EFFECTS OF EGG REMOVAL ON BALD EAGLE PRODUCTIVITY IN NORTHERN FLORIDA

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Abstract: We removed eggs from bald eagle (*Haliaeetus leucocephalus*) nests in northern Florida from 1985 through 1988 to determine if pairs would lay again and to evaluate how egg removal affected subsequent productivity. Of 58 pairs that had first clutches removed, 45 (78%) laid a second clutch within an average of 29.4 days. In 1 study area, productivity of pairs that had their first clutch removed (1.00 young fledged/breeding attempt) was less ($P = 0.02$) than control pairs (1.47) that produced their clutches during the same time period. In contrast, no difference ($P = 0.75$) in productivity occurred between donor (1.17) and control pairs (1.09) produced during the same period in a second study area. Productivity of donor nests 1 year prior to egg removal was greater ($P = 0.03$) than 1 year after egg removal. However, a simple age-structured demographic model (RAMAS) revealed that population size after 25 years was only slightly higher for the control population. Consequently, egg removals over a limited number of seasons and nests were effective in providing large numbers of eagles for release, with limited adverse effects on Florida's donor population. An egg-removal program may be an effective alternative strategy to captive breeding and translocation of young in recovery actions among raptor populations requiring active management, particularly for tropical species that have long breeding seasons.

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Historically, a contiguous breeding population of southern bald eagles (*H. l. leucocephalus*) extended from eastern Texas through the Carolinas (U.S. Fish and Wildl. Serv. 1989). This population was extirpated from much of its range, and several southeastern states had <5 breeding pairs (Wood et al. 1990). Consequently, efforts intensified to reestablish bald eagles in suitable habitats throughout their former range.

Double clutching has long been used to increase production among many species of captive birds, including bald eagles. The technique involves removing the entire first clutch of eggs from a nest and allowing the nesting pair to lay and raise a second clutch. It has been used successfully in the wild with several species of raptors including ospreys (*Pandion haliaetus*), prairie falcons (*Falco mexicanus*), peregrine falcons (*F. peregrinus*), and California condors (*Gymnogyps californianus*) (Kennedy 1977, Morrison and Walton 1980, Snyder and Hamber 1985).

Hacking is the primary process used to reintroduce bald eagles. In this technique, nestling eagles are placed in towers at the chosen release site, habituated to the area, and released (Barclay 1987). Availability of nestlings for release, however, always has been a chronic problem (Nye 1988). Chicks are sometimes available from captive breeding facilities, although the expense of maintaining captive pairs, compared with the limited number of chicks they produce, has generally precluded this method from widespread use. Nye (1988) summarized the source of eagles that have been used for hacking in North America during 1976–85: 15% came from captive breeding sources; 82% came from wild populations; and 3% came from wild eggs and other sources. Several southeastern states have reintroduction programs that use hacking techniques to release fledgling eagles into suitable, unoccupied habitats. Some of these programs used chicks from captive-breeding facilities; however, most nestlings were obtained from the nests of wild populations outside of the Southeast (e.g., Alas., Minn.) (Wood et al. 1990).

A problem associated with obtaining large numbers of eaglets by removing them directly from nests is the potential for reducing local productivity, and for a long-term detrimental effect on donor populations. Introducing young from other populations also may be detrimental or unworkable. The Bald Eagle Recovery Plan

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(U.S. Fish and Wildl. Serv. 1989) recommended hacking young of "regional genetic origin." Southern bald eagles are considered by many to be a distinct subspecies that may be better adapted to the southern environment (King 1981). For example, during an August 1987 attempt to hack 9 Alaskan bald eagle chicks in North Carolina, avian malaria was suspected to have contributed to the deaths of 6 of 7 birds (Sherrod et al. 1990). A nestling eagle from the Chesapeake Bay hacked in June 1987 at the same location showed no ill effects (T. Henson, N. C. Wildl. Resour. Comm., pers. commun.). The mosquito vector is common in North Carolina during these months. Immunity for this disease is thought to be genetically programmed rather than acquired (van Riper et al. 1986).

Efforts to restore bald eagles in the Southeast likely will need to rely on the Florida population for birds, because it accounts for approximately 85% of the pairs breeding in the region (U.S. Fish and Wildl. Serv. 1989). In 1984, a cooperative egg-translocation program was established between the Sutton Avian Research Center (SARC), Bartlesville, Oklahoma, and the Florida Game and Fresh Water Fish Commission (FGFWFC). The goal of this program was to take the first clutch of eggs from a sample of bald eagle nests in Florida, hatch and rear them in captivity, and release young at selected hack sites throughout the Southeast. As a part of this process, the Florida Game and Fresh Water Fish Commission required that a study be conducted on the donor pairs to evaluate the impact of egg removal on subsequent reproductive activity. Our objectives were to determine whether recycling occurred (i.e., second clutches were laid); to determine how the timing of clutch removal influenced recycling; to determine how egg removal affected subsequent nesting success and productivity; and to evaluate the sensitivity of donor pairs to egg removal in successive or alternate years.

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STUDY AREA

We focused our research on 2 areas of north-central Florida (Fig. 1) that have traditionally supported nesting bald eagles (Robertson 1978). The first study area was located primarily on private lands surrounding the eutrophic lakes and marshes in southern Alachua and northern Marion counties (AMC) south of Gainesville, Florida. This area contains 340 bodies of open water ranging from 0.4 to 2,702 ha ($\bar{x}$ = 12.6 ha) in size (Wood 1992). Pine (*Pinus* spp.) flatwoods, mixed hardwood and pine forests, freshwater marshes, and cleared areas dominate AMC (Davis 1967, Hartman 1978). Several major lakes in the area are rimmed primarily with bald cypress (*Taxodium distichum*), hardwoods, and wet prairies.

The second study area included the Ocala National Forest and private lands on the east side of Lake George (ONF). This area also contains numerous lakes and wet prairies. Most eagle nests are close to Lake George, a major water body located in the St. Johns River System. The lake is surrounded by bald cypress, hardwoods, and pine forests. The lands surrounding Lake George are used primarily for timber production. Vegetation in ONF is primarily sand pine (*P. clausa*) scrub habitat with swamp forests and pine flatwoods (Davis 1967, Hartman 1978).

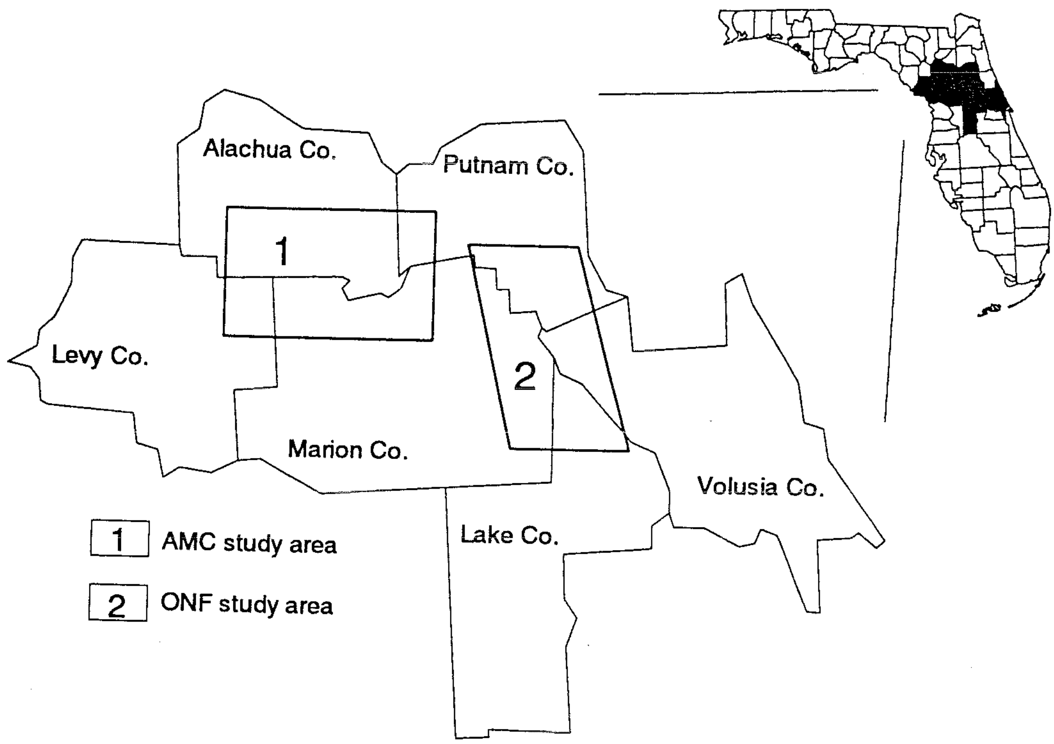

Fig. 1. Location of Alachua and Marion counties (AMC) and Ocala National Forest (ONF) study areas in northcentral Florida.

METHODS

Field

Between November 1984 and May 1990, we monitored 191 nests used by an estimated 115 different pairs of breeding bald eagles (53 pairs in AMC, 62 in ONF). All nests were monitored during the entire 6-year study or from the time they were first detected or established. We conducted fixed-wing (Cessna 172 or 152) aerial surveys of bald eagle nests in AMC and ONF to monitor nesting chronology and productivity. Eggs were removed by SARC personnel from selected nests during the first 4 years of the study; none were removed during the last 2 years. Size of the second clutch was determined from aerial surveys by counting the eggs or, if they were always covered by an adult, estimated by counting the maximum number of young observed in each nest.

We examined the tendency for donor nests to recycle if their clutches were removed in successive and alternate years, compared to having their eggs taken just once. To accomplish this, donor nests during 1986–87 and 1987–88 included nests from which eggs were removed in alternate years, in successive years, and in only 1 year.

Aerial surveys during the 1984–85 through 1987–88 breeding seasons were initiated on each study area prior to egg-laying (first week of Nov) and were flown approximately weekly until nearly all eggs hatched (mid-Mar). From mid-March until the eaglets fledged, we conducted surveys approximately once every 2 weeks to monitor the productivity and chronology of events for all breeding attempts. During the 1988–89 and 1989–90 breeding seasons, all known nests were surveyed once every 2 weeks between November and May, to document the productivity of all breeding pairs in years following egg removal.

Although none of the adult birds we studied were banded or otherwise marked, we evaluated all potential recycling observations by examining the relative chronology of egg-laying, the proximity of alternate nests to the donor nest, and present and past records of other eagle pairs nesting in the area. In all cases the evidence from a combination of these criteria indicated that the donor pair laid again in a nearby nest.

To evaluate the long-term effects of this egg-removal program on a bald eagle population, we used a simple age-structured demographic model (RAMAS; Ferson et al. 1987) to simulate population growth over 25 years in a control population versus a population manipulated for 5 years and another for 10 years. Initial population size (100) and distribution among the age classes was the same for all scenarios. Parameters used in this stochastic model included age-specific fecundity and survival. We used the productivity data from only control nests as the fecundity estimates (0.61 female young/adult female) in the control simulation. For the 5-year manipulated population simulation, we used fecundity estimates based on the combined productivity of donor and control nests for the first 5 years (0.56), the post-donor productivity for the next 2 years (0.59), then the control productivity for the final 18 years of the simulation (0.61). Estimates of survival for 1- to 4-year-old birds were obtained from a radio-telemetry study of subadult bald eagles (69.5–86.9%; Wood 1992), and adult survivorship estimates were available for South Carolina eagles from 5 to 12 years of age (90.0–92.7%; T. Murphy, S. C. Wildl. and Marine Resour. Dep., pers. commun.). Variance estimates calculated from these fecundity and survival estimates allowed use of a stochastic model with 250 simulations.

Statistical Analyses

We summarized and analyzed data using primarily the Statistical Analysis System (SAS Inst., Cary, N.C.). Data were examined for equal variances using the *F*-test in SAS and the F_{max}-test (Sokal and Rohlf 1969), and for normality using the Shapiro-Wilk test (Schlotzhauer and Littell 1987). Since some of the same pairs were breeding in successive years, we calculated mean productivity for each pair before calculating an overall mean when appropriate. Because data were not normally distributed, statistical comparisons were made with the non-parametric Kruskal-Wallis test. We made multiple comparisons with the Waller-Duncan *K*-ratio *t*-test and least squares means test when sample sizes were greater than 30 and when non-parametric tests yielded the same results as ANOVA.

All donor nests and only those control nests for which we had complete nest histories were used in control versus donor comparisons. For analyses of pre-donor and post-donor year productivity, we excluded all nests used as donors in consecutive years. Pre-donor productivity data for years before 1984–85 were obtained from the Florida Game and Fresh Water Fish Commission (S. Nesbitt, FGFWFC, pers. commun.), which has been aerially monitoring bald eagle productivity in Florida since 1972.

RESULTS

We conducted a total of 88 aerial surveys both in ONF and in AMC during the 4 years eggs were collected (1984–85 to 1987–88). During 1988–89 and 1989–90, when no clutches were collected, 30 surveys were conducted in AMC and 19 in ONF. During the 6 years of this study, the earliest clutch was laid on approximately 2 November; whereas the latest clutch was laid on about 4 March (Fig. 2). Most pairs laid eggs in December.

During the 4 breeding seasons between 1984–85 and 1987–88, SARC personnel removed the initial clutch of eggs from 59 nests (Table 1). Mean first clutch size was 2.1 eggs. For those pairs that produced replacement clutches (i.e., recycled), the average size of the second clutch was 1.8 eggs, a slight but significant decrease (Kruskal-Wallis test; $\chi^2 = 12.19$, $P = 0.0005$). Size of the second clutch may have been underestimated because clutch size was based on a direct count of eggs in only 8 nests. One donor nest in 1987–88 was excluded from all further analyses because we had insufficient data. Of the 58 remaining pairs that had eggs removed, 31 subsequently recycled in the same nest. An additional 14 donor pairs also recycled, but in nearby alternate nests. A total of 78% (45 of 58) of the pairs recycled. The productivity of pairs renesting in their original nests was similar (Kruskal-Wallis; $\chi^2 = 0.39$, $P = 0.53$) to the production of those using alternate nests (1.45 vs. 1.29 young/pair, respectively). Of pairs which renested in alternate nests, 21% (3 of 14) failed; whereas 16% (5 of 31) of pairs that recycled in the original nest failed.

Over the 4 years that eggs were removed, the mean recycling interval (i.e., the number of days between egg removal and subsequent egg-laying) was 29.4 days (Table 2). The shortest single recycling interval was 20 days in 1986–87, whereas the longest was 57 days in 1984–85. Pairs that recycled in the same nest had a 29.6-day recycling interval compared to a 28.8-day interval for those recycling in an alternate nest. Similar recycling intervals ($\bar{x} = 32.7$ days) were documented at nests where pairs lost their first clutch to natural causes early in the breeding season.

We hypothesized that pairs would recycle

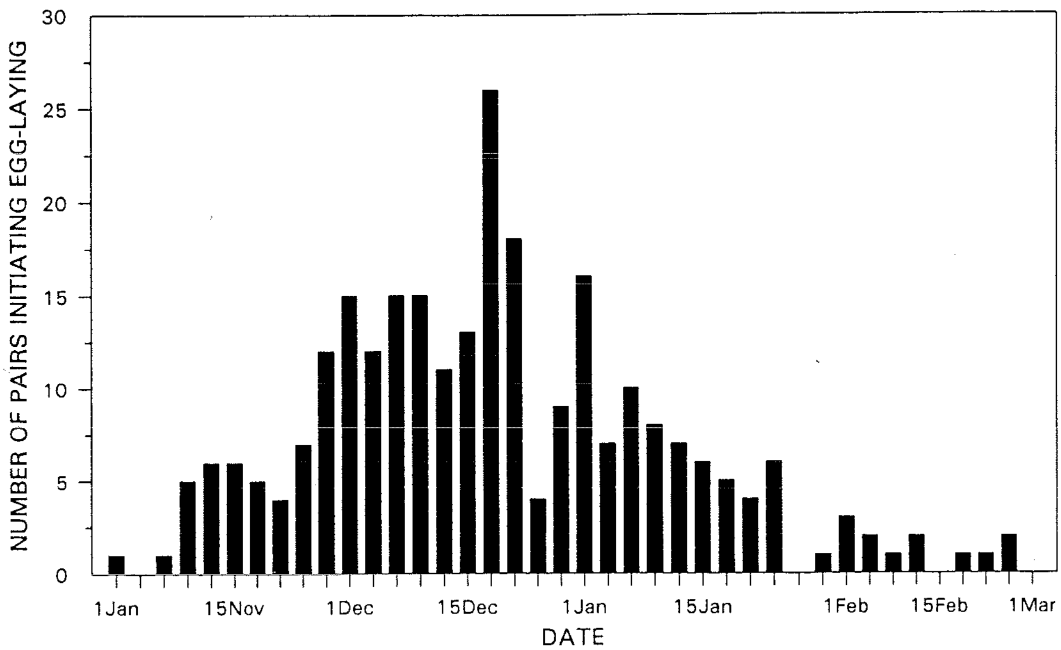

Fig. 2. Distribution of egg-laying dates for southern bald eagles, northcentral Florida, from 1984–85 to 1987–88.

more quickly if their eggs were removed early in incubation. To test this initial assumption, the ages of the eagle eggs at the time they were collected were estimated by back-calculating 35 days (the typical incubation interval; Stalmaster 1987) from their subsequent hatching dates. We found no correlation (r = 0.16, n = 44, P = 0.28) between the age of the clutch when removed and the recycling interval.

In 3 of the 4 field seasons, eggs were removed at 2 different times to allow us to examine the effect of removing clutches later in the nesting cycle. Eighty-two percent (n = 39) of pairs recycled after their eggs were removed in mid- to late December. Only 68% (n = 19) of the pairs that had eggs removed after 1 January recycled, although the difference was not significant (Fisher's exact test; P = 0.32). These recycling rates showed a pattern similar to that found for control nests that recycled naturally. Seventeen pairs of eagles at control nests lost clutches during the first 4 years of the study, 5 during November–December and 12 during January. All of the November–December pairs recycled (5 of 5) while only 2 of the 12 January pairs recycled. In addition, none of the 3 pairs that lost newly hatched chicks in January produced replacement clutches.

Although number of young fledged from nests used as donors in successive (1.00 young fledged/breeding attempt) and alternate (1.00 young) years was slightly lower than from nests used just once (1.13 young) the difference was not significant (Fisher's exact test; P = 0.81). The percent of nests fledging young also was not

Table 1. Productivity data for southern bald eagle donor nests, northcentral Florida, from 1984–85 to 1987–88.

Year	Number donor nests	Number eggs removed	Mean productivity per breeding attempt: First clutch	Second clutch[a]	Fledged[a]
1984–85	9	18	2.0	1.8	1.2
1985–86	16	34	2.1	1.8	1.3
1986–87	17	35	2.1	2.0	1.8
1987–88	17	37	2.2	1.8	1.0
Overall	59	124	2.1	1.8	1.4

[a] Means included only the 45 pairs that laid a second clutch of eggs. Second clutch smaller (P = 0.0005) than first; (Kruskal-Wallis test; χ^2 = 12.19).

Table 2. Recycling rates and intervals for southern bald eagle donor nests, northcentral Florida, from 1984–85 to 1987–88.

Year	n	n recycled	% recycled	Recycling interval (days): $\bar{x}$	SE
1984–85	9	9	100.0	32.4	3.8
1985–86	16	12	75.0	31.0	2.5
1986–87	17	12	70.6	26.2	1.1
1987–88	16[a]	12	75.0	28.8	2.5
Overall	58	45	77.6	29.4	1.2

[a] One donor nest excluded due to insufficient data.

Table 3. Productivity (no. of young fledged per breeding attempt) in early (first 25%), peak (middle 50%), and late (last 25%) control nests, Alachua and Marion counties (AMC) and Ocala National Forest (ONF), northcentral Florida, 1984–85 to 1989–90.

	AMC				ONF			
Timing	n	w − n[a]	$\bar{x}$	SE	n	w − n[a]	$\bar{x}$	SE
Early	50	25	1.41 A[b]	0.148	42	23	1.10 A[b]	0.153
Peak	99	44	1.33 A	0.111	69	41	1.21 A	0.119
Late	60	30	0.63 B	0.109	45	27	1.07 A	0.152

[a] w − n = Weighted sample size to account for repeated measurements of some pairs.
[b] Within a column, means with the same letter do not differ ($P < 0.05$; Waller-Duncan K-ratio t-test).

different (Fisher's exact test; $P = 0.88$) for the 3 treatments (successive: 62.5%, alternate: 50.0%, once: 69.0%).

Because neither study area ($F = 0.73$, $P = 0.40$) nor year ($F = 0.91$, $P = 0.43$) affected productivity of either control or donor nests, we combined data for the 2 locations over the 4 years. Overall, productivity of donor nests (1.11 young fledged/breeding pair) was not different (Kruskal-Wallis test; $\chi^2 = 0.58$, $P = 0.45$) from control nests (1.21 young fledged/breeding pair).

We further analyzed the productivity data from control nests to determine if timing of egg laying was related to productivity. These analyses indicated that egg-laying attempts occurring late in the breeding season (i.e., the last 25% of clutches laid) in 1 study area (AMC) were not as productive (Kruskal-Wallis test; $\chi^2 = 18.81$, $P = 0.0001$) as either early (first 25%) or peak (middle 50%) nesting attempts (Table 3, Fig. 2). In the ONF study area, timing of egg-laying did not affect productivity (Kruskal-Wallis test; $\chi^2 = 0.73$, $P = 0.70$).

Because the original clutches removed from donor nests were laid during the early or peak egg-laying period, we compared productivity of donor nests with those control nests in AMC initiated during these 2 periods. Our intent was to contrast the resulting productivity of donor nests with those control nests that were initiated at the same time and under similar environmental conditions. We found lower productivity for the donor nests in AMC (Kruskal-Wallis test; $\chi^2 = 5.28$, $P = 0.02$), but not in ONF (Kruskal-Wallis test; $\chi^2 = 0.10$, $P = 0.75$), when late nesting attempts were excluded from the control nests in AMC (Table 4). Productivity also changed (Kruskal-Wallis test; $\chi^2 = 10.37$, $P = 0.03$) (Fig. 3) in years before and after egg-removal.

Although the differences were not statistically significant (Fig. 4), productivity 1 year following egg removal was twice as high if the donor pairs had recycled (Kruskal-Wallis test; $\chi^2 = 1.74$, $P = 0.19$) or were successful ($\chi^2 = 0.90$, $P = 0.34$) the year eggs were taken. Switching to an alternate nest 1 year following egg removal also did not affect productivity ($\chi^2 = 0.34$, $P = 0.56$).

The RAMAS models indicated that population size after 25 years was slightly higher for a non-manipulated control population ($n = 209$) beginning with 100 females than for a population that had eggs removed from a sample of nests for the first 5 years ($n = 199$) or for the first 10 years ($n = 196$; Fig. 5). Size of the control population was slightly greater throughout the simulation, although 95% confidence intervals for all 3 models overlapped. However, since some of the most productive eagle pairs in our study areas were used as donors, the fecundity estimates used to model the control population were slightly lower than they would have been otherwise. This resulted in a slower predicted con-

Table 4. Productivity (no. young fledged per breeding attempt) of control versus donor southern bald eagle nests, Alachua and Marion counties (AMC) and Ocala National Forest (ONF) study areas, northcentral Florida, 1985–88.

	AMC[a]				ONF			
Treatment	n	w − n[b]	$\bar{x}$	SE	n	w − n[b]	$\bar{x}$	SE
Control	75	39	1.47 A[c]	0.118	84	41	1.09 A[c]	0.112
Donor	25	16	1.00 B	0.183	33	26	1.17 A	0.173

[a] Results exclude late control nests in AMC.
[b] w − n = Weighted sample size to account for repeated measurements of some pairs.
[c] Within a column, means with the same letter are not different ($P < 0.05$; Kruskal-Wallis test).

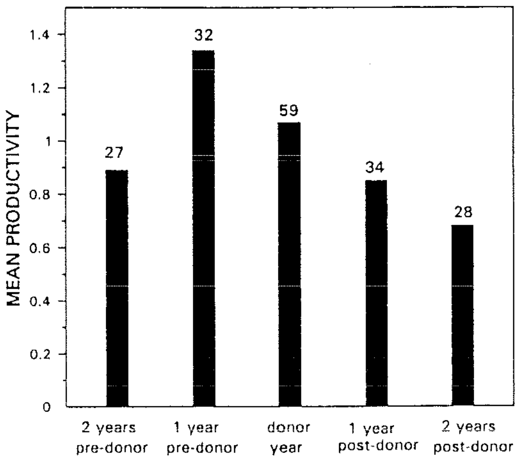

Fig. 3. Productivity (no. of young fledged per breeding attempt) of donor southern bald eagle nests 1 and 2 years before, and 1 and 2 years after eggs were removed (Kruskal-Wallis test; $\chi^2 = 10.37$, $P = 0.03$). Eggs were removed from nests in 1985 ($n = 9$), 1986 ($n = 16$), 1987 ($n = 17$), and 1988 ($n = 17$). Each bar represents mean productivity over 4 years; number above each bar represents sample size.

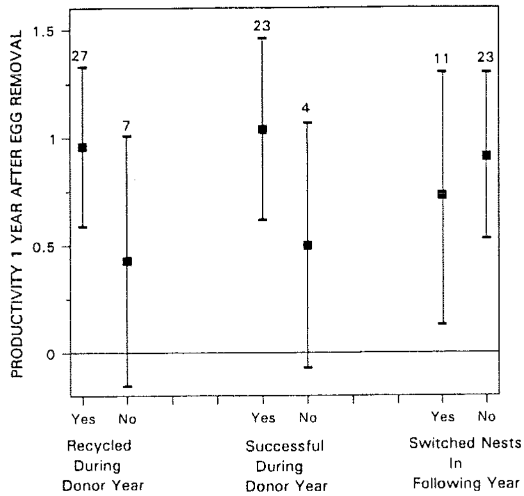

Figure 4. Productivity (young fledged per breeding pair) of southern bald eagles in Florida 1 year after egg removal when the pair recycled during the donor year, successfully produced young during the donor year, and switched to an alternate nest the following year (Kruskal-Wallis test; $P > 0.19$). Error bar represents the 95% confidence interval; number above each bar is sample size.

trol population growth and a conservative estimate of the differences between control and manipulated populations.

We also calculated the percentage of the population that was comprised of adults (i.e., ≥ 5 yr old) during the first 15 years of the simulations. The percentage of adults in the control population was fairly stable, varying between 48.6% and 49.4% (Fig. 6). The percentage of adults in the population manipulated for 5 years also was fairly constant, although the proportion of adults increased through year 6 of the simulation (egg removals occurred through yr 5). The percentage of the population that was adult declined thereafter, approaching that of the control population by year 10. These changes in the composition of the population reflect the decreased productivity observed in donor years.

DISCUSSION

Bald eagles in Florida that had eggs removed early in the breeding season recycled readily, although productivity was depressed during the donor year on 1 study area and 1 year following egg removal on both study areas. In areas with a high nesting population such as Florida, however, the lower productivity we observed should not significantly affect the population when egg removals occur over a limited number of seasons and include a limited number of nests. Grier (1980) determined that survival was more important in limiting eagle populations than productivity. Furthermore, modelling of a control population and a population manipulated for 5 years revealed that the control population was only slightly larger than the donor after 25 years.

Recycling did not occur as readily at nests from which eggs were taken late in the egg-laying season (i.e., after 1 Jan). These results suggested that eagles in northern Florida might be less likely to produce replacement clutches if their eggs are removed in January after the peak egg-laying period. This interpretation was further supported by the data obtained from control nests that recycled naturally.

Although Herrick (1934) reported that a pair of eagles in Canada laid a second clutch after the first was removed, bald eagles nesting in coastal Alaska (Hensel and Troyer 1964), the Aleutian Islands (Morrison and Walton 1980), and northern California (G. Carpenter, San Francisco Zool. Soc., pers. commun.) did not recycle after loss of eggs. In these northern populations of eagles, egg laying is much more synchronous than in Florida (Stalmaster 1987), reducing the time period within which re-laying can successfully occur. Double clutching in more temperate regions is most frequently observed in small raptor species with short breeding cycles (Newton 1979, Morrison and Walton 1980).

When evaluating the benefits of this program,

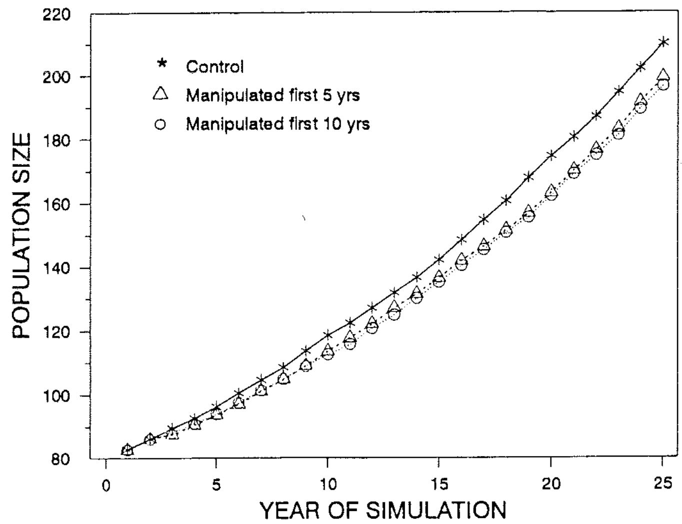

Fig. 5. Size of control and manipulated populations for each year of a 25-year simulation using a simple age-structured demographic model (RAMAS). Initial population size (100 individuals) and distribution among the age classes were the same for all scenarios.

one also must consider the need to have large numbers of young eagles available for simultaneous release in hacking programs. Nye (1988) reported that limited availability of eagles has been a common problem facing hacking programs throughout North America. Recognizing this, several of the states cooperating in this study did not hack bald eagles until a large number became available through this egg-removal program. During the 4-year collecting phase of this study, 86 young were produced and subsequently released in Alabama, Georgia, Mississippi, Oklahoma, and North Carolina (S. Sherrod, SARC, pers. commun.).

MANAGEMENT AND RESEARCH IMPLICATIONS

We recommend that southern bald eagle egg collections be made sufficiently early (i.e., before 1 Jan) to allow a high probability of recycling by the donor adults. The tendency for fewer numbers of young to fledge from nests used as donors in successive and alternate years than from nests used as donors in only one year,

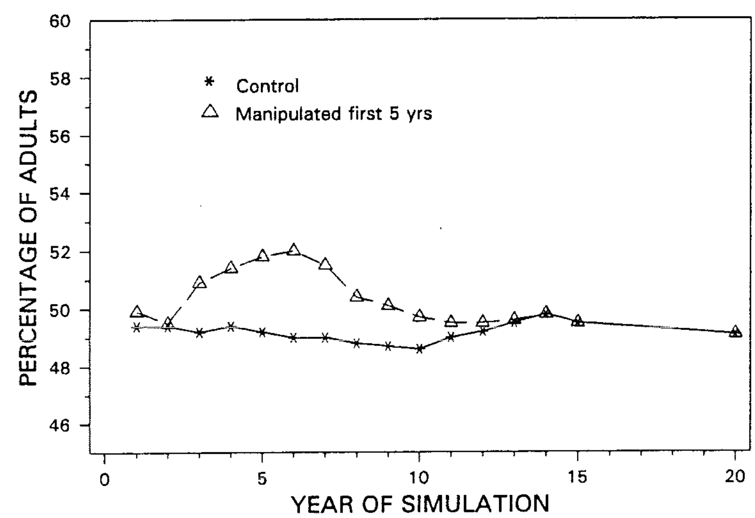

Figure 6. Proportion of adults in a control and manipulated population modelled over 15 years using a simple age-structured demographic model (RAMAS). Initial population size (100 individuals) and distribution among the age classes were the same for both scenarios.

also leads us to believe that it is prudent to be cautious about removing eggs from nests in >1 breeding season.

Our study demonstrated not only that a large raptor can, under certain conditions, be double clutched successfully in the wild with minimal impact on the donor population, but also that recovery strategies other than captive breeding and translocation of young exist for raptor populations in need of active management. Captive propagation is an expensive means for producing nestlings for mass release in reintroduction efforts and may not be an affordable strategy for most species. Translocating young from an area with an established breeding population may be appropriate in certain cases, but not before questions related to disease transmission, population genetics, and their effects on the annual recruitment of the donor population are evaluated. The recycling technique also can be used to augment productivity of small wild populations that may be difficult to breed in captivity. Young raised from an egg-removal program then can be released back into the donor population and potentially almost double the productivity of donor pairs.

The applicability of this technique to other species and other areas, particularly those in more tropical latitudes where many species have long breeding seasons (Newton 1979), has not been evaluated. However, it may be worthy of consideration by those research institutions and zoos that are interested in developing active in-country conservation programs for species such as raptors, but are not able to translocate young or develop full-scale captive breeding programs.

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