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RESEARCH ARTICLES

Captive-rearing Piping Plovers: Developing Techniques to Augment Wild Populations

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Techniques for captive-rearing and releasing piping plovers *(Charadrius melodus)* were developed using a surrogate species, killdeer *(Charadrius vociferus)*. We compared captive- and parent-reared killdeer, and parent-reared piping plovers and determined that growth and behavior were similar. After surrogate trials determined that captive-rearing was feasible, we used the same methods to raise piping plover chicks from salvaged eggs. For captive-reared chick of both species, survival to fledging was higher than and behaviors similar to parent-reared chicks in the wild. Rearing techniques were fine-tuned, and ten piping plover fledglings were released to the wild. Based on our results, we developed recommendations for captive-rearing piping plovers using salvaged eggs to enhance productivity of small populations. Zoo Biol 16:461–477, 1997. © 1997 Wiley-Liss, Inc.

Key words: killdeer; piping plovers; *Charadrius melodus; Charadrius vociferus;* endangered species; reintroduction; surrogate species

INTRODUCTION

Piping plovers *(Charadrius melodus)* were listed as federally threatened (Great Plains and Atlantic Coast populations) and endangered (Great Lakes population) in 1986 [U.S. Fish and Wildlife Service, 1985]. In the years since listing, populations remained relatively stable through 1991 [Haig, 1992]. Results from the 1996 International Census indicate a significant increase in the Atlantic Coast population, a significant decrease in Great Plains plovers, and no change in the Great Lakes population [J. Pissner, pers. comm.]. Management techniques have included protection of nesting areas from human disturbance, predator management, and vegetation control [Powell, 1991; Haig, 1992]. A population model for the Great Plains determined that

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this population is likely to be extirpated in <100 years unless productivity is increased [Ryan et al., 1993]. To date, no attempts have been made to reintroduce piping plovers to previous ranges or to augment small populations such as in the Great Lakes. However, opportunities to salvage eggs from wild populations due to nest abandonment and flooding occur on a regular basis [Powell and Cuthbert, 1993; Kruse and McPhillips, pers. comm.]. In anticipation of using these opportunities to increase the reproductive success of wild piping plovers, we tested captive-rearing techniques using a surrogate species, compared the behaviors of the surrogate and target species in the wild, and then fine-tuned our captive-rearing methods on piping plovers.

Although captive rearing is frequently used to augment rare populations of reptiles, birds, and mammals, it often is done without appropriate testing beforehand and has had limited success in establishing self-sustaining populations in the wild [Byrd et al., 1984; Zwank and Wilson, 1987; Reed et al., 1993]. Despite this criticism, use of surrogate species to develop augmentation techniques is relatively infrequent [Scott and Carpenter, 1987; Wallace and Temple, 1987; Kuehler et al., 1993; Powell and Cuthbert, 1993]. In a previous study, we developed and compared cross-fostering and captive-rearing using a surrogate species, killdeer *(Charadrius vociferus)*, to test population augmentation techniques for piping plovers [Powell and Cuthbert, 1993]. In the present study, we first examined brood-rearing and chick behaviors of wild killdeer and piping plovers to strengthen the argument for using closely related species to test population augmentation techniques. Behavioral similarities between two species that co-occur in the same habitat justify the use of closely related species to develop captive-rearing protocols. Although the breeding biology of killdeer and piping plovers has been well documented [Bunni, 1959; Wilcox, 1959; Cairns, 1982; Prindiville-Gaines and Ryan, 1988; Brunton, 1990; Haig, 1992], few studies have specifically examined brood-rearing and chick behaviors as they relate to juvenile survival [Flemming et al., 1988]. Our initial objectives were to determine whether captive-rearing protocols developed using a surrogate species were appropriate for use on piping plovers. The following criteria were used in our evaluation: (1) survival of captive-reared young before and after release to the wild, (2) comparable behaviors of captive-reared young and wild-reared young, and (3) return of captive-reared birds as adults.

After determining that captive-reared protocols used for the surrogate species were appropriate, we tested these techniques on piping plover eggs collected opportunistically from clutches laid in the wild. This was a preliminary study to establish captive-rearing protocols for eggs that otherwise would not hatch. Captive-reared piping plover fledglings were then released to augment an existing wild population with the goal of increasing annual productivity.

METHODS

Study Area

The study was conducted on the Great Lakes piping plover population, in northern Michigan in Emmet, Charlevoix, Cheboygan, and Chippewa counties. Sites used for behavioral observations of wild broods had minimal human disturbance. Piping plover nests were monitored from mid-May through August 1987–1996. Between 15 May and 15 August 1987–1989, we observed killdeer and piping plover families from the time nests were initiated through chick independence.

Captive-rearing Surrogates

Eggs from six killdeer nests (total = 22 eggs) were collected from the wild in 1989. Complete clutches were transferred to small boxes lined with cotton balls and transported immediately to a laboratory at the University of Michigan Biological Station (UMBS) where they were placed in an incubator at 37.4°C between 78–82% humidity [Malone and Proctor, 1966]. We tried to collect eggs during the first week of incubation to allow time for parent birds to renest; no eggs were collected within 10 days of hatching. All collecting was done under the authority of federal permits. Guidelines for the use of animals in research were followed in all aspects of this study [Guidelines, 1992].

Chicks were removed from the incubator as they hatched and placed into a 0.5 × 0.5-m box that was maintained at 34°C. Tubifex worms mixed with water were provided in shallow pans. On the day after hatching, captive chicks were individually color banded and placed in 2 × 4-m outdoor pens. Siblings remained together from hatching to release. Each pen held two broods, placed together by proximity of hatching dates. Pens were constructed of wire mesh over a wooden frame and were covered with a slanted wooden roof 3 m high. Preliminary work showed that visual contact with neighboring chicks elicited escape behavior and chicks tried to squeeze through the fencing. Plastic garden edging 30 cm high placed around the bottom perimeter of each pen eliminated this problem. Concrete floors were covered with sand, and driftwood and rocks provided spatial heterogeneity for exercise and visual stimulus. Heat lamps located at one end of the pens provided warmth as needed. Chicks were fed a mixture of tubifex worms, mealworms, earthworms, and crumbled commercial moist cat food. Both food and water were presented in pans of shallow water over a sand substrate, with a flat rock protruding from the center. In addition, chicks fed on insects attracted to the heat lamps. Alarm calls of adult killdeer were played on a portable tape player whenever we approached the captive-rearing pens.

When chicks were fully feathered and had been observed flying (~35 days), they were banded with standard U.S. Fish and Wildlife Services (USFWS) aluminum bands and released in sibling groups on an isolated beach at Cheboygan State Park (Cheboygan County, MI). The site had little human activity, and the trauma of moving the fledglings was minimized by the short distance from the rearing site.

Behavioral Observations of Wild Broods

From 1987–1989, we located killdeer and plover nests by walking through potential habitat until an adult bird was seen. If we observed territorial behavior, we retreated to a distance where the bird was no longer disturbed by our presence (50–100 m). Observations continued until adults returned to their nests, or we determined they were not nesting. Natural features were used to mark nests to avoid leading predators to the nest site [MacIvor et al., 1990]. We determined hatching success as percentage of eggs hatched per clutch and fledging success as the percentage of hatched young that survived to fledgling. Reproductive success is reported as the number of fledglings per nesting pair of adults.

We banded wild killdeer chicks at hatching with individual combinations of USFWS aluminum bands and colored plastic bands. Piping plovers were not banded at this time because a moratorium on banding had been imposed. Because we did not always observe copulation, the sex of adult killdeer often was not known. We collected behavioral data only for early nesting attempts. The results of suspected renesting attempts were not recorded because adult killdeer were unbanded. We used a Pesola spring scale to weigh chicks to the nearest 0.5 g on alternate days or whenever possible.

We made behavioral observations on killdeer and piping plover families from hatching to fledging. We observed from a distance previously determined not to disturb the birds (~50–100 m) with 7 × 35 binoculars and a 15-60 × spotting scope. Instantaneous scanning [Lehner, 1979] was used for each family unit every 10 min (1 min observation per individual) for 2-hr periods, resulting in twelve 1-min observations on each individual chick and each attending parent. Due to logistical problems and the large study area, our observations were opportunistic: every other day whenever possible, and at least once a week for each family unit. We conducted observations in daylight hours, between 0700–1900, and not during inclement weather. For each instantaneous scan, we recorded one of the following activities: foraging, resting, preening, and other. Habitat use, estimated distance to attending adult and closest sibling (to the nearest m), and response to potential predators were recorded for each individual during each 1-min scan. We determined foraging rates of chicks by counting the number of pecks per minute for each individual. We recorded antipredator behaviors of adults and chicks whenever a potential predator was seen. In addition, responses to approach by humans (usually ourselves) were recorded.

Data were pooled for individual chicks into sibling groups because variability among sibling groups was greater than among siblings. Time budget data were normalized using arcsine transformations before analysis [Sokal and Rohlf, 1981], but we report actual percentages in the text. We analyzed our data using unpaired t-tests and ANOVAs (P set to 0.05), and report means ± one standard error [Lehner, 1979; Sokal and Rohlf, 1981].

Captive-rearing Piping Plovers

Piping plover eggs from abandoned nests were collected from 1992–1997 under the authority of federal and state endangered species permits. Abandonment of completed clutches was considered to have occurred when either one or both adults had not been incubating the clutch and had not been seen for a period of >24 hr. In the absence of recent information about the presence of incubating plovers, abandonment of completed clutches was presumed to have occurred when: no bird was seen on or near the nest when observation of the nest was initiated, no bird appeared or began to incubate within 1 hr of the initiation of observation, and no adult appeared or defended the nest when we approached it. Partial burial of eggs by sand and the absence of plover tracks around the nest constituted additional evidence that abandonment had occurred. Asynchronous hatching of eggs within plover clutches sometimes results in continued incubation of unhatched eggs by one adult while the other adult attends and broods chicks away from the nest. Unhatched eggs were presumed to have been abandoned when both adults were observed attending hatched chicks away from the nest and neither defended the nest when we approached it.

Salvaged eggs included those abandoned during the incubation stage and eggs left in the nest after the other eggs hatched. We report numbers of salvaged eggs only for years when some salvaged eggs were viable. We salvaged eggs from seven piping plover nests (total = 14 eggs) in 1992, four nests (total = 18 eggs; one nest was a 6-egg clutch) in 1993, eight nests in 1996 (total = 15 eggs), and five nests (total = 11 eggs) in 1997. Eggs were transferred to small boxes lined with cotton inside a small cooler containing a hot water bottle. The eggs were transported immediately to UMBS and placed in a Lyon-Marsh incubator maintained under the same conditions reported for killdeer.

Chicks were removed from the incubator as they hatched and were placed in a sand-lined box maintained at 34°C with a heat lamp. Chicks were provided with water in a shallow dish, live food (pin head crickets, small mealworms, chopped earthworms, and mayflies when available), and cobble and driftwood for cover. Chicks of different ages were separated by a partition for the first few days to prevent aggressive behavior by older chicks. Dummy adults made from socks and feather dusters were provided to allow chicks to be ‘‘brooded.’’ We minimized visual contact with plover chicks by providing food from behind a blind and played tape-recorded piping plover alarm calls to chicks when we approached. After 7 days, chicks were transferred to the same 2 × 4-m outdoor pens used for killdeer rearing in 1989. Soon after transfer, the plover chicks reduced their feeding frequency and did not gain weight at the expected rate. We returned them to sand-lined boxes indoors and placed them outdoors for a few hours on days when weather conditions were favorable for exposure to direct sunlight. The outdoor pen enclosed 6.1 × 9.1 m of natural sand beach and extended approximately 1 m into Douglas Lake, UMBS, to allow bathing opportunities and the development of natural foraging behaviors. A heat lamp was provided in a corner of the pen. Commercial mealworms, crickets, and wild insects caught in sweep nets were released in the center of the pen before the chicks were placed into the enclosure. We monitored chick activities in the outdoor pen from a blind. After this change in housing, the plovers continued to gain weight.

When chicks were capable of flight (~35 days) they were released. Areas used but not fully occupied by wild plovers that had minimal human disturbance and predator activity were considered appropriate release sites. In 1992, we released the captive fledglings on an isolated beach at Vermilion Station (Chippewa County, MI) where monitoring was feasible for only 2 days after release. In 1993 and 1996, fledglings were banded with individual combinations of standard USFSW aluminum bands and colored plastic bands and released at Wilderness State Park (Emmet County, MI) where we were able to observe them on a regular basis until they disappeared from the site.

RESULTS

Survival of Captive-reared Surrogates

Four of the 22 killdeer eggs collected were infertile. All the fertile eggs hatched, and 14 chicks survived to fledging (Table 1). Mortality occurred within the first 3 days of hatching when the chicks failed to thrive. Captive-reared killdeer chicks responded to taped alarm calls by crouching and freezing in place when less than 2 weeks old; they gave alarm calls and ran to cover after age 2 weeks. Captive-reared fledglings remained together at the release site for 3 days after release and then dispersed. One of the 14 captive killdeer fledglings that was released returned to the study area as a 1-year-old bird. The captive-reared killdeer was of unknown sex and was seen among a flock of wild killdeer on the mainland ~50 km from its release site.

Survival of Parent-reared Killdeer and Plovers in the Wild

We located 22 killdeer nests and 11 piping plover nests. Hatching rates were higher for wild piping plovers than killdeer during the years that behavior was re-

TABLE 1. Reproductive success of captive- and wild-reared killdeer and piping plovers

	No. nests	No. eggs	% Hatched	% Fledged
Killdeer				
Wild	22	90	54	27
Captive	6	22	82	78
Piping plovers				
Wild (this study)	11	41	85	37
Wild (1988–97)[a]	196	736–748	79–86	50–55
Captive	21	22[b]	59	77

[a]Michigan piping plovers, unpublished, Michigan Department of Natural Resources.
[b]Potentially viable eggs (58 eggs salvaged).

corded (Table 1). Fledging rates were higher for wild piping plovers than killdeer both during the study years and over an 8-yr average (Table 1). No piping plovers eggs were destroyed by predators, but one incomplete clutch was destroyed by wave action during a storm. Killdeer eggs were eaten by coyotes *(Canis latrans),* American crows *(Corvus brachyhynchos),* and possibly ring-billed gulls *(Larus delawarensis).* In one case, a killdeer egg was broken by children but the three remaining eggs subsequently hatched. Known predation on piping plover chicks was due to avian predators. Chick mortality occurred before age 1 week for all piping plover chicks and 76% of killdeer chicks that died.

Behavioral Comparison of Parent-reared Surrogates and Parent-reared Piping Plovers

From hatching to fledging, we observed eight wild killdeer and eight piping plover families, for a total of 1,560 observation-hours during 1987–1989. Families that lost all chicks within 1 day after hatching were discounted from the analysis. Adults of both species brooded their chicks on the nest on the day of hatching. Nonbrooding parents remained close to their nests (usually within 5–10 m) during this time. Both killdeer and piping plover families left nest sites within 24 hr of hatching.

Diurnal brooding activity continued for the first 2 weeks after hatching and was associated with weather conditions and the age of chicks. In cases where the sex of parents was known, male piping plovers spent 23% less time brooding than females during the day (39% males; 62% females; n = 8 pairs). Adults and chicks of both species initiated brooding events. Chicks initiated brooding by approaching the attending adult. Parents responded to chick approaches with a soft brooding call and stood so chicks could move underneath them. Chicks foraging nearby often responded to the brooding call and joined the sibling being brooded. Adults initiated brooding by crouching, fluffing their feathers, and giving brooding calls. During daylight hours, killdeer brooded chicks younger than 10 days and piping plovers brooded chicks less than 14 days old.

Killdeer did not maintain distinct brood-rearing territories, but defended areas around the chicks as they traveled over large areas. Killdeer used a broad range of habitats for brood rearing including beach shorelines, mowed yards, pastures, and plowed cornfields [Powell and Cuthbert, 1993]. Killdeer families exposed to human disturbance moved frequently, and over longer distances, than families rearing young in remote areas. In one case, a killdeer family with 5-day-old chicks moved over 1 km within 48 hr. In contrast, piping plovers led their chicks to beach shorelines for brood rearing, and defended brood-rearing territories along the lakeshore [Powell and Cuthbert, 1992]. Piping plover families remained within 100 m of a line perpendicular to their original nest site. However, two piping plover families exposed to human activity remained within 200 m of their nest site and returned to a general brood-rearing area after being displaced by disturbance. Parents of both species remained with their broods until fledging or loss of chicks in all cases. In two piping plover families, the female parent disappeared 30 days after hatching and the males remained with their broods for several weeks after fledging. Adults that lost their chicks left the study areas within 5 days; renesting only occurred after egg loss. In contrast, killdeer occasionally renested after raising a brood.

Killdeer and piping plover adults exchanged duties as brood attendants. Attending parents stood or sat in a location where their young were visible and oriented toward the chicks (piping plovers 88%; killdeer 84% of time observed). Attending parents of both species maintained close contact to their broods by gathering them using vocalizations and physical means. Parents were seen chasing and leading young in response to disturbance by humans and predators. Although attending parents occasionally fed alongside chicks, these foraging bouts lasted <30 min. Nonattending piping plover parents foraged along the shoreline within the brood-rearing territory. Observations of nonattending killdeer adults were limited, but responses to alarm calls from the parent attending the chicks indicated they were within hearing distance of their families. An attending parent remained within 3 m of the chicks during the first week after hatching for both species (Fig. 1). Distances between attending adults and their broods increased with age, and piping plover adults maintained closer distances than killdeer after chicks were 1 week old ($\bar{x}$ = 5.52±0.7 m for piping plovers, 7.92±0.8 m for killdeer, t = 2.07, P = 0.04) (Fig. 1).

Chicks of both species exhibited similar behaviors. On the day of hatching, chicks were brooded nearly 100% of the time, occasionally taking <30 sec to stand next to the brooding adult. Chicks <1 day old walked around within 0.25 m of the brooding adult, but were unsteady on their feet. These chicks were observed pecking at the ground, but did not appear to be capturing prey. Approximately 24–48 hr after hatching, chicks followed their parents to brood-rearing areas in response to leading vocalizations. Chicks fed independently within 24 hr of hatching and adults were not observed showing food to their chicks.

Killdeer and piping plover chicks did not differ significantly in percentage of time spent brooding, feeding, resting, and preening (Fig. 2). Percentage of time spent feeding increased from <75% during the first week of hatching to >80% as chicks were brooded less. In addition to percentage of time spent feeding, the rate of feeding also increased as chicks got older (<1 week: killdeer = 5.7±0.9, piping plovers = 4.3±0.4 pecks/min; 1–2 weeks: killdeer = 14.5±1.7, piping plovers = 12.7±0.5 pecks/min; >2 weeks: killdeer = 19.3±1.8, piping plovers = 15.5±0.6 pecks/min) (Fig. 3). Observations indicated that chicks became more successful at capturing prey several days after hatching. Average time spent preening increased from 2.0% during age 1 week to 12.2% after age >2 weeks (Fig. 2). This increase corresponded to feather development. Both feeding rates and time spent feeding dropped after age 2 weeks when chicks begin to practice flying. Chicks of both species began stretching their wings and jumping at 2 weeks of age. Killdeer and piping plovers were able to fly short distances (<5 m) by 25 days, and longer distances by 30 days.

Both killdeer and piping plover foraged in sibling groups. Distances main-

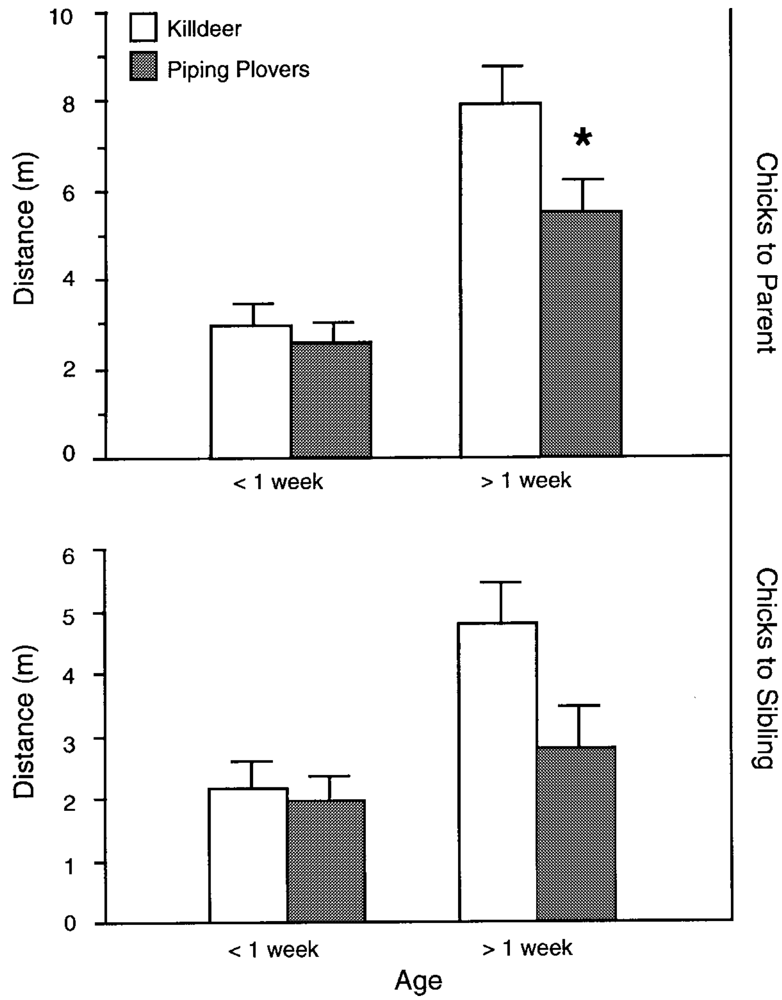

Fig. 1. Spacing between wild parent-reared chicks and their parents. Means ± standard error, significant differences ($P < 0.5$) are noted with an asterisk.

tained between siblings were smaller than distances maintained between chicks and their attending parent (Fig. 1). After age 1 week, mean distance between chicks was greater for killdeer than piping plovers, but the difference was not statistically significant (killdeer = 4.80±0.7 m, piping plovers = 2.81±0.7 m, t = 1.8, P = .08). In both species, chicks sometimes became separated from siblings. Lost chicks gave distress calls that resulted in attending parents searching for them. Searching by the attending adult was accompanied by vocalizations that usually resulted in all chicks approaching the adult. Sometimes the nonattending parent responded to these vocalizations as well and returned from foraging to join the family group. Siblings of both species remained together until fledging. Killdeer fledglings dispersed away from their families at approximately age 5 weeks and remained on the study areas until late August. Piping plover fledg-

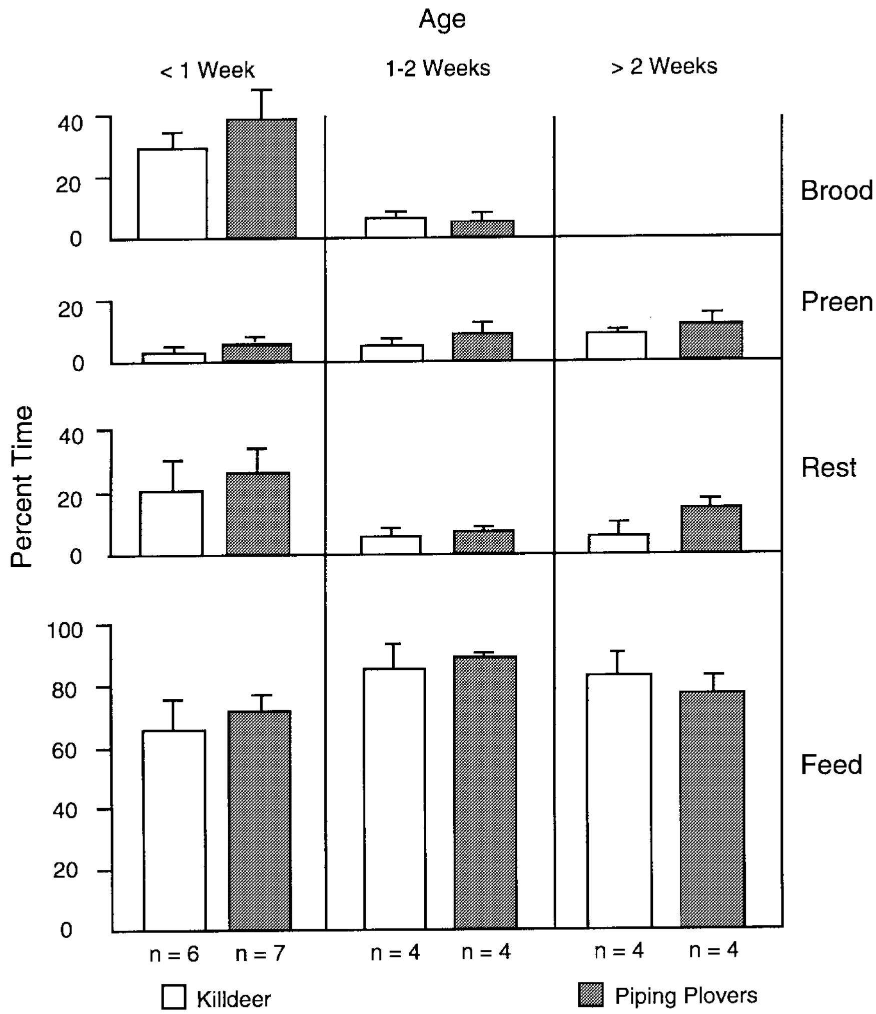

Fig. 2. Activities of wild parent-reared killdeer and piping plover chicks, shown as percentages. ANOVA was used to test for significance (P = 0.05) after pooling and transforming data. Means ± standard error, n = number of family units observed in each age category.

lings remained together, occasionally joined groups of conspecific fledglings, and left the study area by mid-July or early August.

Both killdeer and piping plover chicks responded to adult alarm calls by crouching or freezing in place and remained in place until one parent initiated contact calls. Chicks older than 1 week typically ran to cover before crouching or freezing in place. Killdeer chicks always froze in response to trill calls. Juveniles of both species responded to alarm calls from neighboring conspecifics as well as from parents. Young of both species were observed ignoring nearby gulls until they heard their parents' alarm calls. No vocalizations were heard from chicks of either species during predator avoidance, but killdeer chicks that were captured by predators or by us gave loud distress calls. Chick distress calls always resulted in intense displaying by both parents.

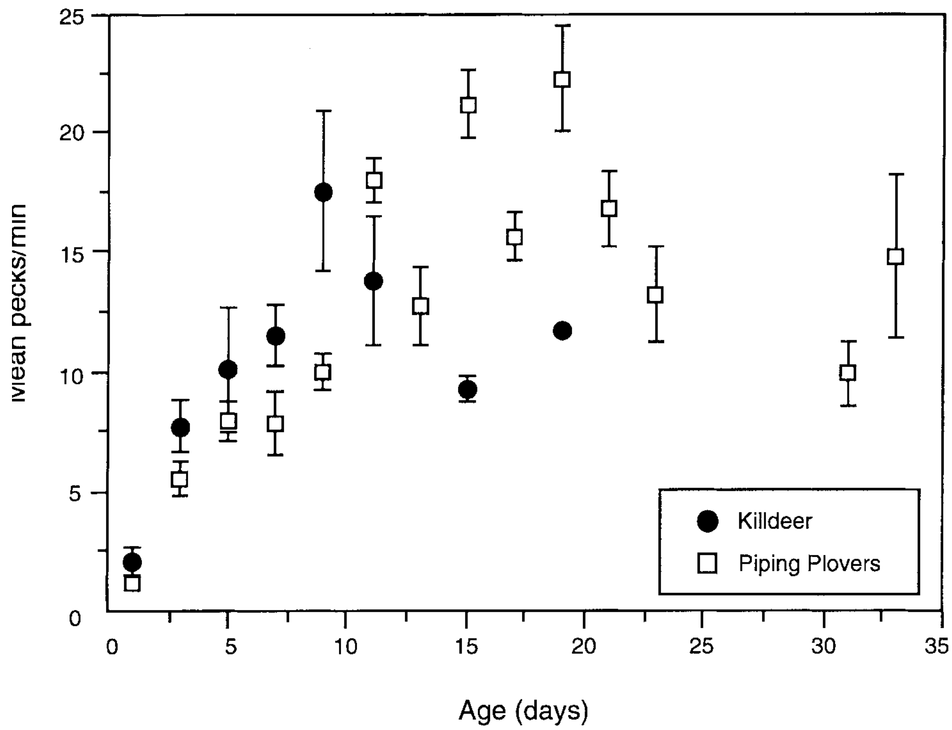

Fig. 3. Feeding rates (means ± s.d.) of wild parent-reared killdeer and piping plover chicks.

Survival of Captive-reared Piping Plovers

Twelve of 58 piping plover eggs salvaged in 1992, 1993, 1996, and 1997 were infertile and 24 embryos probably died prior to removal from the wild. Of the 22 potentially viable eggs, 13 hatched, and 10 of the 13 chicks survived to fledging (Table 1). We believe low hatchability of salvaged eggs was caused by susceptibility of embryos to extreme temperatures prior to collection. Susceptibility of the embryo to temperature varies with stage of development [Hunter et al., 1975; Webb, 1989]. The eggs that hatched were those abandoned soon after they were laid or recovered almost immediately after abandonment occurred.

Like captive-reared killdeer, captive-reared piping plover chicks responded to taped alarm cells of conspecifics by freezing and crouching in place during the first 2 weeks and by giving alarm calls and running to cover after age 2 weeks. Captive piping plover chicks were observed crouching in response to gulls in flight over their outdoor pen even when taped alarm calls were not given. Unlike captive-reared killdeer chicks, captive piping plover chicks did not readily consume inanimate food items. A more natural foraging situation (sand beach and shoreline) seemed to stimulate feeding behavior and also provided opportunities for bathing and sunning. Interaction with siblings was also important to normal behavioral development. The first chick reared in captivity paced the walls of its enclosure and peeped constantly for 3 days until a second newly hatched chick was introduced. The older chick initially exhibited aggressive behavior toward the younger chick but stopped after the young chick was able to stand steadily and run.

After release, captive-reared fledglings were seen mingling with wild fledglings and adults but were chased by wild adults with young chicks. The responses of released captive-reared fledglings to the approach of humans (crouching, alarm calls, running, or flying away) were similar to those of wild fledglings. In 1992, the two captive-reared piping plover fledglings remained together during the 2 days they were observed and maintained contact through vocalizations. In both 1993 and 1996, the two released fledglings did not stay together but remained in the same 3.23 km stretch of shoreline for the first 3 days following release. In 1993, only one captive-reared fledgling was observed after 3 days; it was sighted periodically during the next 3 weeks at locations up to 13 km from the release site. In 1996, one captive-reared fledgling was seen at the release site for 7 days and the other was observed repeatedly at the release site for 3 weeks. In 1997, the four captive-reared fledglings remained at the release site for 2 weeks; at times they remained together as a group and at other times they foraged in separate areas but with wild fledglings. After 2 weeks, the captive-reared fledglings moved to a site ~6 km south of where they were released. One week later, they were observed back at the release site. The movements and disappearance of captive-reared fledglings from release sites coincided with dispersal of wild fledglings from breeding territories. To date, none of the captive-reared piping plovers has been sighted in the years following release.

Growth of Captive-reared vs. Parent-reared Plovers

Adult killdeer are larger than piping plovers, averaging 72–92.4 g as opposed to 34–63 g [Bunni, 1959; Haig, 1992]. These size differences were reflected in the weights of fledglings of both species (Fig. 4). Adult weights were reached by age 30 days, and the period of most rapid gain was between 12 and 26 days (Fig. 4). In 1992, captive-reared piping plovers did not thrive until moved to another pen, then rapidly gained weight between age 17 and 26 days.

DISCUSSION

Value of Using Surrogate Species

Our comparisons of captive- and wild-reared killdeer and wild plover broods supported the use of surrogate species to test population augmentation techniques before applying them to piping plovers. The methods we developed were successful for raising fledgling killdeer and piping plovers from wild eggs. Hatching and fledging success were higher for captive-reared killdeer than their wild counterparts, and there was evidence that captive-reared young survived in the wild and interacted appropriately with conspecifics [Powell and Cuthbert, 1993]. Fledging success of captive-reared piping plovers was higher than that of parent-reared young, and low hatching rates were attributed to using eggs salvaged from abandoned nests.

Comparisons between parent-reared killdeer and piping plovers in the wild indicated that brood behaviors were similar for both species and that observed differences were related to habitat use. Killdeer in this study raised broods in areas where they were frequently disturbed, whereas piping plovers raised their young in more remote locations. Killdeer and piping plover chicks spent similar amounts of time in somatic activities. Foraging time and efficiency increased with age and were highest

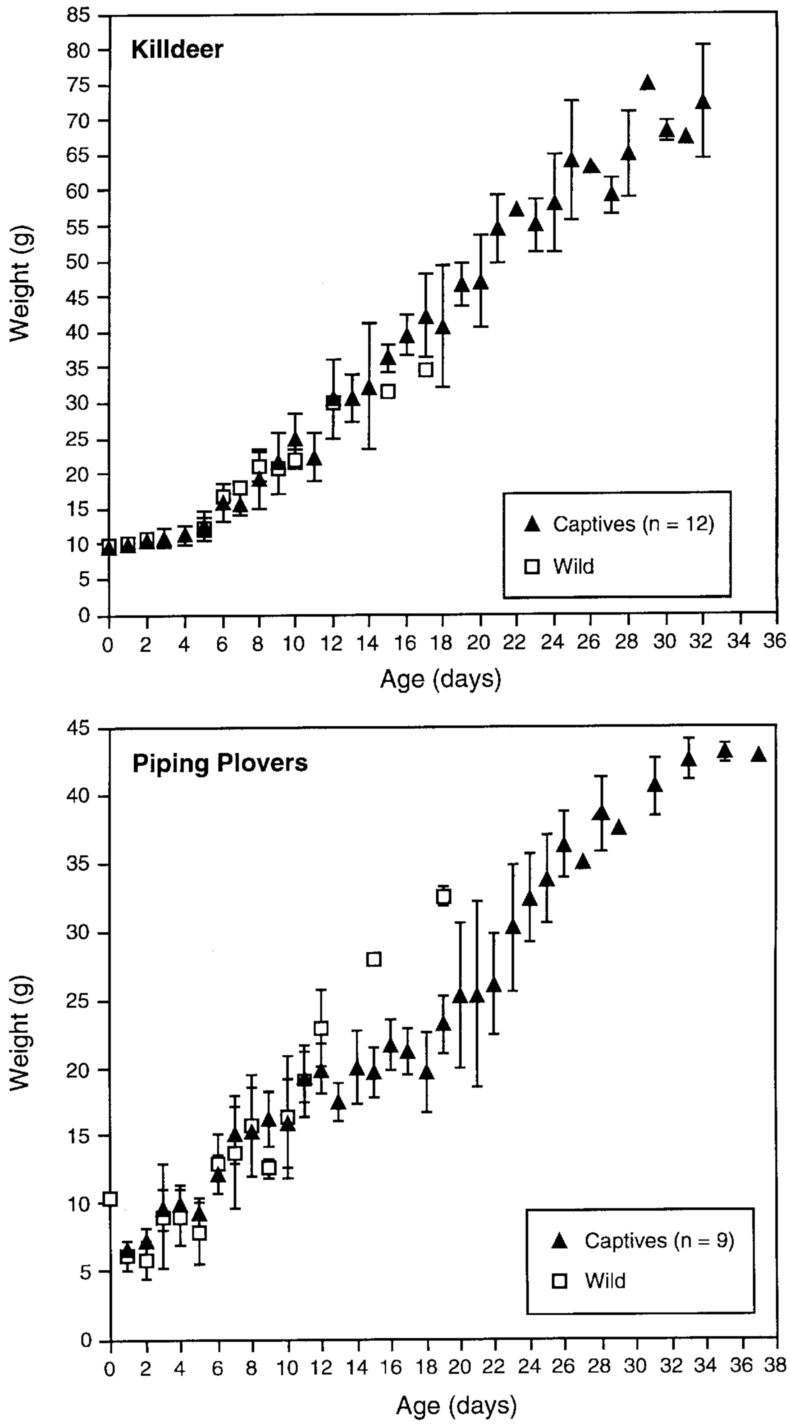

Fig. 4. Growth (means ± s.d.) of captive- and wild parent-reared killdeer and piping plover chicks.

during the period of rapid weight gain and feather development (between 5 and 20 days in age). It is imperative that plover chicks have adequate foraging skills and opportunities to gain sufficient weight during this critical period, or their survival is reduced [Bunni, 1959; Cairns, 1982]. Foraging activities can be restricted by bad weather, disturbance by predators, and human activity [Pienkowski, 1984; Flemming et al., 1988; Patterson et al., 1991]. We found that activities of killdeer chicks older than 1 week are comparable to activity patterns for nonbreeding, adult piping plovers [Johnson and Baldassarre, 1988]. Based on similarities between the surrogate and target species, we concluded that killdeer were appropriate surrogates for testing captive-rearing techniques for piping plovers. The success of reintroduction and population augmentation of endangered species can be evaluated by comparing reintroduced and wild-born animals [Kleiman, 1990]. Likewise, the comparison of closely related surrogates and their target species can allow evaluation of reintroduction techniques before using them on small, vulnerable populations of endangered animals.

Captive-rearing and Releasing Plovers

Use of killdeer surrogates allowed us to develop methods to captive rear piping plover chicks from abandoned eggs and release them back into the wild when they achieved independent flight. Although not originally an objective in our study, our results have also been useful for captive rearing piping plovers in zoos [Anita Cramm, Lincoln Park Zoo, pers. comm.]. Transfer of knowledge from the killdeer studies to piping plovers helped identify methods that needed fine-tuning to enhance successful reintroduction of the plover fledglings. Some of our results are also relevant for plovers maintained permanently in captivity.

We identified several recommendations for rearing chicks in captivity that we believe may influence reproduction and survival of reintroduced piping plovers. First, careful attention to the immediate posthatching environment is important for chick survival. We recommend that captive chicks be placed with their siblings or same age chicks from another brood. Single individuals do not develop normally and younger chicks in multi-age groups are subjected to aggressive behavior by larger chicks. Second, techniques for captive-rearing plovers should include survival training (e.g., learning appropriate responses to local predators by exposing chicks to alarm calls). Captive-reared young of some species require a high level of learning or imprinting to adults in order to survive after release [Horwich, 1989; Carpenter et al., 1991; Marshall and Black, 1992]. Previous reintroductions have shown that captive-reared animals may have low survival rates because they were unable to recognize and avoid predators [Kleiman, 1990; Carpenter et al., 1991; Brittas et al., 1992]. Killdeer and piping plover chicks may not recognize predators per se. Previous work on captive-reared and cross-fostered killdeer indicated that chicks innately respond to tape-recorded conspecific alarm calls, as well as to alarm calls of foster parents [Powell and Cuthbert, 1993]. The response of plover chicks to alarm calls in general (including those given by their parents, neighboring adults, and older chicks) is critical to their avoidance of predation. Third, chicks reared in captivity need regular exposure to their natural habitat. After piping plover chicks were several days old and when weather conditions were favorable, they were placed in outdoor pens containing shoreline features (e.g., sparse vegetation, sand, water). Their apparent innate responses included bathing, picking up tiny objects along the shore, and foraging for insects on the vegetation. We believe this is a critical transitional stage between captivity and release. Finally, identifying an appropriate release site is an important component of the reintroduction effort. We suggest release sites be located within historical piping plover breeding habitat, preferably at a location where captives can associate with wild plovers. Release should not occur within a currently occupied plover territory. The site also should be carefully selected to minimize exposure to predators and human disturbance. Because it is important to determine postrelease survival, the site should be accessible for frequent monitoring for 2–3 weeks after release. All released birds need to be banded with USFSW bands and unique combinations of colored plastic bands and birds need to be followed after release to evaluate survival. To date, our efforts have terminated when released juveniles disappeared from the general area of the release site. To evaluate the usefulness of captive rearing, information on postfledging movements, survival, and reproduction is critical [Page et al., 1989]. To justify a formal reintroduction effort using captive reared birds, breeding by released individuals needs to be documented.

CONCLUSIONS

1. Comparison of closely related surrogate and target species allows evaluation of reintroduction techniques before application to vulnerable populations of endangered animals.
2. Growth and behavior of captive and parent-reared killdeer were similar.
3. Captive-reared killdeer chicks showed appropriate behaviors after release to the wild.
4. Somatic activities of chicks were similar in parent-reared killdeer and piping plovers.
5. Adult killdeer and piping plover brood-rearing behaviors were for the most part similar.
6. Captive-reared killdeer and piping plover chicks reached average fledging weights in the appropriate time.
7. Fledging rates of captive-reared killdeer and plover chicks were higher than their wild counterparts.
8. Techniques developed using killdeer surrogates were modified to captive-rear and release 10 piping plover fledglings.

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APPENDIX: PROTOCOL FOR ABANDONED PIPING PLOVER EGGS OR CHICKS

Collection and Transportation

Eggs

Make sure location of the nest and reasons for abandonment are noted.

Record approximate age of the eggs.

Collect eggs from the field immediately, place in a padded container (*not* air-tight): a small box filled with cotton balls works well.

Do *not* let eggs warm >99°F (37°C), or cool <65°F; eggs can tolerate cooling for up to 24 hr, but must never overheat. If overheating or cooling has occurred, however, note that the eggs may still be viable.

Chicks

Note location, reasons for abandonment, and age of chicks.

Keep chicks together in a box without visual contact with people or the outdoors.

Reduce visual stress and noise levels.

Chicks <7 days old should be kept warm with a heat lamp (or lightbulb for the short term); 93°F is ideal. Older chicks should be kept at ~85°F.

Water should be supplied at all times in a shallow dish (a pie pan works well).

If chicks are dehydrated and weak, drops can be applied to the edge of the bill with an eyedropper. Do *not* attempt to force food or water by prying open the bill; this is too stressful to the bird.

Incubation

Eggs should be kept at 99.4°F (37.4°C) and between 78 and 82% humidity.

Make sure that eggs are turned properly.

Eggs should be attended closely around hatching time (incubation 25–30 days, usually 28; incubation may be slightly longer if eggs have been cooled).

Remove chicks at hatching and place in a box with a heat lamp and small water dish until they are strong enough to be moved into the pens; keep chicks in sibling units.

Chicks

Housing

Chicks <7 days old should be kept at 93°F (34°C) with a heat lamp.

Older chicks should be provided with heat lamp, but be allowed to vary ambient temperatures by moving away from the heat source at will.

Pens should be sterilized before use; clean sand should be provided as substrate; place several rocks and/or pieces of wood for cover and variety.

Minimize noise levels and visual contact with birds.

Play tape-recorded plover alarm calls when approaching chicks.

Remove chicks from outdoor pens at night, continue using heat lamp indoors.

Feeding

If chicks are dehydrated on arrival, place drops of water on edge of bill with an eyedropper; do *not* force feed.

Provide chicks with fresh water at all times; use a pie pan with a flat rock placed in the center; make sure that very young chicks can get over the edge of the pan.

For the first 1–2 days, provide chicks with pinhead crickets and smallest mealworms available.

Gradually introduce other food items; small mealworms, cut up earthworms, cut up mayflies, chopped egg yolk may also be used; moving ‘‘prey’’ is important to stimulate feeding behavior.

Chicks should fledge in 20–32 days.