REPRODUCTIVE SUCCESS AND EGGSHELL THINNING OF A REESTABLISHED PEREGRINE FALCON POPULATION

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Abstract: Reestablishment of the peregrine falcon (*Falco peregrinus*) as a breeding bird in the eastern United States is a highlight in endangered species management and recovery programs. We examined numbers of pairs, reproductive success, and eggshell thinning of a reestablished peregrine falcon population in New Jersey during 1979–88. Productivity of these falcons ($\bar{x}$ = 1.38 young fledged/pair) was comparable with that of stable populations, but productivity was lower (P = 0.02) for pairs near Delaware Bay and River (0.58 young/pair) compared to those in other regions of New Jersey (1.55 young/pair). Lower productivity and nest success of 4 pairs near Delaware Bay and River that we studied intensively in both 1987 and 1988 were due to low hatching success and predation, probably by great horned owls (*Bubo virginianus*). During 1985–88 eggshell thickness from New Jersey peregrines averaged 16.4% below pre-DDT levels and apparently has decreased steadily since 1979. This decrease in eggshell thickness statewide suggests that falcons continue to be exposed to environmental contaminants.

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Extirpation of the peregrine falcon as a breeding bird in the northeastern United States is well documented (Hickey 1969, Ratcliffe 1980, Cade et al. 1988). Regions in the Northeast that once supported nesting peregrines (Hickey 1942), including areas in and around New Jersey, were devoid of nesting peregrines by the mid-1960's (Herbert and Herbert 1965, 1969; Rice 1969). Attempts to locate breeding falcons in these areas from the mid-1960's through 1975 were unsuccessful (Berger et al. 1969, Fyfe et al. 1976). Although extinction of the northeastern and other peregrine populations was caused by a variety of factors, none was as devastating as contamination by organochlorine pesticides, particularly DDE, a metabolite of DDT (Peakall et al. 1975, Peakall 1976, Risebrough 1986).

Due to successful efforts to captively breed these falcons and reintroduce them into areas where they once bred, as well as into new areas (Barclay and Cade 1983, Cade 1985), the peregrine again breeds in many regions of the Northeast (Barclay 1988). Reestablished peregrines have steadily increased in number, and in 2 of 5 recovery regions, they have attained or exceeded minimum recovery goals (U.S. Fish Wildl. Serv. 1987).

The first known nesting attempt of captively-reared, introduced peregrines in the Northeast occurred in New Jersey in 1979, about 15 years after the last wild peregrines attempted to breed in this area. New Jersey's Endangered and Nongame Species Program, in conjunction with The Peregrine Fund, Inc., has monitored this reestablished peregrine population in New Jersey since that time.

The founders of this reestablished population were captively produced and thus, free of environmental contaminants when released. Hence, reduced productivity or eggshell thinning in this population would suggest recent exposure to contaminants. Therefore, we investigated temporal and regional variation in productivity and eggshell thickness of peregrines breeding in these nontraditional habitats.

We report numbers of pairs, reproductive success, and eggshell thickness of reestablished falcons in New Jersey during 1979–88. Also, from several pairs studied intensively during 1987–88, we describe factors affecting regional differences in reproductive success of peregrine falcons in coastal New Jersey.

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STUDY AREA

Most pairs of falcons occupied towers designed to release ("hack") young birds and provide returning adults with nesting sites. These towers were placed in areas of abundant prey, low human disturbance, and limited predators (Barclay and Cade 1983). Towers were placed in coastal habitats throughout the southern half of New Jersey, on salt-marsh estuaries dominated by salt-marsh cordgrasses (*Spartina patens* and *S. alterniflora*), within 0–7 km of the Atlantic Ocean ($n = 7$) or Delaware Bay ($n = 2$).

After available towers became occupied, falcons nested on other substrates, which included 3 bridges, 1 water tower, and 1 high-rise building. The water tower and building were located in coastal areas. The bridges span the Delaware River, north of Delaware Bay, in urbanized areas near Philadelphia.

METHODS

Numbers of nesting pairs, productivity, and nesting success of falcons were determined by observing eyries, usually at weekly intervals, from early March through July, or until young dispersed. We used spotting scopes to observe falcon pairs and determine laying dates so we could approximate hatching dates. About 3–4 weeks after young hatched, we climbed eyries to band nestlings and collect any unhatched eggs or eggshell fragments. We calculated productivity based on nestlings that successfully fledged, and we excluded any manipulated nests (those in which eggs or nestlings were added or removed) from these calculations. We defined active nests as those at which a pair laid eggs and successful nests as those that fledged ≥ 1 young.

To determine factors influencing falcon productivity, we studied 4 coastal pairs nesting atop towers during both 1987 and 1988, two from the south Atlantic Coast and two from Delaware Bay. These nests were also visited weekly prior to hatching, but were climbed once to count eggs and again every 6 days after hatching.

Table 1. Number of pairs, nest success, and productivity (young fledged/pair) of peregrine falcons in New Jersey, 1979–88.

	Pairs				Young fledged/pair[a]	
			Successful[b]			
Yr	n	Known[a] outcome	n	%	Known outcome	Successful
1979	1	1	0	0	0	
1980	3	3	2	67	1.33	2.00
1981	3	3	2	67	2.00	3.00
1982	4	4	3	75	1.50	2.00
1983	4	4	4	100	2.25	2.25
1984	9	8	4	50	1.12	2.25
1985	13	10	5	50	1.30	2.60
1986	13	12	8	67	1.25	1.87
1987	14	14	8	57	1.00	1.75
1988	12	9	6	67	2.00	3.00
Total	77	68	42	62	1.38	2.24

[a] Excludes nests that were manipulated or of unknown outcome.
[b] Pairs fledging ≥ 1 young.

We measured thickness of eggshells and eggshell fragments from successfully and unsuccessfully hatched eggs during 1985–88. Eggshells were rinsed in tap water, air dried for >3 months, and measured for thickness to the nearest 0.01 mm with a dial-gauge micrometer. Measurements were taken near the egg's equator whenever possible.

We used ANOVA and t-tests for unequal samples to compare regional and temporal differences in eggshell thickness and productivity, and log-likelihood ratio tests (G-tests) to compare regional differences in nest success. To compare means after ANOVA's, we used the Least Significant Difference test because it yielded the minimum significant difference of all applicable techniques (Sokal and Rohlf 1981: 245). We used Wilcoxon 2-sample tests with an approximation to the normal distribution, Z, to compare clutch size, hatching, and fledging success among nests climbed weekly. All statistical tests were 2-tailed.

RESULTS

Numbers, Productivity, and Nest Success

Seventy-seven nesting attempts occurred statewide from 1979 to 1988: 74% on coastal towers, 16% on bridges, and 5% each on buildings and water towers. The number of falcon pairs nesting in New Jersey steadily increased since 1979, but leveled off after 1985 (Table 1).

Table 2. Regional productivity (young fledged/pair) and nest success (pairs fledging ≥1 young) of peregrine falcons nesting in New Jersey, 1979–88.

Region	All nesting substrates[a]							Coastal towers only[b]						
	% nest success	Young fledged/pair[c]						% nest success	Young fledged/pair[c]					
		Known active pairs			Successful pairs				Known active pairs			Successful pairs		
		n	$\bar{x}$	SE	n	$\bar{x}$	SE		n	$\bar{x}$	SE	n	$\bar{x}$	SE
South Atlantic Coast	77	26	1.85A	0.26	20	2.40A	0.21	95	19	2.42A	0.23	18	2.56A	0.20
North Atlantic Coast	57	30	1.30AB	0.26	17	2.29A	0.27	57	30	1.30B	0.26	17	2.29A	0.27
Delaware Bay and River	42	12	0.58B	0.26	5	1.40A	0.40	25	8	0.50B	0.38	2	2.00A	1.00
Overall	62	68	1.38	0.17	42	2.24	0.16	65	57	1.56	0.19	37	2.41	0.16

[a] Includes all nests on all substrates (coastal towers, bridges, buildings, water towers).
[b] Includes only those nests on man-made towers in salt-marsh habitats.
[c] Means within categories followed by the same letter are not significantly different ($P > 0.05$, Least Significant Difference test).

Productivity (young fledged/pair) and nest success (percentage of pairs fledging ≥1 young) remained relatively stable (Table 1).

To compare productivity and nest success, we divided the state into 3 regions: Delaware Bay and River, northern Atlantic Coast, and southern Atlantic Coast. We found no differences in productivity among years for all regions ($F = 0.68$, 8 df, $P > 0.10$) so we combined years for analyses. Productivity of active nests differed among regions (Table 2) ($F = 3.95$, 2 df, $P = 0.02$) and tended to be highest along the south Atlantic Coast and lowest near Delaware Bay and River. Regional productivity trends of successful nests paralleled those of active nests (Table 2) but showed no overall difference, probably because of small sample sizes ($F = 2.02$, 2 df, $P = 0.15$). Nest success of Delaware Bay, north and south Atlantic coasts indicated the same regional trend as productivity (Table 1) ($G = 5.02$, 2 df, $P = 0.08$).

To eliminate the potential influence of different habitats and nesting substrates on productivity, we compared only those nesting attempts that occurred on man-made towers, which were all located on coastal salt marshes (83.3% of all known-outcome nesting attempts), to all other nesting attempts. Productivity on salt-marsh towers was greater than on all other substrates combined ($t = 4.55$, 66 df, $P = 0.0001$). Productivity of known active nests on these towers also differed among regions ($F = 7.98$, 2 df, $P = 0.009$) and was highest along the south Atlantic Coast (Table 2). Productivity of successful nests on salt-marsh towers varied similarly among regions but differences were not significant ($F = 0.47$, 2 df, $P > 0.6$). Nest success on towers also differed among regions ($G = 16.0$, 2 df, $P < 0.001$) and paralleled regional trends in productivity of these nests (Table 2).

Differences in productivity and nest success of pairs studied intensively during 1987 and 1988 were consistent with previous years. All (4 of 4) south Atlantic Coast nests successfully fledged young, whereas no nests (0 of 3; 1 pair did not nest in 1988) along the Bay fledged young during both years. Bay nests usually failed during incubation, either from egg abandonment, egg predation (possibly by raccoon [*Procyon lotor*]), or failure of eggs to hatch. Although numbers of eggs laid per nest ($\bar{x} \pm$ SE) were similar between Delaware Bay (3.33 ± 0.33) and south Atlantic regions (3.25 ± 0.25) ($Z = 0.01$, 1 df, $P > 0.9$), only 1 of 10 eggs laid

Table 3. Eggshell thickness and percent below pre-DDT thickness levels of eggshells collected from reestablished peregrine falcons from 3 regions of New Jersey, 1985–88.

Region	n	Eggshell thickness (mm) $\bar{x}$	Eggshell thickness (mm) SE	% below pre-DDT thickness $\bar{x}$	% below pre-DDT thickness SE
South Atlantic Coast	23	0.312	0.006	16.9	1.5
North Atlantic Coast	14	0.314	0.004	16.3	1.0
Delaware Bay and River	21	0.315	0.006	15.9	1.6
Overall	58	0.313	0.003	16.4	0.9

along the Bay hatched, compared to 12 of 13 along the south Atlantic ($Z = 1.98$, 1 df, $P = 0.048$). All nestlings hatched along the Atlantic Coast successfully fledged ($n = 12$), whereas the single nestling hatched along the Bay was killed 26 days after hatching, probably by a great horned owl.

Eggshell Thickness

We compared eggshell thickness from whole eggs and eggshell fragments collected from peregrines nesting in New Jersey from 1985 to 1988 ($n = 58$). We found no difference among years for all regions ($F = 1.17$, 3 df, $P > 0.33$), so we compared thickness among regions for all years combined. Eggshell thicknesses were nearly identical in all regions (Table 3) ($F = 0.13$, 2 df, $P > 0.85$).

Eggshell thickness of reestablished peregrine falcons from the Northeast has decreased with time (Table 4). Eggshells collected during 1985–88 were significantly thinner than pre-DDT eggshells ($t = 15.07$, 150 df, $P < 0.0001$), as well as significantly thinner than 1981–84 levels ($t = 4.47$, 94 df, $P < 0.0001$).

DISCUSSION

Falcon productivity in New Jersey (Table 1) compared favorably with recent peregrine falcon reproductive success throughout North America (see Cade et al. 1988). Although productivity levels indicate a positive outlook for a stable eastern peregrine population, several factors suggest that recovery, at least in New Jersey, may be hindered. Whereas statewide productivity seemed adequate to maintain the population, we found that productivity varied considerably among different regions of the state (Table 2). These differences do not appear related to DDE levels (the contaminant thought most responsible for eggshell thinning) because eggshell thickness was similar among regions (Table 3).

Lower productivity of nests near Delaware Bay and River suggests that these falcons may be influenced by factors not affecting birds in other regions of the state. Perhaps differences in levels of contaminants more embryotoxic than DDE, such as PCB's (Peakall and Peakall 1973, Kubiak et al. 1989), were responsible for low productivity of nests in this region. Evidence from other species suggests this may be true. High levels of specific PCB's and other microcontaminants reduced hatching success and impaired parental behaviors of Forster's terns (*Sterna forsteri*) nesting near Lake Michigan (Kubiak et al. 1989). Eggs collected from ospreys (*Pandion haliaetus*) nesting near Delaware Bay from 1987 to 1989 contained elevated levels of PCB's and DDT-related contaminants (R. J. Steidl and C. R. Griffin, unpubl. data).

Falcons Nesting on Coastal Towers

A possible explanation for higher productivity on salt-marsh towers than on other nesting substrates is that younger, more inexperienced pairs occupied these alternative substrates after all available towers were occupied. In raptors, as in many birds, inexperienced breeders produce fewer young than older, experienced birds (Newton 1979:145). Further evidence to support this contention is that salt-marsh towers have been occupied since 1979, but alternative substrates have only been used since 1984.

Table 4. Eggshell thickness of reestablished peregrine falcons nesting in the eastern United States compared to pre-DDT (1947) levels.

Time period	n	Eggshell thickness $\bar{x}$	Eggshell thickness 95% CI	% below pre-DDT thickness
Pre-1947[a]	94	0.375	0.005	
1981–84[b]	38	0.340	0.011	9.4
1985–88[c]	58	0.313	0.006	16.4

[a] Anderson and Hickey (1972).
[b] Gilroy and Barclay (1988).
[c] This study and M. Gilroy, The Peregrine Fund, unpubl. data.

Although nesting towers were placed on coastal marshes, in part, to provide peregrines with a sufficient prey base in areas devoid of predators (Barclay and Cade 1983), aspects of these locations are applying new pressures on this reestablished population. Predation by great horned owls, a problem during reintroduction and reestablishment of peregrine falcons in the Northeast (Barclay and Cade 1983, Cade 1985), continues to hamper productivity, even on coastal marshes. The only young successfully hatched from our intensively-studied Bay pairs during 1987–88, as well as 1 young that successfully fledged from these south Atlantic Coast pairs, apparently were killed by owls that nested in the woodlands surrounding these marshes. Although towers are generally >2 km from these woodlands, these towers are tall, prominent structures on otherwise flat, featureless salt marshes. While hunting on these marshes, owls are probably attracted to the falcons' towers as perches. On at least 3 occasions, we have observed great horned owls attempting to nest on these towers.

Declining Eggshell Thickness

Eggshell thinning near 20% below pre-DDT levels has been associated with population declines from reproductive failure in peregrines (Anderson and Hickey 1972, Peakall et al. 1975). These thickness levels were associated with 15–20 ppm (wet mass) of DDE (Peakall et al. 1975). All populations where thinning exceeded 17% were either declining or became extirpated (Peakall and Kiff 1988), whereas productivity of peregrine populations with average thinning <14.5% appeared normal (Fyfe et al. 1988). The 16.4% thinning we observed for our population from 1985 to 1988 did not appear to be responsible for differences in productivity, yet it indicates substantial exposure to contaminants such as DDE (Lincer 1975, Enderson et al. 1982). Diets of these coastal falcons are dominated by migratory birds (Steidl 1990), which in general contain substantially higher contaminant loads than resident bird populations (White et al. 1973, Enderson et al. 1982, DeWeese et al. 1986).

Eggshells collected from reestablished peregrines nesting in the Northeast seem to have thinned with time (Table 4). Although a single egg examined from New Jersey's first nesting attempt in 1979 had "normal" thickness and low contaminant levels (Barclay and Cade 1983), eggshells collected during 1981–84 were significantly thinner (9.4%) than pre-DDT levels (Gilroy and Barclay 1988). Levels of DDE in these eggs (>50% were from New Jersey) ranged from 1.9 to 18 ppm, and for the New Jersey eggs in the sample, from 5.3 to 18 ppm (Gilroy and Barclay 1988). Several of these eggs contained contaminant levels within the range associated with population declines and reproductive failure.

MANAGEMENT IMPLICATIONS

Given the decrease in eggshell thickness of New Jersey peregrines over time, the status of this falcon in New Jersey may be more precarious than would appear by current levels of reproductive success and population increase. Continued releases of captive-reared falcons in other parts of the eastern United States will supplement this reestablished population but will also dilute our ability to evaluate the effects of deleterious factors to which these falcons are exposed, particularly environmental contamination. Fortunately, peregrine falcons can withstand relatively high levels of organochlorines compared to other falcons (Fyfe et al. 1988); they breed in captivity, and they nest on structures created by man—all factors greatly facilitating their recovery. Future studies of contaminant relations in the peregrine and its prey, and attempts to determine and eliminate sources of these pollutants, are imperative in evaluating and protecting the health of this renewed population.

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