyer and Hickey 1977), but populations subsequently recovered rapidly and continued their expansion. While monk parakeets have not become a significant agricultural pest in the United States, another problem has arisen. In several states, most notably Connecticut, Florida, Illinois, New York, and Texas, monk parakeets cause regular and persistent problems with electrical reliability and public safety because the birds often build their nests on electrical utility structures (transformers, substations, and transmission lines), causing power outages, electrical fires, and disruption to electrical service to customers (Avery et al. 2002, 2006).

Population trends of monk parakeets have been analyzed with Christmas Bird Count data (Van Bael and Pruett-Jones 1996, Pruett-Jones and Tarvin 1998, Pruett-Jones et al. 2005), but detailed demographic analyses of individual populations are not currently possible due to the paucity of life history data for the species in the United States. Nevertheless, such data are available for the species within its native range in Argentina (Spreyer and Bucher 1998). These data can be used in population simulations to ask, given the patterns of population growth that the species has exhibited in the United States, whether such population growth can be explained by the demographic patterns the species exhibits in its native range.

Simulation of a monk parakeet population comprises Part I of this paper. Part II consists of modifying the model developed in Part I to examine the sensitivity of the model (i.e., population size) to changes in specific demographic parameters. The objective of Part II is to examine the efficacy of alternative management measures that could be used to reduce population size in monk parakeets.

Methods

Part I. Baseline simulation of a monk parakeet population

We modeled monk parakeet populations using the computer program VORTEX (version 9.61), an individual-based simulation model for population viability analysis (PVA; Lacy 2000*a*, Lacy et al. 2003, Miller and Lacy 2003). Such models are most typically used to model the dynamics of or threats to small populations as these relate to conservation objectives (Lindenmayer and Possingham 1995, Beissenger and Westphal 1998, Lacy 2000*b*). Nevertheless, PVA models generally and the VORTEX model specifically, are robust and useful for modeling population growth or decline of a species through time (Brook et al. 1997*a*, *b*, 2000).

Because VORTEX is an individual-based model, it tracks the fate of individuals (their birth, survivorship, reproduction, and death) and

Table 2. Life history parameters for monk parakeets that were incorporated into the simulation of parakeet population growth. Unless indicated otherwise (i. e., Captivity) all data are from studies of wild parakeets in Argentina. No life history data are published for monk parakeets in North America.

Parameter	Value	Reference
Mating system	Monogamous, cooperative breeding rare	Eberhard 1998
Sex ratio	1:1	Bucher et al. 1991
Age at maturity	No birds breed in 1st year; 50–63% breed in 2nd year; a substantial but variable proportion of 2+ year olds do not breed	Martin 1989, Martin and Bucher 1993
Clutch size	5–7, $\bar{x}$ = 6 Captivity: 5–8	Navarro et al. 1992 Kolar and Spitzer 1990, Alderton 1992
Broods/year	Only 5% of successful pairs renest Captivity: 2–3 possible	Navarro et al. 1992 Kolar and Spitzer 1990
Breeding success	Hatching: 56% Fledging: 45% Eggs laid to fledged young: 25%	Bucher et al. 1991, Navarro et al. 1992
Survivorship	First year: 61% Adult: 81%	Spreyer and Bucher 1998
Longevity	> 6 years Captivity: 12–15	Martin 1989 Alderton 1992, Lowell 1994
Dispersal	Natal to breeding area: $\bar{x}$ = 1.2 km, range = 0.3–2.0 km	Martin and Bucher 1993

calculates population parameters (population size, growth, etc.) as the sum of the actions or fates of individuals. The VORTEX model is a stochastic simulation model in that it calculates the fate and success of individuals randomly, based on the value of parameters put into the model. Thus, if annual mortality of adult males is set at 20%, each individual has a 20% chance of death each year. Because of this feature of the model, the actual percentage of adult males that is modeled as having died may be much lower or much higher than 20% in any given year.

The VORTEX model requires many input parameters (Table 1). Although VORTEX provides a mechanism for evaluating the effects of inbreeding, we did not include analysis of inbreeding because it is not presently assumed to be important in monk parakeet populations. We modeled monk parakeets as a single population, an assumption we recognize is not correct, but all populations of monk parakeets in the United States appear to exhibit similar patterns of population growth (Pruett-Jones et al. 2005). As such, simulation of a single population may reflect what is happening in each of the separate populations in the United States.

We based the simulations on published life history data from monk parakeet populations studied in South America (Table 2). It is, however, important to acknowledge that estimates had to be made about some of the parameters for which no data were available in the literature. These variables were: (1) environmental variability in the percentage of females breeding each year; (2) standard deviation in number of offspring produced by each female; (3) standard deviation in female mortality; (4) standard deviation in male mortality; (5) catastrophe frequency; and (6) catastrophe severity. As we did not have specific values from the literature for these values, we made our best guesses for the values of these parameters (Table 1).

We ran each simulation 100 times, and the final parameters (size, intrinsic rate of growth) of the population are expressed as mean values of the 100 populations simulated. For all simulations, the initial population size was set as 1,000 individuals. This value is arbitrary, but results of the simulation do not depend on initial population size except that random effects of reproduction and survival are more pronounced in very small populations.

For the baseline simulation we modeled the population for 27 years. This corresponds to the period 1976–2003 following the USFWS parakeet eradication program (Neidermyer and Hickey 1977). Population trends documented with Christmas Bird Count data reveal that monk parakeets in the United States have exhibited an intrinsic population growth rate of 0.119 during the 27-year period (Pruett-Jones et al. 2005). We used this value of population growth for comparison to our simulations.

Part II. Consideration of alternative management strategies

We evaluate two alternative strategies: capturing and euthanizing adult birds or destroying nests. All simulations described in this section use the adjusted baseline population derived in Part I as their starting point (see Results). We then assess the effects on this population of either removing adults or preventing some birds from breeding by

Table 3. Parameters of the VORTEX model that varied in the simulation of alternative management strategies for monk parakeets and the values of the parameters used in each specific simulation. Only those parameters that were allowed to vary are listed here. Parameters for which fixed default values were used are not listed. In all simulations, the initial population size was 1,000 (# = number; F = female; M = male; J = juvenile; A = adult; AF = adult female).

Variable	Adult removal			Nest destruction		
	6%	10%	20%	10%	20%	50%
# of years	10%	10%	10%	10%	10%	10%
Proportion of AF breeding	66%	66%	66%	59%	53%	33%
A removal	30% F 30% M 50% J 50% A	50% F 50% M 50% J 50% A	100% F 100% M 50% J 50% A	None	None	None

destroying nests. All simulations assume an initial population size of 1,000 birds and the populations are simulated for a period of 10 years. We use a 10-year time period because we assume that any control program that might actually be carried out would seek reductions in the parakeet population relatively rapidly and that the control program would not be carried out indefinitely. Input parameters used in this set of simulations are shown in Table 3.

Capture and euthanasia. Within the VORTEX model, simulation of the removal of birds is accomplished through the harvest option. We considered 3 scenarios: removal and euthanasia of 6%, 10%, and 20% of individual birds each year from a population. Because actual removal programs would trap birds indiscriminately, we assumed that for all of these scenarios equal numbers of males and females were removed. We also assumed that trapping programs would not differentiate between juvenile and adult birds.

In each of these scenarios, the percentage reduction was set by the initial size of the population, and this value was fixed each year. Thus in the 20% harvest scenario, the simulation was run assuming that 200 birds were removed from the population each year even after the population began to decline. The actual percentage of the population that was being removed thus increased as the population began to decline.

Table 4. Results of the simulations of monk parakeet population growth using the model VORTEX. Parameter values are listed in Table 1, except where changed as listed below. In all simulations, the number of years was set at 27 and the initial size of the population was set at 1,000 (# = number; F = female).

Simulation	Final population size: mean (SD)	Intrinsic rate of growth r
Baseline	6,469 (3,195)	0.064
Baseline with 10% reduction in mortality	15,936 (6,249)	0.100
Baseline with 10% increase in proportion of F breeding	12,790 (5,854)	0.090
Baseline with 10% increase in mean # of offspring produced/F	11,886 (5,325)	0.088
Adjusted baseline: 10% reduction in mortality and 10% increase in proportion of F breeding	28,227 (10,402)	0.122

Nest removal. We started with the same basic parameters as the adjusted baseline simulation (see Results), and then we modified model parameters to simulate reduction in reproduction within the population. The VORTEX model accommodates 2 methods of lowering reproductive output. The mean number of offspring produced per female can be reduced (e.g., by destroying eggs) or the percentage of females breeding each year can be reduced (e.g., by destroying nests). The 2 control methods have similar effects (the number of offspring produced is reduced), but within the model they are handled differently. Because any control program would most likely center on nest destruction rather than repeatedly removing eggs from individual nests, it seemed more realistic to model the situation where the proportion of females breeding each year is reduced. Thus our modification of the parameters in these simulations assumed that nests were destroyed during the breeding season. We simulated the population for 10 years because we assumed that this reflects a reasonable duration for an actual control program. We simulated 3 scenarios (Table 3): removal of the nests of 10%, 20%, or 50% of the females nesting in an area, such that those females do not breed. If females rebuilt their nests, this simulation assumes that the replacement nests are also removed.

Results

Part I. Baseline simulation of a monk parakeet population

From a starting population of 1,000 birds, in 27 years the mean population size (mean size of 100 simulated populations) was 6,469, and the average intrinsic rate of population growth (r) was 0.064 (Table 4; Figure 1). This is approximately half the observed rate of growth of monk parakeets recorded on Christmas Bird Counts in the United States. The population of monk parakeets in the United States appears to be growing faster than predicted based on life history data obtained for the species in Argentina.

Many aspects of monk parakeet biology could differ between Argentina and the United States. We examined the sensitivity of the model to changes in 3 specific parameters: mortality rate, proportion of females breeding each year, and fecundity of females. A reduction in mortality or an increase in either the proportion of females breeding each year or female fecundity each increased the intrinsic rate of growth but did not lead to population growth as rapid as observed from Christmas Bird Count data in the United States (Table 4).

Table 5. Results of the simulations of monk parakeet populations examining the effects of alternative control measures. In all simulations, the number of years was set at 10 and the initial size of the population was set at 1,000.

Simulation	Final population size: mean (SD)	Intrinsic rate of growth *r*
Adjusted baseline	3,576 (823)	0.125
6% adult removal	2,407 (705)	0.083
10% adult removal	1,655 (635)	0.041
20% adult removal	152 (221)	-0.238
10% nest destruction	2,604 (725)	0.091
20% nest destruction	2,013 (546)	0.067
50% nest destruction	454 (115)	-0.082

Next, we simulated population growth by allowing changes in multiple parameters simultaneously. The combination of parameter changes that yielded a population growth rate most similar to that observed in Christmas Bird Count data in the United States was a 10% reduction in mortality rate plus a 10% increase in the proportion of females breeding each year. With this adjusted set of parameters, an initial population of 1,000 birds grew to a mean size of 28,227 birds in 27 years (r = 0.122; Table 4). Because this adjusted baseline population grew at similar rate as that observed for parakeets in Christmas Bird Count data in the United States, we used this set of parameters as the basis for assessing the effects of two alternative control measures (Part II). We refer to this simulation as the adjusted baseline simulation.

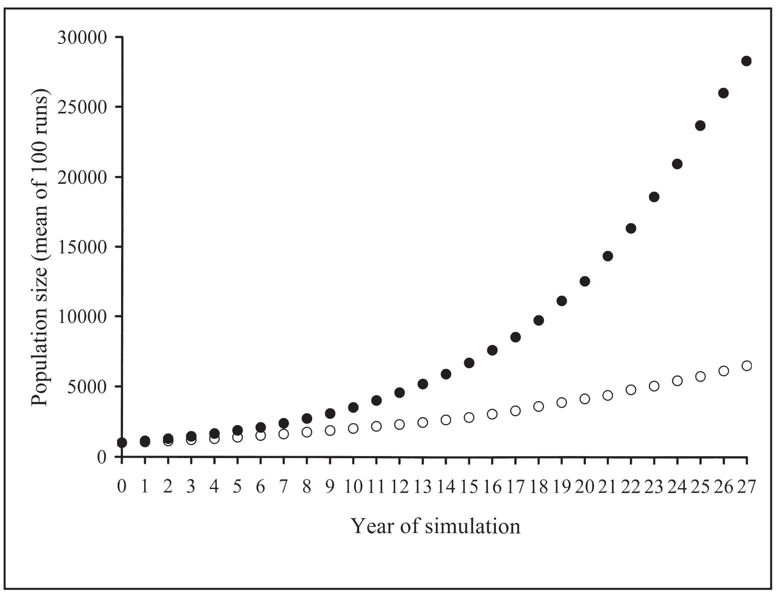

Figure 1. The baseline simulation (open circles) of a monk parakeet population, using published life history data gathered on natural populations in South America. The mean size of the populations (100 populations simulated) is shown for every year of the simulation (27 years). In the adjusted baseline simulation (filled circles), the mortality rate was decreased by 10% and the proportion of females breeding each year was increased by 10%. Monk parakeets in the United States have exhibited similar rates of growth, as illustrated by the adjusted baseline simulation.

Part II. Consideration of alternative management strategies

Capture and euthanasia. Removal of 6% of the population (60 birds) each year slowed the rate of population growth to r = 0.083 but did not control the population size (Table 5; Figure 2). The population still doubled during the 10-year time frame. Similarly, removal of 10% of the population (100 birds) each year reduced the rate of population growth but the population still increased by more than 50% in the 10-year period (Table 5; Figure 2). An actual reduction in population size required removal of 20% of the population (200 birds) annually. This level of removal caused the rate of population growth to become negative and the overall population size decreased by approximately 80%. The majority of populations (54 out of 100) went extinct before the end of 10 years.

Nest removal. Extensive nest removal (> 20%) was necessary to slow the rate of population growth or reduce the overall population size (Table 5; Figure 3). Removal of 20% of the nests allowed the population to continue to grow, albeit at a slower rate, and the population more than doubled (to 2,013 individuals) during the 10-year time frame. Removal of 50% of the nests, which might be unrealistic in terms of effort, had a dramatic effect on population growth, and at the end of the simulations the mean population size was just 454, slightly less than half of the original population. None of the

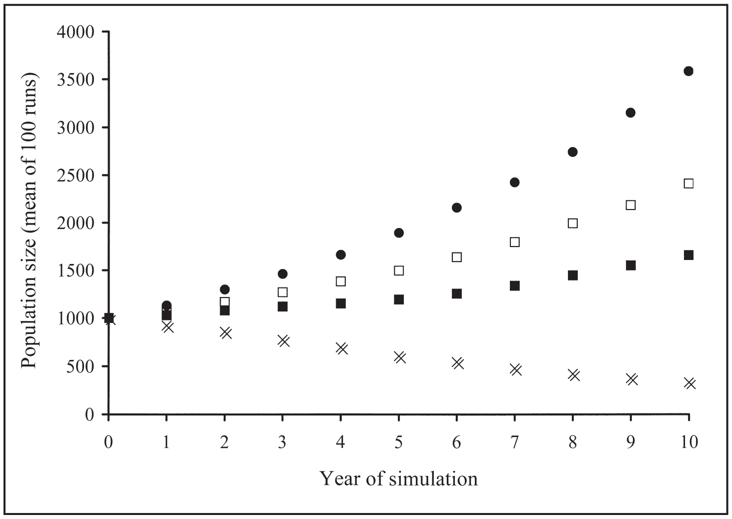

Figure 2. Simulation of population growth of monk parakeets when individual birds are removed from the population (captured and euthanized). The mean population size is shown for 10 years of simulation. Standard deviation values are left off for clarity. Three scenarios are imagined: removal of 6% of individuals (open squares), 10% of individuals (filled squares), and 20% of individuals (Xs). The adjusted baseline results (filled circles) are included for comparison.

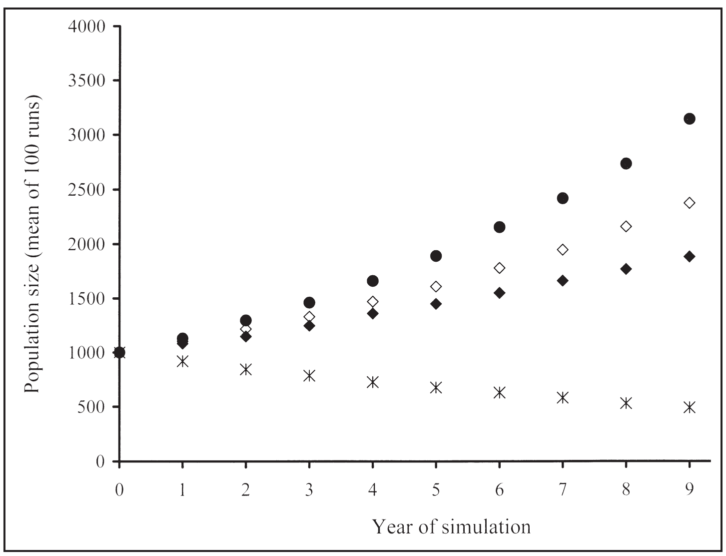

Figure 3. Simulation of population growth of monk parakeets when nests are removed, having the consequence that the proportion of females that breed each year is reduced. The mean population size is shown for 10 years of simulation. Standard deviation values are left off for clarity. Three scenarios are imagined: removal of 10% of nests (open triangles), 20% of nests (filled triangles), or 50% of nests (stars). The adjusted baseline results (filled circles) are included for comparison.

nest removal simulations caused the population to go extinct in 10 years.

Discussion

The use of Christmas Bird Count data to make inferences on population growth or decline is controversial (Anderson 2001, 2003, Engeman 2003). Christmas Bird Count records for a given species are generally considered poor estimates of the actual size of a population at any 1 time, but comparison of the data for a given species over time has been shown to accurately reflect actual population increases or decreases quantified or observed through other census techniques (DeHaven 1973, Schreiber and Schreiber 1973, Bock and Lepthien 1976, Morrison and Slack 1977, Morrison 1981, Kricher 1983). With respect to monk parakeets, the patterns of population growth indicated by Christmas Bird Counts reflect actual counts in the field (Van Bael and Pruett-Jones 1996, S. Pruett-Jones personal observations).

We have demonstrated that monk parakeet populations can be modeled using PVA models such as VORTEX, and the results have potential value in the consideration of alternative management programs for this species. Our original baseline simulation based on published life history data from monk parakeet populations in Argentina revealed population growth approximately one-half of that observed in Christmas Bird Counts of parakeets here. One possible explanation for this discrepancy is that monk parakeets in the United States possess different life history traits than their native counterparts in South America. If this is true, we suspect that such differences relate to mortality rates and reproductive parameters. Monk parakeets here have colonized urban parkland habitats where they exploit a seemingly endless food supply even in harsh environments. Monk parakeets are also highly flexible in their food habits. During winter months in Chicago, for example, when there are virtually no food plants available, monk parakeets switch to a diet consisting almost exclusively of seed at backyard bird feeders (South and Pruett-Jones 2000).

We had to estimate the values of a number of parameters for which there were no data in the literature (Table 1). Although we used conservative values in our estimation, variation in these parameters could have influenced the outcomes of the simulations. Nevertheless, as these parameter values were fixed in all of the simulations, they should not have affected our examination of alternative management programs in which we varied the level of harvesting (removing individuals) or reducing the proportion of females breeding (by nest destruction).

With respect to those alternative management programs, based on our simulations, extensive effort would be necessary to reduce the rate of population growth of monk parakeets or to reduce the overall population size using either of these methods. Such effort might not be practical. Monk parakeet populations seem to be growing at such a rapid rate that only a massive effort would slow or reverse this trend. Additionally, removing individuals and removing nests are not as effective as a long-term strategy because large efforts would be needed every year. If utility companies take a removal approach, a more realistic strategy would be to focus efforts on offensive nests (such as those on power structures) and not attempt large-scale population control. If monk parakeets tend to build nests in places similar to the locations of their natal nests, then such focused management efforts could be effective in reducing the negative impacts of the species to utility structures. Whether monk parakeets exhibit nest-site fidelity in terms of nest type is unknown at present but will be critical information in order to effectively evaluate removals as a control measure.

There are other possible control measures that could be considered. Diazacon is a chemosterilant that inhibits the formation of reproductive hormones, and birds exposed to Diazacon are unable to produce viable eggs or sperm (Yoder et al. 2004). Initial trials using Diazacon on monk parakeets in captivity have shown that it can reduce reproductive output in this species as it does in others (M. L. Avery unpublished data). Validation of this management approach to parakeet population reduction is warranted through field testing.

It is likely that monk parakeet populations will continue to expand and grow for the foreseeable future. It also seems difficult to stop this trend without impractically large efforts. For agencies or businesses dealing with the adverse impacts of monk parakeets, an integrated management approach including localized nest removal and population reduction through trapping or the use of chemosterilants will likely be necessary.

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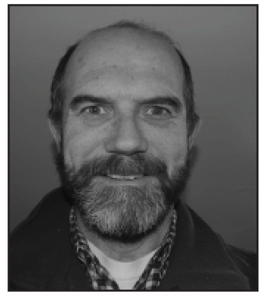
Steve Pruett-Jones is an associate professor in the Department of Ecology and Evolution at the University of Chicago. He received his Ph.D. degree at the University of California, Berkeley, in 1985. His research interests are in behavioral ecology and population biology. Since 1976 he has worked in Australia and Papua New Guinea on aspects of social behavior of birds of paradise, bowerbirds, and most recently, fairy-wrens. His interest in monk parakeets began when he moved to Chicago and discovered a large, thriving, and expanding population of parakeets nesting locally. He regularly directs undergraduate students in research projects on the parakeet population in Chicago.



James R. Newman is a principal scientist at Pandion Systems, Inc., in Gainesville Florida. He received his Ph.D. at the University of California at Davis in 1970. Dr. Newman's research interests are on the effects of human activity on wildlife, especially birds. These studies include the effects of human activity on wintering bald eagles and effects of human activity, including noise, on wood storks. He has also specialized in assessing avian interactions with power lines and wind turbines. For the past 5 years, he has been co-principal investigator studying effects of nesting of monk parakeets on utility structures in Florida, New York, and Connecticut. Dr. Newman is a co-founding editor of the journal *Environmental Bioindicators*.

Christian M. Newman has an M.S. degree in wildlife ecology and conservation and an M.B.A. degree from the University of Florida. For the past 10 years, He has been working on wildlife-human related issues, specifically with protected species, as well as invasive exotic species, such as the monk parakeet, throughout the United States. He is currently president and co-founder of Pandion Systems, Inc., in Gainesville, Florida.

Michael L. Avery has an M.S. degree in zoology from North Dakota State University and Ph.D. in wildlife ecology from the University of California at Davis. He is an elective member of the American Ornithologists' Union and former associate editor of the *Journal of Wildlife Management*. As supervisory research wildlife biologist at the Florida field station of the USDA's National Wildlife Research Center, he directs research to resolve conflicts between human activities and abundant populations of birds such as black vultures and turkey vultures, crows, and monk parakeets.

Jim Lindsay has been employed by Florida Power and Light Company (FPL) since graduating from Florida Institute of Technology in 1980 with degrees in oceanography and biology. Jim is a principal biologist with FPL's environmental services department and has corporate responsibility for managing natural resource issues related to the production of electricity. Jim has managed FPL's research and development efforts on monk parakeets since 2000 when it became apparent that the ever-increasing monk parakeet population posed a significant threat to the reliable transmission and distribution of electricity to FPL's customers.