THE PROPAGATION OF LARGE FALCONS IN CAPTIVITY

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Abstract

Wild falcons have been trained and held in captivity for more th. three thousand years, but only in the last decade have falconers and other devotees made sustained attempts to propagate these birds. Since 1965, a worldwide interest has developed in perfecting methods for breeding birds of prey in captivity, particularly the large falcons.

The first consistent and encouraging results were achieved with American and European Kestrels (*Falco sparverius* and *F. tinnunculus*), although a German falconer, Waller (1962), had succeeded in breeding a pair of Peregrine Falcons (*Falco peregrinus*) in 1942 and 1943. Greatest interest has focused on the Peregrine because of the severely threatened state of breeding populations in North America and Europe and because of its high desirability as a bird for falconry.

Results in the last few years show that practical, large-scale production is feasible for most species, including the Peregrine. Some of the attempts to breed falcons are detailed in the references listed in table 1. At least fifteen species of *Falco* and three interspecific crosses have produced fertile eggs and reared young in captivity. The American Kestrel is an easy species to propagate, as is the European Kestrel; reproduction by first- and second-generation progeny has been obtained with both species. Among the large falcons, breeding by F_1 individuals has occurred with the Prairie Falcon (*Falco mexicanus*), Lanner (*Falco biarmicus*), and Peregrine Falcon. The Gyrfalcon (*Falco rusticolus*) was the most recent of the large species to reproduce in captivity, and it now seems likely that all species of falcons can be domestically propagated under the right circumstances.

The Peregrine Fund's research program was started in 1970 to develop techniques necessary for breeding falcons in captivity and to build up a captive population to produce a supply of birds large enough to reestablish breeding Peregrines in the eastern United States. Subsequently we extended our goals to include work with the severely endangered western *anatum* Peregrines, and we have also continued to work experimentally with other species, particularly the Prairie Falcon and the Gyrfalcon.

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Table 1. Records of falcons reproducing in captivity.

Species	No. Breeding Females	Sources
AMERICAN KESTREL *Falco sparverius*	200+	Willoughby & Cade 1964, Koehler 1969, Porter & Wiemeyer 1970, Lincer 1975, Bird et al. 1976, G. L. Richards 1974, unpubl.
EUROPEAN KESTREL *Falco tinnunculus*	20+	Koehler 1969, Glasier 1972, Santer 1972.
LESSER KESTREL *Falco naumanni*	1?	Mendelssohn & Marder 1970.
°MAURITIUS KESTREL *Falco punctatus*	1	Temple 1975.
RED-FOOTED FALCON *Falco vespertinus*	1?	Fodor post-1964 (trans. 1971).
°NEW ZEALAND FALCON *Falco novaeseelandiae*	1	N. Fox 1976, unpubl.
RED-HEADED FALCON *Falco chicquera*	1	Koehler 1970.
ELEONORA'S FALCON *Falco eleonorae*	1	P. L. Whitehead 1975, unpubl.
MERLIN *Falco columbarius*	6+	Glasier 1972, Fyfe 1976, Campbell & Nelson 1975, L. H. Hurrell 1976, unpubl.
PEREGRINE *Falco peregrinus*	75+	Waller 1962, Beebe 1967, Schramm *vide* Peterson 1968, Meng 1972, Cade 1973, Fyfe 1976, Cade and Temple 1977.
LUGGAR *Falco jugger*	3	Dallimore 1972, Byron 1972, L. H. Hurrell 1974, unpubl.
LANNER *Falco biarmicus*	8+	Snelling 1973, Glasier 1972, Terrasse 1972, Trommer 1973.
SAKER *Falco cherrug*	2	Fodor post-1964 (trans. 1971), E. Laage 1972, 1973, unpubl.

GYRFALCON *Falco rusticolus*	7+	Cade 1974, 1975; Cade & Dague 1976, Fyfe 1976, E. Müller 1976, unpubl., L. G. Swartz 1976, unpubl.
PRAIRIE FALCON *Falco mexicanus*	30+	Kendall 1968, Enderson 1971, Fyfe 1972, Cade 1972, 1973, 1974; Burnham & Heinrich 1976.
INTER-SPECIES CROSSES *F. peregrinus* male X *F. cherrug* female	1	Morris & Stevens 1971, 1972.
F. peregrinus male X *F. rusticolus* female	2	Cade and Weaver 1976.
F. mexicanus male X *F. peregrinus* female	1	Boyd and Boyd 1975.

*Chicks died accidentally before flying.

Table 2. Birds of prey produced through domestic breeding by the Peregrine Fund at all facilities, 1972-1976.

Falco peregrinus	Peregrine Falcon	137
Falco biarmicus	Lanner Falcon	27
Falco mexicanus	Prairie Falcon	68
Falco rusticolus	Gyrfalcon	14
Falco sparverius	American Kestrel	25
Falco rusticolus X *F. peregrinus*		4
Parabuteo unicinctus	Harris Hawk	5
Aquila chrysaetos	Golden Eagle	1
Buteo jamaicensis	Red-tailed Hawk	1
Accipiter gentilis	Goshawk	6
	Total	288

The main facility is located at Cornell University, but a similar-sized operation was established in 1974 at Fort Collins, Colorado, in collaboration with the Colorado Division of Wildlife. Cooperative private breeding lofts also exist in Pennsylvania under R. B. Berry's management and in New Mexico under F. M. Bond. In its brief existence the Peregrine Fund has produced 288 fledged birds of prey through domestic propagation (table 2).

The purpose of this paper is to present a detailed description of the procedures used and the results of their successful and unsuccessful applications. The data relate

primarily to Peregrines and secondarily to other large falcons. This report also serves to update and correct a previous one by Weaver and Cade (1974, BPIE no. 90).

Facilities and Maintenance

The Cornell facility is a pole barn 69 m long by 14 m wide, with steel roof and siding at the ends. It is divided into 36 chambers 3 by 6 m in area and 2 that are 6 by 6 m, plus various utility and office areas (fig. 1). Each chamber is 5.5 m high at the apex and 4.3 m at the eaves. The entire sidewall is open to the weather but enclosed on the outside by 13 mm welded wire mesh and on the inside by 13 mm tubular steel, vertical bars, spaced 63 mm apart. The lowest meter of this wall is covered with a sheet of fiberglass to prevent the drifting of snow into the chambers. The roof provides complete cover with a single 60-cm-by-240-cm sheet of white, translucent fiberglass in each room to allow for additional light from above.

In Fort Collins we have three separate buildings of 12 chambers each. The work and utility areas are separate from the birds. We feel that this arrangement minimizes the chance of total loss from fire or disease. The individual chambers are identical, with a few exceptions. Higher water pressure has made possible the use of a remote watering system that allows bath and drinking water to be changed by periodic flushing without anyone's entering the room. Owing to the drier climate we have also been able to do away with the fiberglass panel in the roof. The opening remains but is barred and screened, allowing more light and air to enter.

Floors are coarse gravel fill covered with at least 5 cm of pea-sized, washed gravel. All chambers are cleaned twice a year. Floors and lower walls are sprayed once a year with a 10 percent formalin solution by an attendant who wears a gas mask. Perches and nest ledge gravel are cleaned and renewed as needed. Birds are moved to holding rooms while the chambers are being cleaned. The chambers are allowed to dry and air out thoroughly before the birds are replaced. Each chamber has fixtures for water, as well as for artificial lights, operated by manual switches or automatic timers from the observation corridors. The layout of a typical chamber is shown in figure 2.

The rooms are furnished with a variety of ledge-type perches arranged at different heights on the walls and with a natural branch that extends 1 m from the wall. We try to keep the middle space of the room free for unobstructed flight and therefore do not place any beams or branches across the full width of the room. There are two nesting ledges in each room (fig. 2). Pairs usually have a preference for one ledge or the other for their first clutches year after year. When we take the first set of eggs for artificial incubation, the female often switches to the other ledge for her second set, as falcons usually do in nature. We recorded the deposition sites for 30 clutches laid by our three most productive pairs. Seventeen times a clutch was removed and a subsequent clutch laid; only 5 of the subsequent clutches were laid on the ledge from which a clutch had just been removed. In the sample of 30 clutches half were laid on ledge 1 and half on ledge 2.

We routinely feed through ports located above a shelf 1.5 m from the floor, but an alternate feeding port is located high on the back wall above shelf 6 (see fig. 2) for special use. The diet consists of five-week-old chickens and Coturnix Quail (*Coturnix coturnix*), the latter forming the bulk of the diet during the breeding season. No vitamin supplements are given. Quail and chickens are raised at the facility; chickens are maintained on unmedicated chick starter and quail on a higher protein game-bird

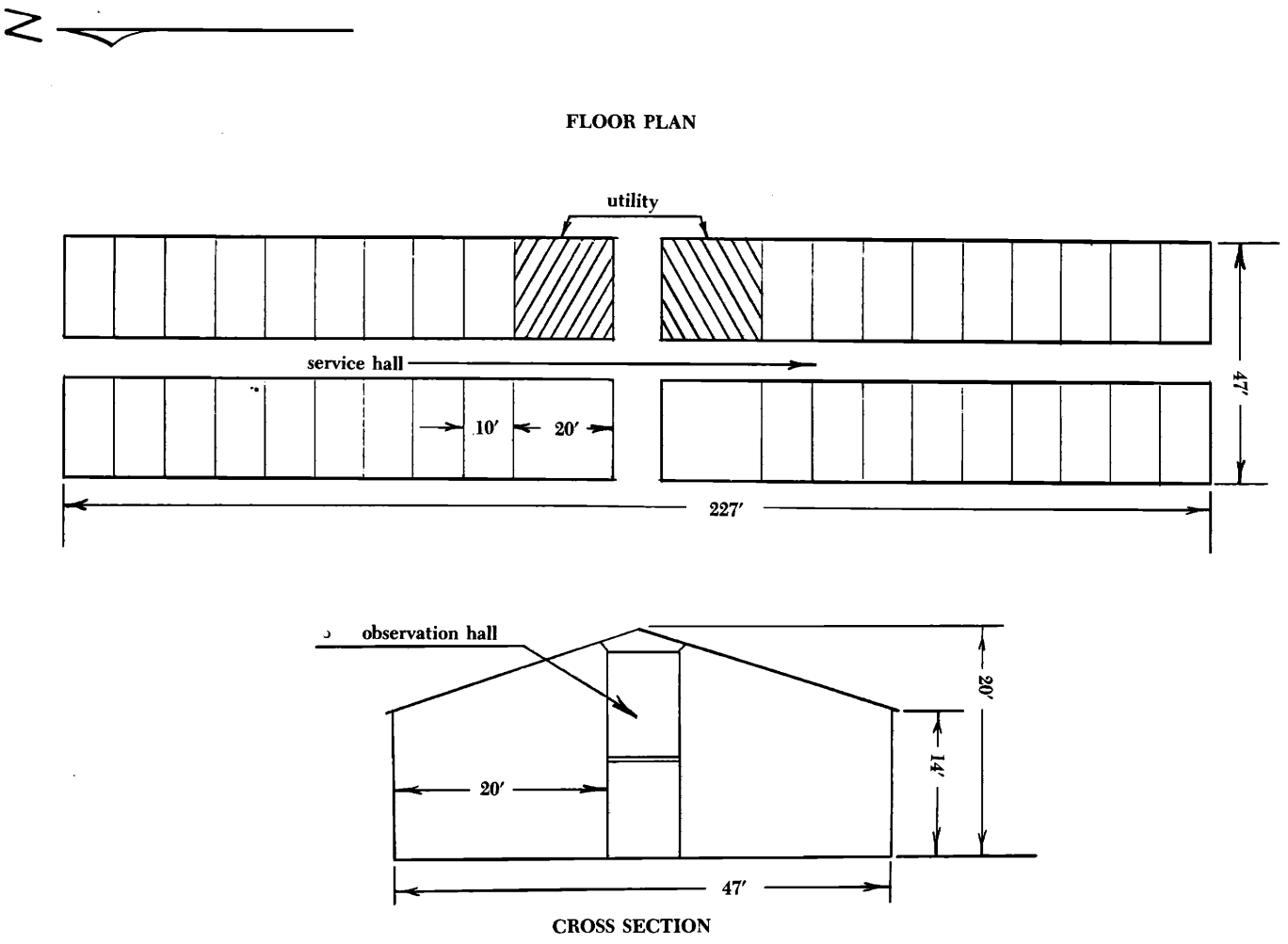

Figure 1. Floor plan and cross section of Cornell University facility.

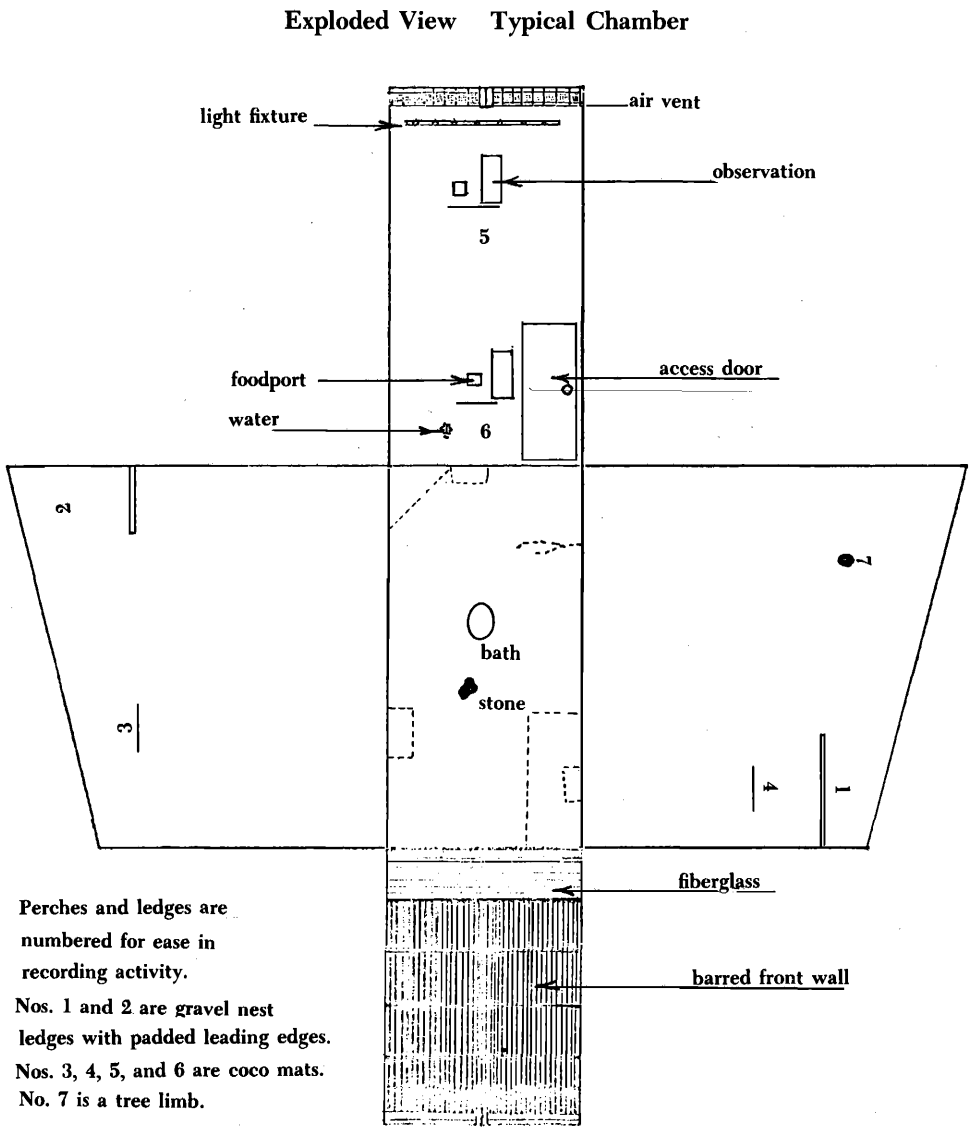

Figure 2. Exploded view of typical chamber.

starter. Carbon dioxide is used to kill these animals as they reach the desirable size. The quail and chickens are allowed to fast for 24 hours prior to killing, thereby eliminating the mess that results from the remains of engorged digestive tracts. No live prey is provided, and all food is given fresh or kept frozen until needed. To avoid confrontations over a single food item, pairs are given two or more pieces. During periods of courtship activity, smaller pieces are provided several times per day, sometimes through the upper foodports. This procedure serves to reinforce the pair bond by increasing the number of opportunities the male has to present food to his mate. Whole quail are particularly valuable for this purpose as they seem to be the preferred food and offer an opportunity for an almost ritualized plucking response by males prior to transfer to their females. Food objects for courtship-feeding should be small enough so that the male can easily pick them up in his beak and fly with them.

To avoid trouble with disease and insects, cached food items are not allowed to accumulate. A day with no feeding or a late feeding usually eliminates cached food. At Cornell someone enters the chambers regularly to exchange bath pans. Water is always available, except on the coldest days when it freezes. A large stone on the floor near the bath serves as a perch should a bird be too wet after bathing to regain one of the low wall perches. Perches and other furnishings are arranged in such a way as to keep birds off the floor as much as possible, since it is the area of greatest accumulation of droppings and food remains. Two concrete, block-sized stones are placed prominently on the nest ledges to provide wear on talons; these stones are often preferred perches.

All nest ledges can be observed through one-way glass. Being able to observe the falcons without disturbing them allows us to monitor their progress in the nesting cycle and to intervene if undesirable behavior develops.

The photoperiod for arctic Peregrines and Gyrfalcons is increased beginning February 1. The natural day length is increased by 30 minutes of incandescent light added at the beginning of the photoperiod every week until a total of 16 hours is reached about April 1. This photoperiod is maintained through the rest of the breeding cycle. In midsummer the breeders are returned to the natural photoperiod of the Ithaca region.

Selection of Breeding Stock

Peregrine Falcons removed from the wild before fledging are much more likely to breed in captivity than are falcons trapped after independence, although several cases have now been reported in which wild-caught postnestlings and adults have reproduced in confinement. The Peregrine Fund has held wild-caught Peregrines in breeding chambers for several years with no success, as have a number of other projects.

Falconer's birds removed from the nest and hand raised without other falcons may breed, but the risk of failure is great. Ideally, we feel birds intended for breeding stock should be fledged in small groups by adult falcons whether they are removed from wild eyries as downies or hatched in captivity. After fledging they should be housed in groups through their first molt. Such treatment prevents imprinting on humans and provides a more normal social development.

The most common cause of breeding failure in mature pairs is abnormal behavior by one or both birds. A bird can become sexually imprinted on humans because of close association with its keeper before fledging. Thus, it partially or completely fails to respond sexually to its mate when of breeding age. Imprinted females may lay

eggs, and imprinted males may produce sperm, but their sexual displays are addressed to people, and they often respond aggressively toward their conspecific chamber mates.

The ontogeny of breeding behavior is quite similar in pairs that are properly raised. Twelve-month-old Peregrines show only sporadic and incomplete courtship activity even when housed as pairs in breeding chambers. At the onset of their second spring, males begin scraping and attempt food transferring. Mutual activities such as food transferring and ledge displays are often incomplete because one or the other falcon responds improperly. It is interesting to note that two females laid eggs (infertile) when only 2 years old; both, however, were paired with 3-year-old males. Wrege and Cade (1977) described in detail the timing and expression of courtship behavior as it normally occurs in fully mature pairs in their third or fourth year.

Copulation usually ceases with the laying of the third egg, but food transferring continues. Females perform most of the incubation. When the eggs are removed after 7 days of incubation, the pair begins scraping almost immediately, but copulation does not occur for 7 to 10 days. The first egg is usually laid 14 days after the previous clutch has been removed, but in a few cases not until the 15th or 16th day.

Peregrines are indeterminate layers. Our females have laid 11 and 12 eggs when no more than 2 eggs were left in the nest. Of 33 undisturbed Peregrine clutches, 25 had 4 eggs, 3 had 5 eggs, and 3 had 3 eggs, for an average of 4.0 eggs per clutch.

Artificial Insemination

When normal mating does not occur in a pair, artificial insemination can often be used to achieve fertilization, particularly with birds that are in some degree sexually responsive to human beings and produce mature gametes. Fourteen female Peregrines and two Gyrfalcons have been artifically inseminated, and we have obtained semen with motile sperm from ten male Peregrines and two Gyrfalcons. All female falcons except one Gyrfalcon had to be forcibly inseminated.

We obtain semen by wrapping the hooded bird in a towel and placing him breast down on a pad of foam rubber, his feet being gently pulled back and down from his tail. One person holds his feet and a fire-polished 1-by-100-mm capillary tube. A second person strokes the bird along his back and sides from the rib cage to the cloaca. The middle fingers of the other hand stroke his abdomen from the keel to the cloaca just slightly ahead of the side and back stroke. After a few preliminary motions, a final stroke is made with increased pressure. The abdominal stroke is stopped at the pubic bones, but pressure is maintained while the side stroke continues to the cloaca where it terminates in a gentle squeeze causing any semen to be expelled. It appears as a drop of semiclear, viscous fluid and is collected by touching it with the end of the capillary tube. Additional stroking will produce more semen. We recommend that no more be taken than is needed if the male is to be used again in a day or so. The minimum safe volume for one insemination is 10 μ l. Microscopic examination of a sample from the last of a series of droplets will usually reveal an increased number of immature spermatazoa not capable of fertilizing the eggs. If a particular male is to be used daily, the sperm count, and not the quantity of semen, will be the main factor that determines his usefulness for artificial insemination. We generally try to obtain semen from a bird no more often than every other day, taking 30 to 50 μ l. Males have produced quite consistently over a 6-week period; however, we have also had males stop production after an initial handling. Other methods are also effective,

such as the one devised by Steve Baptiste of Reno, Nevada, in which the male is placed on his back. Bird et al. (1976) describe other methods used successfully on Kestrels.

We have used two techniques for insemination. Until 1976 females were simply held while the capillary tube was inserted a few mm into the cloaca and the semen forced out. Encouraged by the success of Boyd (1974) and Bird et al. (1976), we began everting the oviduct and placing the semen directly into it. This procedure entails some risk to the falcon and should be attempted only by those who have witnessed it and practiced it under the guidance of an experienced person.

To be safe, the female should have laid an egg no more than 12 hours before the attempt to evert the oviduct. Sooner after laying is better, as this timing insures she will not have an advanced egg that could be broken in the oviduct during handling. We generaly inseminate after each egg to fertilize the second egg to follow. The bird is hooded, wrapped in a towel, and placed on her breast. Her feet are pulled gently down and away from her body. To evert the oviduct, the thumb and two fingers of one hand partially roll back the lips of the cloaca while pressure is applied to the abdomen with the fingers of the other hand. This steady pressure is maintained throughout the insemination. It is this pressure on the viscera that causes the oviduct to protrude from the cloaca. It appears as a red-purple hemisphere with the opening being an off-center indentation to the bird's left side.

To inseminate, rubber tubing about 40 cm long is attached to the vacant end of the capillary tube containing the semen. The capillary tube is then carefully slipped into the entrance of the oviduct to a depth of no more than 15 mm. The oviduct walls are very delicate and can be punctured by rough treatment. After the glass tube is inserted, the semen is expelled by gently blowing (almost breathing) through the tubing. Blowing too hard causes the semen to flow back out of the oviduct and has the potential of damaging or infecting the oviduct.

As the tube is withdrawn, the pressure on the belly is released allowing the oviduct to return to its normal position. Inseminations are done in the chambers and require less than one minute. Eversion of the cloaca and oviduct increased our rate of successful artificial insemination from 27 percent to 73 percent (table 3). Again, other methods of insemination can be used—both forced and cooperative (Berry 1972, Temple 1972, Boyd 1974, Bird et al. 1976).

Artificial insemination is a common practice in the poultry industry, and a great deal can be gained from working with these people and becoming familiar with their literature. Valuable experience can be had from practicing with chickens, ducks, and even pigeons. The birds must be in breeding condition, and it should be remembered that an oviduct is easier tc evert if an egg has been laid recently.

Laying

The laying of eggs usually occurs about 2-4 weeks after the first copulation. The female enters a condition known as "egg-laying lethargy" (Olendorff 1968) about 5 days before the first egg. She spends more and more time in the scrape and appears to be ill. Her eyes are often half-closed; she dozes and appears to move with difficulty. Her cloaca and lower abdomen are swollen. When she excretes, she does so in a squatting, spread-legged posture. The excretion is voluminous, and the enlarged lips of her cloaca are conspicuous and rosy. This lethargic condition persists throughout egg-laying but in varying degrees. Eggs are generally laid at approximately 48-hour

Table 3. Relative success in fertilizing Peregrine Falcons by two methods of artificial insemination.

Semen Placement	Number of Females	Number of Eggs Laid	Number of Eggs Fertilized	Percent Fertilized
In oviduct	10	45	33	73
In cloaca	3*	22	6	27

*One female during two seasons and one female during one season.

intervals, but instances of a 72-hour interval are not unusual. Drops in ambient temperature may cause such delays.

Incubation

Full incubation begins with laying of the last egg, typically the fourth, but individual females may begin partial incubation with the second or third egg. Actual incubation differs from "standing over" or "laying on" the eggs. The erection of the feathers on the lower back and rump and vigorous settling and shuffling motions indicate that actual incubation is under way. With incubation both birds begin to exhibit total attentiveness to the eggs. At times prior to the completion of the clutch, activities at the scrape seem to endanger the existing eggs in that they may be kicked completely out of the scrape by overzealous scraping, usually by the male. The female will usually roll them back within a few hours.

We have had experience with 14 pairs of Peregrines, 1 pair of Lanners, 1 pair of Gyrfalcons, and 5 pairs of Prairie Falcons that exhibit normal brooding behavior. Such birds are allowed to incubate their eggs for 7 days after completion of the clutch. The eggs are then placed in an incubator. Seven days is an arbitrary compromise. Since we want the pairs to recycle, there is an advantage in removing the eggs as soon as possible, as the longer the pair incubates the less likely they are to recycle. On the other hand, it is important to give the eggs some natural incubation, since it is known that this experience increases the hatchability of wild birds' eggs that are artificially incubated. The eggs are placed in modified Marsh Farms Roll-X forced-air incubators. They are placed large end up in a chicken egg-sized grid and turned by hand at least eight times a day. Temperature is monitored with high quality mercury thermometers. Because temperature varies within the unit, the thermometer is placed very near the eggs. Humidity is monitored with a wet-bulb thermometer or hair hygrometer and modified by varying the amount of water present in the incubator. The eggs are weighed and candled every 5 days. The breeding results for all our falcons for the years 1973-76 are summarized in table 4.

Our program has produced 216 fertile Peregrine eggs in 4 years. Seventy-two percent (156) of them hatched. A four-egg clutch of *F.p. tundrius* eggs requires 32 days from the laying of the last egg to the hatching of the last chick. Thirty-five days are required for a clutch of *F.p. pealei* eggs to hatch. Usually three chicks hatch simultaneously and the fourth a day later. It is important to note that the number of days required for an egg to hatch in an incubator is a function of temperature and humidity. An experiment conducted by Card and Nesheim (1973) involved three machines operating at the same dry bulb temperature (99° F) but with different humidities. Wet bulb temperatures in the machines were 75°, 85°, and 90° F, respectively. These correspond to 35, 56, and 70 percent relative humidity. A spread of 48 hours

existed in hatching time between the first and third machines. When the temperature in the low-humidity machine was adjusted to 100° F, and that in the high-humidity machine adjusted to 98° F, all three machines hatched chicks in the normal 21-day period for chickens. The number of days required to hatch can be critical, as the degree of yolk-sac absorption may be affected, and unretracted yolk-sacs may occur at hatching; however, many other factors can also cause unretracted yolk-sacs.

Table 5 presents the conditions we consider optimum for artificial incubation of eggs after 6-7 days of natural incubation. Under these conditions 85 percent of the eggs (52 of 61) incubated hatched; however, individual eggs respond differently. The crucial determinant of the embryo's environment for successful hatching is the amount of water loss. Depending on their size, Peregrine eggs must lose 0.7 to 0.9 grams per 5 days of artificial incubation. The relative humidity can be modified within limits to increase or decrease weight loss after each weighing, when it has been determined that an egg is losing too much or too little moisture.

We calculated weight loss from laying to hatch for 63 eggs of various species and subspecies of large falcons (table 6). The average of 16 percent approximates the 18 percent predicted by Rahn and Ar (1974). Though data are limited, severe decreases in hatchability occur when weight losses are lower than 14 percent and higher than 20 percent. When figuring weight loss per day, the 2-day loss from pip to hatch must be considered separately since it will be more than twice the prepip losses. The figures (table 6) are presented only as a guide and may not prove optimal for all eggs under all conditions; but all these eggs produced viable chicks.

Table 4. Summary of breeding performance by falcons in the Peregrine Fund projects.

	No. Laying Females				No. Fertile Females				Total Eggs Laid				No. Eggs Fertile				No. Eggs Hatched				No. Young Raised			
Species	'73	'74	'75	'76	'73	'74	'75	'76	'73	'74	'75	'76	'73	'74	'75	'76	'73	'74	'75	'76	'73	'74	'75	'76
Peregrine	4	6	11	25*	3	5	8	21	41	59	109	191	26	34	44	112	22	24	27	83	20	23	25	69
Gyrfalcon	1	2	2	3	0	1	1	3	7	14	14	24	0	6	8	13+	0	3	6	13	0	2	3	13
Lanner Falcon	2	1	1	1	2	1	1	1	12	11	8	10	9	10	8	10	6	8	6	8	6	7	6	8
Prairie Falcon	5	5	7	1	2	5	7	1	27	38	47	5	14	35	38	5	7	30	34	3	7	29	30	2

*Includes one successful pair at Bob Berry's facility.
+Includes four hybridized eggs.

Table 5. Most successful conditions for artificial incubation of eggs after six to seven days of natural incubation.

Species	Temperature Degrees Fahrenheit	% Relative Humidity[1]
Falco peregrinus tundrius	98.5–99.2	40–45
Falco peregrinus pealei	98.5–99.2	45–50
Falco peregrinus anatum		
(New York)	98.5–99.2	35–40[2]
(Colorado)	98.2–98.9	25–30
Falco peregrinus brookei	98.5–99.2	35–40[2]
Falco mexicanus		
(New York)	98.5–99.2	35–40
(Colorado)	98.2–98.9	25–30
Falco rusticolus	98.5–99.2	15

[1]Relative humidities must be manipulated to insure proper water loss from the egg.
[2]These humidities have not been properly tested; there is evidence that they are too high.

Table 6. Weight loss percentages for falcon eggs.[1]

Species Subspecies	Percent of Fresh Weight[2]	Number of eggs
Falco peregrinus pealei	15	4
Falco peregrinus tundrius	16	4
Falco peregrinus brookei	16	3
Falco peregrinus anatum	16	2
Falco mexicanus	18	42[3]
Falco biarmicus	15	4
Falco rusticolus	16	4

[1]Selected representative figures for successfully hatched clutches.
[2]Loss from day 1 to hatching.
[3]Burnham and Heinrich (1976).

The relative humidities listed in table 5 produce the desired weight loss for successful hatching. It is interesting that the *pealei* subspecies requires a higher humidity than other North American Peregrines. It is a race native to the humid coasts of British Columbia and Alaska. We examined Peregrine eggshells using a scanning electron microscope (A. Schwartz et al., unpublished manuscript). The shells of *F.p. pealei* have larger pores than those of *F.p. anatum*. Wild Gyrfalcons, on the other hand, incubate at low relative humidities because the ambient temperatures are between +5° and –40° C (Platt 1976). It will be most interesting to see how the shells of Gyrfalcons and Prairie Falcons compare with those of Peregrines.

At Cornell University three fertile *F.p. anatum* eggs were incubated full term by their parents. Only one egg hatched, and the chick from it was abnormal. The two dead full-term embryos were edematous; perhaps the high (above 50 percent) relative humidity of the Ithaca region was too great. The adults are from New Mexico.

Artificial Incubation of Eggs from Day 1

Pairs not exhibiting normal nest attentiveness and females whose clutches we wish to extend have their eggs removed as they are laid. Artificial incubation at 98.5 to 99.2° F from the day of laying has proved to be less successful than if some natural incubation has taken place. We have tried several techniques to improve our success.

Two fertile eggs were removed from a highly successful pair on the day they were laid and placed in a 90° F incubator. The temperature was increased 1° F per day until 98.8° was reached. The embryos ceased development early in their incubation.

Foster parents successfully provided the start with natural incubation needed to hatch eggs removed from their parents at day 1. Either all fertile eggs placed under a setting Lanner or Prairie Falcon hatched in our incubators, or their failure was attributable to some factor other than their early incubation under a bird.

In 1976 we removed 46 eggs from females that had been artificially inseminated and were unwilling to incubate. To start such a large number of eggs we used Silkie Chickens. Falcons' eggs were stored at 5° C until a clutch could be formed or were placed under a hen a few hours after being laid. Of the fertile eggs started by Silkies, 84 percent hatched (7 out of 10 Peregrine, 6 out of 6 Gyrfalcon, 4 out of 5 Lanner, and 3 out of 3 hybrid eggs).

For chickens, whether they are Silkies, Cochens, or another breed, to provide the greatest benefit, they must be conditioned properly to the point of being completely

tame so that they may be handled easily. To accomplish this end they are handled and fed special handouts each day at a particular time. They will come to look forward to this routine, and this reward is important if they are to be trusted with special duties. They may then be picked up from nests without struggling and possibly breaking eggs.

Broodiness can be brought on by an increase in photoperiod, provision of nesting sites and materials, and the presence of a rooster. Once a hen becomes broody over her own eggs, she is placed on a similar nest of crushed sugar cane litter, which contains the falcon eggs. When hens are incubating, other birds should be excluded. We lock the hen in a nest box with her clutch of eggs. Each day at the appointed time we remove the hen to let her eat, drink, and defecate. We place her back on the eggs about 20 minutes later.

In 1973 and 1974 all incubating eggs were cooled to room temperature twice daily for 10 minutes. No benefit (or harm) could be attributed to the practice, so it was stopped as production increased.

Hatching

About 48 hours before the chick first pips the shell, the air cell within the egg begins to expand and may extend halfway down one side of the egg. This change is necessary to provide the chick with room to turn inside the shell; it also indicates that proper water loss has occurred during incubation. Chicks that have not lost sufficient moisture prior to this time are edematous; their larger size and lack of muscle tone prevents a successful hatch even though they may be able to pip the shell. When an egg has pipped (developed a small bump and tiny crack in the shell), it is placed in a still-air hatcher with a slightly lower temperature (98° to 98.5° F) and a much higher relative humidity, up to 80 percent. The eggs are placed on their sides with the pips uppermost. Normally the chicks are left alone to complete the hatching process. If water loss has been adequate prior to pip, and if the membranes are not allowed to dry out after pipping, hatching occurs about 55 hours after pipping (range 24 to 78 hours).

We monitor the chick's condition by noting its movements at the opening in the shell and by listening to its vocalizations. Assisting the chick out of the egg is done only as a last resort. The membranes surrounding the chick contain blood vessels which must be shut down before hatching. Premature rupture of these vessels by "helping" is fatal. The eggs may be misted with water to retard desiccation of the membranes during the last half of hatching. Dry membranes become leathery and retard hatching. The drying of membranes generally results from opening the hatcher too often to check progress.

The approximately fifty hours necessary for a successful hatch are spent largely in periods of inactivity. After pipping, the chick "breaks up" an area 10 to 20 mm in diameter around the pip. The chick, turning within, begins to cut the egg open by scoring the shell. The time required to complete the turn varies from 20 minutes to several hours.

An unretracted yolk-sac is the most frequent problem we have encountered with hatching chicks. It is possible to reduce partially unretracted yolk-sacs, up to 20 mm in diameter, by gently forcing the yolk into the body cavity with lubricated fingers. If this fails, the protruding sac must be ligated and removed. Using surgical gut, one can ligate the sac at the sphincter and cut it off 2 mm below the knot. The chick

will need special feeding, smaller amounts more frequently, as well as a vitamin and mineral supplement to substitute for the loss of the yolk, necessary for early growth and bone development. The prognosis is generally good, but the real task is to discover which of the various incubation conditions was responsible for the problem.

Three chicks were malformed at hatching. Two sibling Prairie Falcons had abnormal muscle control. Even when 14 days old they were not able to lift their heads or sit up. Bone and feather development appeared normal, and their brood mates were normal. A possible cause was that they were produced by a brother-sister pair, which itself was produced by a brother-sister pair. A single Peregrine was hatched with slightly malformed feet and beak. He was the only chick to hatch from three fertile eggs incubated by their parents during a period of very high ambient humidity. Although he developed normally, he was abnormally active. His nest mates killed him at 20 days of age.

Of the 156 Peregrines hatched, five died exhibiting symptoms of rickets. It should be noted that four of these five hatched with unretracted yolk sacs. The removal of the yolk sac may have reduced the calcium phosphate available to the chick or the vitamins required for calcium mobilization into bone.

Posthatching

Hatched chicks receive an antibiotic salve on the umbilicus and are placed back in the hatcher for up to 1 day. Two to four chicks of the same age are then placed in a 40-mm-deep disposable aluminum pan containing 30 mm of San-i-cel, a sanitary litter made from ground corn cobs. Wood shavings or sawdust can be more easily eaten by eyasses and should not be used as nest material. The pans are placed in brooders. Temperature is regulated by an ether wafer thermostat and heat coil. For the first few days the temperature is kept at 95° F, but afterward it is reduced 1° F per day until the chicks begin to thermoregulate at room temperature. The behavior of the chicks provides clues to help determine the correct temperature. They huddle, shivering and cheeping, when cold and lie apart from one another with wings and legs outstretched when too warm. They are comfortable when they quietly sleep while touching one another.

The first food is provided 12 to 18 hours after hatching. A gaping response can be elicited by the handler's giving an imitation of the "chup" call of the adult as he presents a tiny shred of meat on blunted forceps. The young are fed freshly killed and ground whole Coturnix Quail with the skin, digestive tracts, and feet removed. Quail are killed without loss of blood, which acts as a moisturizer for the ground mass. The task of feeding a number of older young is made easy through the use of disposable plastic bags. A bag is filled with ground food, the corner is snipped off, and then it is used much like a cake decorator, by squeezing out bite-size portions into the chick's gape. Each bird can be given its allotment in a few seconds. Ground 5-week-old chickens are gradually worked into the diet as the young reach 10 days of age. No casting or vitamin supplement has been given in the past, but we will begin using Vionate (Squibb) in small amounts during our 1977 season. The chicks are fed small meals every 2 to 4 hours for the first few days. As soon as food can be seen building up in the crop, the meal is over. Excess food may spoil in the digestive tract and result in poisoning, a very real possibility. As the young grow, crop capacity increases; hence, meals become larger and less frequent. Feedings are given only on empty crops.

Return of Young to Parents

Young are introduced to adult Peregrines when they are 15 to 20 days old. We return young only to adults that are sitting on eggs or feeding young. If adults have never fed young, we test their reaction with a Lanner or Prairie Falcon chick. The chicks have no problems relating to adults. Some adults will not accept young and may attempt to kill or remove them from the scrape. The sudden arrival of the adults on the nest ledges causes the older young to hiss and exhibit a defensive attitude, but this condition rarely extends into the second day. Reaction of the young to the "chup" call of the female adult is immediate. Pairs that will care for one or two young can be given as many as six at a time with no problem. One female Prairie Falcon successfully fed and fledged eight young. Pairs have been given new broods of downy young as older broods are removed.

No aggression between adults and their fledged young has been seen even when the young are left with adults for several months. Usually, however, young are placed in large rooms (double chambers) containing Peregrines of similar ages a few weeks after fledging. Some birds are left in these large chambers until after their first molt. Such groups of falcons must be watched, especially after one year of age, to make sure aggression does not become too severe.

Discussion and Conclusion

Much progress has been made in the *domestic breeding* of falcons since 1970 (see Jack 1977 for terminology). Whereas at that time only kestrels had been produced in large numbers, now impressive numbers of Peregrines, Prairie Falcons, Lanners, and Gyrfalcons are being raised each year, and it is only a matter of time before the Saker and some other species are included among those that reproduce regularly under domestic husbandry. As we noted earlier, it is likely, in fact, that all species of the genus *Falco* can be induced to breed in captivity, once the right set of conditions has been determined for each case.

The major technical hurdles have been surmounted, at least sufficiently so that utilizable numbers of some species—Peregrine, Prairie Falcon, Gyrfalcon, and Lanner—have become available. Reproduction by members of F_1 and F_2 generations has occurred for several years among domestically propagated kestrels and, recently, reproduction by F_1 individuals among Peregrines, Prairie Falcons, and Lanners. It appears probable that self-sustaining domestic populations are realizable, barring unforeseen problems in reproduction by subsequent generations of progeny.

This prediction means that endangered forms (gene pools) can be perpetuated indefinitely by domestic breeding and husbandry. Rare species such as the Mauritius Kestrel (*Falco punctatus*), Teita Falcon (*Falco fasciinucha*), Orange-breasted Falcon (*Falco deiroleucus*), and Kleinschmidt's Falcon (*Falco kreyenborgi*) immediately come to mind. With the proven techniques we now have for propagating birds of prey in captivity, there is no reason why any species has to become extinct, although some may eventually no longer be able to survive as wild populations. There is no reason why any species should become so rare that reasonable use of individuals for falconry, scientific study, or other legitimate purposes cannot be justified.

At the Conference on Raptor Conservation Techniques, convened by the Raptor Research Foundation in 1973, Cade (1974) outlined three basic reasons why a number of people have become involved in attempts to breed Peregrines and other raptors in

captivity. The first concerns our human nature to respond to challenging circumstances and to try to succeed in an undertaking that most people consider impossible to accomplish. Thus, from the standpoint of personal motivation, the breeding project "becomes an exciting intellectual and technological game—a true form of recreation and competitive sport—in which science and craft become inextricably bound together."

Today, stretching across the North American continent and, indeed, over much of the world, there is a network of private and institutional breeding projects that will insure continuing progress in the domestic propagation of raptors and the husbandry of sufficient numbers of birds so that all interests in the Peregrine and in other falcons can be satisfied. Thanks in no small degree to the early leadership and focus of the Raptor Research Foundation, there has been, and continues to be, close communication and cooperation among the private breeders and institutional programs. We believe that this is the main reason why the breeding of falcons in captivity has made such rapid progress.

Kenward (1977) has recently tabulated world figures to show that, as of 1975, the private breeders—mostly falconers—have raised half of all the Falconiformes produced in captivity. We cannot emphasize too much the importance of dedicated and qualified private breeders as continuing sources of new information and techniques and as husbanders of the reserve breeding stock from which future generations of birds will come. The Peregrine Fund currently enjoys close working relations with eight private breeding projects in the United States and with one overseas, as well as with the CWS program in Canada, and we have always tried to make our information fully and freely available to all.

With the level of friendly competition and enthusiasm running high among breeders, the remaining problems in domestic propagation of the large falcons should be quickly resolved. The principal ones still are (1) incompatibility between some mates and their failure to copulate, even though full gonadal development may occur, and (2) artificial incubation and hatching of eggs. If all eggs laid by falcons in our program had been fertile in 1976, and if 80 percent of them had hatched (a reasonable expectation), we would have produced 184 chicks instead of 107. There are still plenty of challenges to test a breeder's ingenuity and knowledge.

A second reason why the domestic breeding of birds of prey has become popular and successful is that most of the people involved are falconers, who have a single-minded, even fanatical, devotion to raptors and 3,000 years of evolved technology at their command for handling and caring for them in confinement (Nye 1976). Many North American and European falconers had realized by 1970 that the future of their sport would depend upon developing methods for captive propagation and the eventual use of domestic birds for hunting—particularly in the case of the Peregrine and the other large falcons, for which so much concern has been expressed by conservationists. All the early successes in breeding large falcons in captivity were accomplished by falconers (see table 1), and institutional programs have relied heavily on the techniques of falconry and on personnel trained as falconers to produce the large numbers of Peregrines required for restocking programs.

Now falconers are beginning to enjoy the fruits of their early vision and labors, as a fair number of domestically propagated hawks and falcons are being flown in the field. In North America these birds include several Prairie Falcons, Gyrfalcons, Lanners, Peale's Peregrines, Goshawks, Harris' Hawks, and one Golden Eagle; in Europe,

several Peregrines, Gyrfalcons, Lanners, and Merlins. Initial reports (Adamson 1974, Shor 1975, Cade in press, L. Hurrell pers. comm.) indicate that these domestically bred hunters acquit themselves at least as well as wild-taken eyasses, and we agree with Smylie and Bond (1975) that a new era in falconry has emerged as a result of domestic breeding. American and European falconers have already embraced domestic breeding as their salvation insofar as continued use of large falcons is concerned. We believe this view will have to be accepted by falconers worldwide before long. In fact, it is already a matter of considerable pride with some falconers that they do not take falcons from the wild any more in order to practice their sport.

The third reason for domestic breeding is to produce a supply of Peregrine Falcons that can be used to restock natural areas where the species has disappeared or been greatly reduced as a breeding bird. Our level of production in the Peregrine Fund's projects has been high enough to allow us to begin some experimental releases of domestically produced Peregrines in 1974, 1975, and 1976, both in the East and in the West. We have now released a total of 62 young Peregrines into nature, 7 by fostering to wild parent Peregrines in Colorado and 55 by hacking at 10 sites in seven eastern states. The Canadian Wildlife Service's project under Richard Fyfe (1976) has put out a similar number, so that the total North American effort will soon assume the proportions of an operational program.

Cade and Temple (1977) have tried to estimate the number of birds and the amount of time that will be required to approximate the pre-DDT population of Peregrines in the eastern United States, on the basis of a yearly introduction of 250 young and assuming a mortality of 66.6 percent the first year and 20 percent yearly thereafter, an average production of 2 young per successful nesting, 50 percent of all pairs successful each year, and a breeding age of 3 years. The first wild-produced breeders would appear in the population in the 7th year, and by the breeding season of the 15th year, after 4,000 young Peregrines had been released, there would be a breeding-age population of 292 pairs and a total population of more than 1,100 individuals. Obviously, restoration to that extent will not be an easily or quickly accomplished goal, but as Newton (1976) points out in his encouraging editorial, while the ultimate success of domestic breeding programs for conservation occurs only when the released birds themselves reproduce in the wild, such projects should in fairness be judged stage by stage. The first two stages (see Cade 1974b) have been accomplished—domestic production of young and their establishment in nature. The third remains to be achieved.

We can now project fairly accurately how many young Peregrines can be raised by the Peregrine Fund's projects over the next 5 years, the period in which we expect to learn whether the third stage is achievable (table 7). We have estimated these figures on the basis of our experience in breeding Peregrines during the past 4 years and on the basis of the number of falcons we are now holding and will be holding that can be expected to reach breeding age in the next 5 years, adding them to our current breeding stock. The values shown in table 7 also assume an annual average production of 9 eggs per female, 60 percent fertility, 70 percent hatchability, and 95 percent success in raising hatchlings, based on our averaged results since 1973. Obviously, if we can increase fertility, for example, or hatchability, then our annual production will go up at a higher rate. Conversely, if these variables decrease as larger numbers of birds, eggs, and young are handled, production will rise less rapidly. We believe our estimate lies on the conservative side of reality; but in any case

production of sufficient numbers of domestically raised falcons will *not* be the limiting factor on the reestablishment of the Peregrine in the United States, so long as the funds to carry on with mass breeding continue to be forthcoming.

Table 7. Estimated production of Peregrine Falcons for the next five years.

Year	No. Breeding Age Females	No. Laying Females	No. Eggs Laid	No. Eggs Fertile	No. Eggs Hatched	No. Young Raised
A. Actual results in past years						
1973	5	4	41	26	22	20
1974	7	6	59	34	24	23
1975	12	11	109	44	27	26
1976	28	25	191	112	83	69
B. Projected figures for next five years						
1977	40	35	315	186	126	120
1978	49	43	387	228	155	147
1979	52	47	416	246	168	160
1980	66	60	540	324	224	213
1981	75	70	630	378	260	247

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PRELIMINARY ANNOUNCEMENT—1978 ANNUAL MEETING OF THE RAPTOR RESEARCH FOUNDATION. The Board of Directors have accepted an offer from Pennsylvania Raptor Rescue to host the 1978 meetings in Allentown, Pa. Co-hosts will include Hawk Mountain Sanctuary and perhaps other local organizations. Pre-meeting activities will begin Friday, November 3, and the conference will culminate with a trip to Hawk Mountain on Monday the 6th. Headquarters will be the Americus Hotel in Allentown, where special rates will be available; all meetings will be held in the Hotel. Local Chairperson is Mrs. W. B. (Hope) Carpenter, R.D. 1, Box 150A, Mt. Bethel, PA 18343. Further details will be circulated early in 1978.

ADVERTISEMENTS

At the 1977 annual meeting, November 11-14 it was announced that paid advertisements would be accepted for publication in *Raptor Research.* Such material will ordinarily be printed at prevailing page costs. Send all such material to the Editor.