

DEMOGRAPHY, HABITAT USE AND MOVEMENTS
OF A RECENTLY REINTRODUCED ISLAND POPULATION
OF EVERMANN'S ROCK PTARMIGAN

by

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Abstract

Translocations are a useful management tool for restoring wildlife species to their native ranges, but require post-release monitoring to determine project success. We report results of a 4-year effort to reestablish a breeding population of Evermann's Rock Ptarmigan (*Lagopus mutus evermanni*) on Agattu Island in the Aleutian Archipelago, Alaska. This endemic subspecies of ptarmigan was extirpated from most of the Near Islands by introductions of arctic fox by fur traders, and natural recolonizations did not occur after fox eradication. All females surviving the 2-week post-release period attempted to nest but initiated clutches later in the season and laid fewer eggs than resident females. Nest success was similar for resident and translocated females. Brood survival was greater for translocated than resident females and differed significantly; however, brood survival varied among years and was reduced by adverse weather conditions in 2006. Seasonal survival of radio-marked birds during the breeding season was 100% for translocated and resident ptarmigan. Over-winter mortality resulted in a low return rate in 2006. Returning birds in 2006 showed strong site fidelity and nest locations in two consecutive years were closely spaced.

We examined nest site selection and determined brood movements and home range size of recently translocated and resident females. Nest sites of translocated females averaged 4.2 km from their respective release location and were not different from nest locations of resident females with regard to topographical features. Female nest site selection was influenced by percent composition of rock and forb coverage but was unaffected by slope, aspect, or general habitat. Broods of both resident and translocated females made movements to higher elevations after hatching. While size of brood home

range was similar for resident and translocated females, distances traveled between the nest site and the arithmetic center of the brood home range were greater for translocated females. Overall, we conclude that translocations are an effective technique for reestablishing island populations of Rock Ptarmigan. Our study provides successful methods which may benefit future projects to reestablish endemic populations of ptarmigan and landbirds elsewhere in the Aleutian Islands.

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CHAPTER 1 - INTRODUCTION

With an increasing rate of species extinction (Wilson 1988, Ricklefs 1996) and the continued loss of overall biological diversity, restoration ecology has become an important discipline in the field of conservation biology. A growing number of wildlife and land managers are using translocations as a tool for restoring plants and animals to their native ranges (Falk et al. 1996, Snyder et al. 1999, Nelson et al. 2001, Bar-David et al. 2005). However, post-release studies and performance evaluations of reintroduced populations remain scarce and standardized criteria for assessing success not available (Scott and Carpenter 1987, Griffith et al. 1989). Post-release monitoring studies are critical for improving release methods, determining the viability and status of the reintroduced population, and developing future objectives and goals.

Today, a growing number of projects include baseline data and post-release monitoring. Less often, but with increasing frequency, projects are beginning to incorporate research objectives with management goals. In particular, researchers from New Zealand and Australia are pioneering the field of reintroduction biology (Serena 1995, Hooson and Jamieson 2004, Blackburn and Cassey 2004). The large number of introduced mammals on many New Zealand islands has pushed several native species toward the brink of extinction. Recognizing the importance and anticipating the need for future reintroductions, biologists and managers began to maximize their opportunities to provide insight into factors that governed the success or failure of the reintroductions. Once much of the information from release projects went unpublished or only documented in the grey-literature, but recently there has been an increase in the number of newsletters, publications, and conferences focused on reintroductions. These results are a testimony to the determination of researchers and managers to investigate the dynamics of translocations and improve their utility as a conservation tool.

The vulnerability of island fauna and the simple nature of many island ecosystems compared to mainland counterparts make islands well suited for the study of life history strategies, particularly during the early stages of recolonization by a wildlife species reintroduced to its historic range. These types of studies can generate models which may

be applied to more dynamic mainland ecosystems, which in turn will refine the reintroduction process.

A restoration program initiated in the Aleutian Islands by the U.S. Fish and Wildlife Service (USFWS) provided an opportunity to examine factors governing the outcome of a reintroduction project by intensively monitoring movements and habitat use while also meeting a conservation objective. Using wild birds from Attu Island, located in the western end of the Aleutian Archipelago, the goals of my thesis were to restore a unique subspecies of Rock Ptarmigan (*Lagopus mutus evermanni*) to a portion of its historic range while identifying successful methods that might be applied to the restoration of other island subspecies in the Aleutians.

This thesis is organized into two core chapters. In Chapter 2, I examine the effects of translocation on reproductive success and seasonal survival by comparing demographic parameters of recently translocated to resident female ptarmigan. In Chapter 3, I assess post-release movement, nest site selection and brood movements to determine whether site fidelity and brood home range vary between translocated and resident females. Chapter 4 is a synthesis of the major conclusions from my studies.

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CHAPTER 2 - DEMOGRAPHIC MEASURES OF TRANSLOCATION SUCCESS: REINTRODUCTION OF AN ISLAND POPULATION OF EVERMANN'S ROCK PTARMIGAN

Robb S.A. Kaler and Brett K. Sandercock

ABSTRACT

Translocations are a useful management tool for restoring wildlife species to their native ranges, but require post-release monitoring to determine project success. We report results of a 4-year effort to re-establish a breeding population of Evermann's Rock Ptarmigan (*Lagopus mutus evermanni*) on Agattu Island in the Aleutian Archipelago. This endemic subspecies was extirpated from most of the Near Islands by introductions of arctic fox by fur traders, and natural recolonizations did not occur after fox eradication. We translocated 75 ptarmigan from Attu to Agattu over 2003-2006, and monitored 35 radio-marked birds (15 resident and 20 translocated) in 2005-2006. Our two-year radio-telemetry study found that 15% of translocated female ptarmigan died during the 2-week acclimation period after release. All surviving transplanted females attempted to nest but initiated clutches later in the season (mean = 12.6 days) and laid fewer eggs than resident females ($P = 0.001$). Nest success was similar for resident (80%, $n = 18$) and translocated females (72%, $n = 10$; $P = 0.64$). An estimated 40% of resident females that were unsuccessful in their first nesting attempts initiated a second nest. Brood survival was greater ($P = 0.001$) for translocated (88%, $n = 8$) than resident females (31%, $n = 13$); however, brood survival varied among years and was reduced by adverse weather conditions in 2006. Seasonal survival of radio-marked birds during the breeding season was 100% for translocated and resident ptarmigan. Over-winter mortality resulted in a low (38%) return rate in 2006. Returning birds from 2005 to 2006 showed strong site fidelity, and nest locations in two consecutive years were an average distance of 123 m (n

= 5) apart. We conclude that translocations are an effective technique for reestablishing island populations of Rock Ptarmigan. Our results are encouraging for re-establishment of endemic populations of ptarmigan and landbirds elsewhere in the Aleutian Islands.

INTRODUCTION

Reintroduction is a fundamental conservation tool for enhancing and restoring plants and animals to their native ranges (Scott and Carpenter 1987, Griffith et al. 1989, IUCN 1998). However, limited funds often have resulted in a majority of resources being allocated to reintroduction efforts, leaving post-release studies and project evaluations to be conducted opportunistically. Post-release monitoring allows researchers to assess the status and viability of reintroduced populations, and to develop evaluation criteria useful for future reintroductions. Data collected from well-monitored projects, combined with demographic modeling, can provide future direction by identifying factors which influence the success or failure of a reintroduction project (Griffith et al. 1989, Wolf et al. 1996, Sarrazin and Barbault 1996). Furthermore, evaluation of release programs aids in the prudent application of scarce resources and reduces the number of translocation attempts which must begin anew.

Translocations have been widely used as a management tool for gamebird populations in North America (Woolf et al. 1984, Hoffman et al. 1992, Musil et al. 1993, Coates et al. 2006). For example, translocations were used to establish a new breeding population of White-tailed Ptarmigan (*Lagopus leucurus*) in the Sierra Nevada of California (Clarke and Johnson 1990) and the Uinta Mountains of Utah (Braun et al. 1978). Declining numbers and ranges of prairie grouse (*Tympanuchus* spp.) and Sage Grouse (*Centrocercus urophasianus*) in North America have prompted translocation efforts to bolster existing populations (Toepfer et al. 1990, Hoffman et al. 1992, Musil et al. 1993, Reese and Connelly 1997).

Translocations have also been used to reintroduce island bird species of conservation concern while also exploring the effects of life history traits on reintroduction program outcome. In New Zealand, reintroduction programs on many islands have restored several native bird populations following the removal of introduced

mammals or initiation of vegetative restoration projects. For example, vulnerable island populations such as the New Zealand Robin (*Petroica australis*), Stitchbird (Hihi; *Notiomystis cincta*), and Saddleback (*Philesturnus carunculatus*) have been restored or augmented while also testing effects of food supply, breeding strategies, and release methods (Serena 1995, Armstrong et al. 2002, Hooson and Jamieson 2004). Furthermore, the simple nature of many island ecosystems compared to their dynamic mainland counterparts make islands particularly well suited for translocation studies because results can be more appropriately extrapolated to more complex systems.

On going restoration programs in the Aleutian Archipelago, Alaska, provided an opportunity to examine factors governing the outcome of an island translocation program while examining potential influences of life history strategies on the demography of an island ptarmigan population. Historically, the Aleutian Islands had no native terrestrial mammals west of Umnak Island (Murie 1937; 1959). Many island populations of native birds were dramatically impacted by the deliberate introduction of Arctic (*Alopex lagopus*) and red foxes (*Vulpes vulpes*) by Russian fur farmers during the 18th and 19th centuries (Bailey 1993, Williams et al. 2003). Depredation of eggs, young and breeding birds by foxes led to population declines and local extirpation of populations of seabirds, waterfowl, and terrestrial birds on many islands. In 1968, the US Fish and Wildlife Service (USFWS) began removing foxes from Agattu and by the late 1970's foxes were eradicated (Bailey 1993, Ebbert and Byrd 2002).

Rock Ptarmigan (*Lagopus mutus*) are an arctic-breeding bird with a Nearctic distribution (Holder et al. 2004). Within the Aleutian Archipelago, the species exhibits considerable phenotypic differentiation with a range of plumage coloration. Seven subspecies have been described from the Aleutians, each confined to groups of one or more islands (Holder et al. 2000). With regard to male nuptial plumage, five subspecies have pale plumage, four subspecies have dark plumage, and only one subspecies has black plumage: Evermann's Rock Ptarmigan (*L. m. evermanni*). Genetic analyses based on mitochondrial DNA have shown that Evermann's Rock Ptarmigan are markedly different from all other Aleutian Rock Ptarmigan, but their origin is unclear (Holder et al. 2000). Evermann's Rock Ptarmigan once occurred throughout the Near Island group in the western range of the Aleutians (Attu, Agattu, Shemya, Nizki and Alaid). Prior to the

translocation to Agattu described here, this subspecies was confined to Attu, the largest island in the group, with an estimated population size of about 1,000 birds (Ebbert and Byrd 2002). Due to its reduced population size and geographic range, Evermann's Rock Ptarmigan has been designated as 'a species of special management concern' by the USFWS.

Although nomadic elsewhere in Alaska, Rock Ptarmigan in the Aleutian Islands are sedentary. Despite Agattu being fox-free for 30 years, birds never successfully established on Agattu Island which is 28 km south east of Attu. In 2003, after conducting comprehensive pre-release surveys, the Alaska Maritime National Wildlife Refuge initiated a four-year translocation program to reintroduce ptarmigan from Attu to Agattu (Appendix A). In addition to re-enforcement releases, the latter two years of the project included a radio telemetry study to quantify post-release survival, seasonal survival of females, and reproductive success of resident and recently translocated Evermann's Rock Ptarmigan on Agattu Island. Our study objectives were two-fold: (1) to determine the effects of translocation on reproduction by comparing nest initiation dates, clutch sizes, egg hatchability, and hatch dates between resident and translocated ptarmigan on Agattu; and (2) compare daily survival rates (DSR) of nests and broods between resident and translocated females. Our primary goal was to identify successful methods that might be applied to the restoration of other island subspecies in the Aleutians. This research is the first comprehensive study of the effects of translocation and reintroduction on the reproductive success and post-release survival of an island ptarmigan.

METHODS

Study Area.--- Five translocations were conducted to reestablish Evermann's Rock Ptarmigan on Agattu Island: four during late-May 2003-2006 and one during September 2003. We conducted post-release monitoring of translocated ptarmigan during two field seasons from May to August 2005 and 2006, on Agattu Island (52.43° N, 173.60° W). Agattu is part of the Near Islands group found farthest west in the Aleutian Archipelago (Fig. 2.1) and has an area of 22,474 ha. Most of Agattu is maritime tundra and lies below 230 m elevation. A mountain range composed of seven sub-massifs lies

along the north side and extends from Armeria Bay eastward to Krugloi Point (Fig. 2.1). The westernmost sub-massif is composed of five peaks that extend to 518 - 630 m, and includes the highest point on the island (630 m).

Agattu Island is comprised of five major habitats. At elevations above 350 m, fellfields and scree slopes on the exposed ridges and summits are interspersed with dwarf shrub mats of crowberry (*Empetrum nigrum*) and decumbent willows (*Salix arctica*). Middle elevations (250 to 350 m) are dominated by upland dwarf shrub mats composed of dwarf willows and heaths (e.g., crowberry is joined by hardy shrubs [*Phyllodoce aleutica*, *Salix arctica*, *Cassiope lycopodioides*] and forbs [*Saxifraga* spp., *Geum calthifolium*]). The lower (150 to 250 m) sloping hillsides of the massif are dominated by two plant community types: tall forbs (*Geranium erianthum*, *Anemone narcissiflora*, *Geum calthifolium*), and dwarf shrub meadows characterized by crowberry/lichen tundra (*Empetrum nigrum*, *Cladina* spp.). Small, isolated patches of willow (*S. rotundifolia*) uncommonly occur in sheltered areas found at the base of the slopes. Below 150 m elevation, wet meadow communities are found in sheltered valley bottoms and are dominated by sedges (*Carex* spp.) and Alaska cottongrass (*Eriophorum russeolum*) with numerous wetlands, ponds, lakes, and streams. Last, the lower beach strand plant community forms a narrow fringe around the island. These areas are dominated by beach rye (*Leymus arenarius*), beach fleabane (*Senecio pseudo-arnica*), and beach greens (*Honckenya peploides*).

Potential nest and brood predators of Rock Ptarmigan observed on Agattu included Glaucous-winged Gulls (*Larus glaucescens*), Common Raven (*Corvus corax*), and Parasitic Jaegers (*Stercorarius parasiticus*). Snowy Owls (*Nyctea scandiaca*) and Peregrine Falcons (*Falco peregrinus*) are present on Agattu during the breeding season and are capable of killing adult ptarmigan.

Temperatures are characteristic of a maritime environment and exhibit limited daily and annual variation. A weather station on Shemya Island, approximately 30 km to the northeast, reported a mean annual temperature of approximately 3.9° C with precipitation occurring on >200 days each year, averaging 80.6 cm per year (1949 to 1995; Western Regional Climate Center). Wind velocities average 42 kilometer per hour on Shemya; gusts of 165-200 kilometers per hour are not uncommon.

Field Methods.---In May through August 2005-2006, we remained on Agattu to monitor the survival and reproductive success of resident and newly translocated birds. Ptarmigan were live-captured on Attu Island using noose poles, noose carpets, and ground nets (Zwickel and Bendell 1967, Braun and Rogers 1971). Captured birds were color banded (batch-marked 2003-2004; uniquely-marked 2005-2006). We recorded standard morphometric data including body mass (± 1 g), wing chord (flattened, ± 1 mm), and tarsometatarsus length (± 1 mm). Age class was assigned based on pigmentation and shape of outer primaries, which allowed us to distinguish between yearlings (≤ 1 year) and adults (> 1 year; primaries 9 and 10 were pigmented and tapered in yearlings, but white and rounded in adults; Weeden and Watson 1967, Parker et al. 1985). Birds were held for up to 48 hrs in fiberglass transport containers and provided with small pieces (5 cm x 5 cm) of melon as a source of food and water. The 28 km strait between Attu and Agattu Island required 3 hrs to traverse by boat.

Upon arrival at Agattu, ptarmigan were immediately released at one of three coastal beach sites to minimize handling. In June and September 2003, ptarmigan were released on the east side of Agattu (McDonald Cove, Fig. 2.1). In June 2004 and 2005, birds were released on the south side (Karab Cove). In 2006, birds were released on the north side (Binnacle Bay). Weight loss of translocated ptarmigan was measured by subtracting mass at release from mass at capture. In cases where females laid eggs during the holding period, we corrected difference in mass by 21 g per egg laid (average egg mass; Holder and Montgomerie 1993).

Prior to release on Agattu, each female ptarmigan was fitted with a bib-style radio collar (2005: 15 g, Telemetry Solutions, Concord, CA, USA) or a necklace-style radio collar (2006: 6 g, Holohil Ltd., Carp, Ontario, Canada) with a battery life of 12-18 months. Radio collars were equipped with mortality switches to facilitate detection of dropped transmitters and mortality events.

Radio-tracking began immediately after release using a 3-element Yagi antenna and portable radio receiver (R2000, Advanced Telemetry Systems, Isanti, MN, USA). For the first three weeks after release, we triangulated each bird daily using standard telemetry techniques; a compass bearing was recorded in the direction of a radio-marked bird from each of 3-4 georeferenced points which were spaced ≥ 100 m apart. Points were

recorded in Universal Transverse Mercator (UTM) coordinates using a hand held Global Positioning System (GPS; Garmin GPSmap 76; Garmin International, Olathe, KS, USA).

In addition to monitoring radio-marked translocated ptarmigan, we also radio-marked resident females (2005 and 2006), and translocated and resident males (2006 only). We define resident individuals to include previously reintroduced ptarmigan (2003-2004 releases) and their unbanded offspring. Nests of translocated ptarmigan were located by radio telemetry (Appendix B). Nests of resident ptarmigan were located by searching suitable nest habitat and areas around the roosts of males, which often acted as sentinels (Holder and Montgomerie 1993). If a nest was located during the laying stage, we returned once the clutch was predicted to be complete to minimize the chance of nest abandonment. At nest sites with complete clutches and an unmarked female, we captured the female on the nest using a long handled dip net. Eggs were counted, length (L) and width (W) measured (± 0.1 mm), and floated in water to estimate the stage of incubation (Westerskov 1950). Female presence at each nest was determined every 3-4 days during incubation by triangulation of the radio signal from a distance of ≥ 30 m from the female. As the nest approached the expected hatching date, visits were made to nests every 1-2 days. Upon hatching, each chick was weighed, measured, and a blood sample was collected. We classified nest fate as successful (produced at least one chick), depredated, or abandoned. We opened unhatched eggs to determine stage of embryo development. To reduce observe impact, we counted young broods (<15 days post-hatch) from ≥ 50 m. For older broods (15-25 days old), if observers were unable to obtain an accurate brood count from ≥ 50 m (i.e., obscured by vegetation), broods were flushed in order to determine fledging success rates. Flushing of brood occurred up to two times during the 15-25 day age period until a good count was obtained for each brood. However, brood flushing was rarely employed (<5 flush events during the 2-year radio telemetry study). Capture, handling, and marking procedures were approved by the Institutional Animal Care and Use Committee at Kansas State University (IACUC Protocol # 2361).

Demographic Parameters.---Sample sizes were small, thus we pooled our data over the 2-year radio-telemetry study period to compare the reproductive attempts of resident and translocated females on Agattu. We estimated demographic parameters following the methods of Sandercock et al. (2005):

1) Date of clutch initiation was calculated by backdating from date of hatching. We assumed Rock Ptarmigan lay 1 egg per day and have an average incubation period of 21 days beginning with the laying of the penultimate egg (Holder and Montgomerie 1993).

2) Total clutch laid (TCL) was the total number of eggs laid in the ground nest and was recorded at the time of the first visit. If buoyancy of eggs indicated that the nest was first found during the laying period, clutch size was determined at a subsequent visit during incubation. Egg volume (V) was estimated using $V = kLW^2$ (Hoyt 1979), where $k = 0.49$ for Willow Ptarmigan (Myrberget 1977), L = maximum length, and W = maximum width.

3) Nest success (NEST) was the probability that at least one egg hatched and produced a chick that departed the nest. Nests were considered successful if we captured hatching chicks at the nest, near the nest, or if shells with detached membranes remained in the nest cup after chicks had left the nest. Total nest failure (TNF) occurred if all the eggs of a nest were depredated (eggs broken, membrane intact, blood vessels) or abandoned before hatching.

4) Renesting rate (RENEST) was the probability of a female producing a replacement clutch if her first clutch was lost. Renesting rates are higher if clutches are lost early in incubation (Robb et al. 1992); thus we modeled the renesting rate as a function of the estimated day of the incubation period when the depredation event occurred.

5) Chicks per egg laid (C/E) was the proportion of eggs laid that eventually hatched and produced chicks that left the nest. C/E was only calculated for successful nests (≥ 1 egg hatched) that survived incubation. Values of C/E < 1 included losses of eggs that disappeared during incubation and eggs that survived incubation but failed to hatch.

6) Fledging success (FLED) was the probability that at least one chick survived until 15-25 days after hatching. Total brood failure (TBF) was readily determined by female behavior and movement patterns; because females fled during observer approach (females are unlikely to abandon broods) or joined small groups of failed breeders.

7) Fledglings per chick hatched (F/C) is the proportion of hatched chicks that left the nest and survived until fledging at 15-25 days. F/C was only calculated for successful nests (≥ 1 chick fledged).

8) Apparent survival of females was calculated based on annual return rates of radio-marked birds from 2005-2006. Radio transmitters recovered near accumulations of ptarmigan feathers were considered mortalities. We assigned unknown fates to all females in which the radio-collar was recovered but no conclusive evidence of fate could be determined. We present lower and upper estimates of female survival where the lower and upper bounds were calculated by assuming radios with unknown fates were mortalities or dropped by surviving females, respectively. For radios and females with unknown fates in 2006, we conducted intensive searches of each female's 2005 nest area. Despite high site fidelity of female ptarmigan, we failed to redetect any non-radioed, color banded females.

Synthetic Estimates.---Ptarmigan nests were located during the early stages of incubation in most cases; however, to obtain an unbiased estimate of fecundity per nest (F_n) that controlled for variation in nest exposure time, we calculated the mean number of female fledglings produced per translocated and resident female by:

$$F_n = \{[\text{BREED} * \text{TCL}_1 * \text{HATCH}_1] + [(1 - \text{HATCH}_1) * \text{RENEST} * \text{TCL}_2 * \text{HATCH}_2]\} * \text{ES} * \text{HS} * 0.5$$

where BREED = probability of breeding, TCL = total clutch laid, HATCH = probability of nests hatching at least one chick, RENESEST = probability of reneesting after clutch loss, ES = probability that eggs survived until hatching, HS = probability of eggs hatching, and subscripts 1 and 2 indicating estimates for first and second nests, and 0.5 is the proportion of females based on a 1:1 sex ratio. Using our estimates of parameter values, we calculated the rate of population change (λ) by:

$$\lambda = F_n * S_{juv} + S_{breed} * S_{winter}$$

where F_n = fecundity per nest, S_{juv} = annual juvenile survival, S_{breed} = survival rate during nesting and brood rearing stages, and S_{winter} = overwinter six month survival rates.

Because we lacked direct estimates of juvenile survival, we used the rate reported by Holder and Martin (2006) for annual juvenile survival of an un hunted Willow Ptarmigan population (0.53) to calculate the rate of population change. We evaluated potential bias

in using their value by calculating a minimum juvenile survival rate for a stable population ($\lambda = 1$) using our observed rates of fecundity and female survival.

Statistical Analysis.---To compare egg size of resident and translocated females, we compared egg volumes between clutches of resident and translocated hens. A complication in studies of egg size is the lack of independence among eggs measured in a single clutch (Sandercock and Pedersen 1994); thus, we used the average egg volume of each female's clutch in a general linear model (Jover et al. 1993; Proc GLM, SAS Institute 2005).

To estimate daily survival rates of eggs and young during the incubation and brood-rearing periods, we used the nest survival procedure in Program MARK, version 4.1 (White and Burnham 1999, Dinsmore et al. 2002, Rotella et al. 2004). For the nest survival analysis, nests were active for a 63-day exposure period from 1 June until 2 August (1 June = day 1). For brood survival analysis, we collected brood data for a 34-day exposure period from 28 June until 5 August. Models were fit to the data using the design matrix and a logit-link function (Lebreton et al. 1992). The nest survival model makes five assumptions (Dinsmore et al. 2002): 1) nests or broods can be correctly aged when they are first found; 2) fates are correctly determined; 3) discovery and subsequent checks do not influence survival; 4) fates are independent; and 5) homogeneity of daily survival rates. We met these assumptions because: stage of incubation could be determined by egg buoyancy; nest fates were easily determined by the presence of neatly opened eggs and females accompanied by chicks on subsequent checks; nest checks were conducted by radio-telemetry; nests were not spatially clumped and re-nest occurred >300 m from first nest sites; and nests experienced similar predator communities and climate condition. We coded encounter histories for the nest and brood survival analyses with five types of information: 1) the day the nest or brood was found (k), 2) the last day known to be active (l), 3) the last day checked (m), 4) the fate where 0 = successful, 1 = depredated (f), and 5) the number of nests or broods with the same encounter history (n). Failure due to research activities were excluded from the survival analysis ($n = 1$).

For our nest and brood survival analyses, we considered nine and eight *a priori* candidate models (Burnham and Anderson 1998), respectively. Daily probability of nest and brood survival was modeled as a function of group (translocated or resident; S_{GROUP})

and time (S_{TIME}). We expected translocated females might have lower survival rates than resident females. Additionally, since vulnerable nests of precocial species are expected to fail earlier in the nesting period, we predicted rates of nest loss might be greater immediately after nest initiation (Klett and Johnson 1982, Dinsmore et al. 2002). Likewise for brood survival, we expected that brood survival rates might vary with group and that rates of brood loss might be greater immediately after nest departure, prior to a chick's ability to thermoregulate or fly. We assessed temporal variation in nest and brood age by comparing fit of models with DSR that (1) was constant over the nesting cycle, (S_{CONSTANT}); (2) showed a linear trend over the nesting cycle, (S_{LINEAR}); or (3) included a quadratic trend over the nesting cycle to accommodate some nonlinearity, ($S_{\text{QUADRATIC}}$) (Dinsmore et al. 2002). We also fit an additive model with main effects ($S_{\text{GROUP} + \text{TIME}}$). The most highly parameterized (global) model included an interaction of main effects ($S_{\text{GROUP} \times \text{TIME}}$). In most mark-recapture analyses, an important first step is to test for any lack of fit between the encounter histories and the global model, followed by a subsequent adjustment by calculation of a variance inflation factor (\hat{c}). Because the global models are saturated in the nest survival model, c is not identifiable, and no adjustments are possible (Dinsmore et al. 2002).

Model selection was based on the information theoretic approach (Burnham and Anderson 1998). We considered the model with the lowest Akaike's Information Criterion corrected for small sample sizes (AIC_C) value to be the best supported by the data. We considered models with a $\Delta\text{AIC}_C \leq 2$ as equally parsimonious (Lebreton et al. 1992, Burnham and Anderson 1998). Guthery et al. (2005) noted that a limitation of the information theoretic approach is the potential for erroneous inference of models with small AIC_C values (< 2) which provide infinitesimally small changes in model deviation. Thus, in cases where the change in number of parameters was one ($\Delta K = 1$), we also sought support from the 95% confidence intervals. We used Akaike's weights (w_i / w_j) between 2 models to quantify the relative degree of support of one model over the other (Burnham and Anderson 1998). In these cases, we calculated parameter estimates using the model-averaging feature in Program MARK (Cooch and White 2006). In model averaging, weighted estimates of survival and standard error are calculated by weighting parameter estimates by the AIC_C weights of each model.

Chick survival of ptarmigan is often positively correlated with temperature and negatively correlated with precipitation during the first week after hatching (Erikstad and Andersen 1983, Hannon and Martin 2005). We used weather data collected on Shemya Island to compare mean daily temperatures and total daily precipitation between years. Tests of significance were done using Program SAS (Proc TTEST, SAS Institute 2005) and were considered significant at $\alpha = 0.05$.

RESULTS

We translocated 75 Evermann's Rock Ptarmigan from Attu to Agattu over a 4-year period (2003-2006 totals: 42 females, 31 males, 2 juveniles; 2003 total: 13 females, 11 males, 2 juveniles; 2004 total: 16 females, 11 males; 2005 total: 10 females, 4 males; 2006 total: 3 females, 5 males).

During the 2-year radio telemetry study (2005-2006), we radio-marked 26 female ptarmigan (13 resident and 13 translocated) and monitored survival, movements and reproductive efforts from 1 June to 9 August in 2005, and from 1 June to 13 August in 2006. Nest and brood success of resident and translocated ptarmigan was monitored from 23 June to 9 August in 2005, and from 1 June to 13 August in 2006. We located 28 nests, including 18 nests of resident females (including first nests and renests) and 10 nests of translocated females. To determine fledging success, we radio-tracked 21 marked females (12 resident and 9 translocated; one female was followed in both years).

There was one mortality during the holding periods and two mortalities during the acclimation period after release on Agattu. Only one bird, a juvenile male, died during holding; however, the cause of death could not be determined from a necropsy (W. P. Taylor, unpublished data). During the 2-week acclimation period, two females died. One female was recovered from a small (2 m x 1 m) pool of water 390 m from the release site and was determined by necropsy to have drowned (W. P. Taylor, unpublished data). Cause of death of the second female, located 914 m from the release site, was not conclusive but based on condition of recovered remains was apparently due to predation by a raptor.

Translocated females lost an average of 11% of their total body mass (mean loss: -63 g, SD = 44.16, range = -18 to -164 g, $n = 12$; 1 yearling, 11 adults). At the time of capture on Attu, the average mass of adult females was greater than that of yearling females (2003-2006: adult females, 592 g, SD = 66.76, range 449 to 710 g, $n = 19$; yearling females, 489 g, SD = 67.80, range 398 to 513 g, $n = 9$).

We compared daily mean temperatures and total daily precipitation for the overall time period when chicks hatched (28 June to 16 July). To examine climatic variations as they may relate to observed hatching periods of resident and translocated female's nests, we also compared two time periods; the earlier (28 June to 7 July) hatching period of resident nests and the later (8 to 16 July) hatching period of translocated nests. While overall mean daily temperature differed between years for the entire hatching period, total precipitation did not (Table 2.1). Of our comparisons between the earlier and later time periods for temperature and precipitation, temperatures for the earlier time were not different; differences between temperatures were detected for the latter time period and for the overall time period (Table 2.1). There were no differences between measurements of total precipitation for the earlier, later, or overall time period of chick hatching (Table 2.1).

Timing of clutch initiation.---In 2005 and 2006, 38.5% (5 of 13) of translocated females had developing brood patches at the time of capture and 46.2% (6 of 13) females laid a single egg in holding containers during transfer from Attu to Agattu. All translocated females surviving the initial 2-week post-release period initiated clutches on Agattu. Pooled over the 2-years, translocated females from Attu began egg laying on Agattu an average of 12.6 days post-release (SD = 2.77, range = 8-17 days, $n = 11$). Clutch initiation dates differed between resident and translocated females (Table 2.2). For first nesting attempts of resident females on Agattu, the mean clutch initiation date was 8 June (pooled 2005-06: SD = 5.52, range = 31 May-20 June, $n = 14$). For first nesting attempts on Agattu by translocated females, the mean clutch initiation date was 16 June (pooled 2005-06: SD = 3.27, range = 11-22 June, $n = 10$).

Reproductive effort and success.---Reproductive effort differed between resident and translocated female ptarmigan (Table 2.2). Clutch size of first nests of resident females was larger than the clutch size of nests laid by translocated females (Table 2.2).

In 2006, two resident females renested after failure and laid second clutches that contained 5 and 6 eggs, respectively. No translocated females were detected renesting after clutch failure. Our examination of variation in egg volume between resident ($23.31 \pm 0.97 \text{ cm}^3$, $n = 16$) and translocated females (23.09 ± 1.61 , $n = 8$) revealed no significant difference between the two groups ($F = 0.17$, $df = 1$, $P = 0.684$).

Nest survival.---For the nest survival analysis, we used encounter histories from 27 nests (15 resident and 12 translocated; two females were followed in both years) monitored over 63 exposure days. Model selection of daily nest survival indicated support for three models (Table 2.3); the best-approximating model, S_{LINEAR} , had 1.7 times greater support than a model with a quadratic function of time, and 2.4 times more support than an additive model including a linear time trend and group. Slope estimates for linear time trend effects were negative with confidence intervals that did not include zero ($\hat{\beta} = -92.8$, $SE = 40.2$, $95\% \text{ CI} = -171.6, -14.0$ on a logit scale). A model with a quadratic time trend received some support ($\Delta\text{AIC}_c = 0.22$), however, the 95% confidence interval of the slope parameter for the quadratic term overlapped zero ($\hat{\beta} = 36.1$, $SE = 42.3$, $95\% \text{ CI} = -46.8, 119.1$ on a logit scale). Slope estimates for the additive model, $S_{\text{GROUP} + \text{LINEAR}}$, were negative and did not include zero ($\hat{\beta} = -98.6$, $SE = 41.3$, $95\% \text{ CI} = -179.5, -17.6$).

Using model averaging in Program MARK, DSR of nests based on weighted averages were similar between resident and translocated females (resident: $\hat{S} = 0.96$, $SE = 0.1$, $95\% \text{ CI} = 0.84, 1.00$; translocated: $\hat{S} = 0.97$, $SE = 0.1$, $95\% \text{ CI} = 0.87, 1.00$) and decreased over the season (Fig. 2.2). Daily survival probabilities of ptarmigan nests were a function of a time trend rather than a constant daily survival rate. Nest survival was greater for both resident and translocated nests during early stages of incubation and decreased with time.

The probability of nest success (proportion of nests producing ≥ 1 chick which departed the nest) of resident and translocated females was similar (Table 2.2). The two groups differed in the proportion of chicks produced per egg laid (C/E) in successful nests (Table 2.2).

The majority (80.0%, 4 of 5) of nest predation events occurred during the last week of incubation (30 June-10 July). In 2005, predators destroyed two nests of translocated females during the last week of the incubation period; neither female attempted to reneest. In 2006, radio-marked resident females experienced three nest predation events and abandoned one nest due to our activities. Of these four nest failures, two females laid second clutches. One female reneested after her first nest was depredated during the final week of incubation. The second female, which abandoned her first nest after being trapped on the nest during egg laying, also abandoned the second nest due to unknown causes. In these two cases, the female initiated her reneest five and 11 days after nest failure or abandonment, and moved 184 m and 851 m from the first nest location, respectively.

Brood survival.---We used encounter histories of 21 radio-marked females (12 resident and 9 translocated; one female was followed in both years) and their broods to model brood survival over 34 exposure days. Selection uncertainty ($\Delta AIC_c < 2$) existed among the top five models (Table 2.4). Based on Akaike's weights (w_i), the top two models, S_{LINEAR} and S_{GROUP} , received 49% of support from the data. Slope estimates for linear time trend effect were positive, but largely overlapped zero ($\hat{\beta} = 83.6$, SE = 51.0, 95% CI = -16.3, 183.6 on a logit scale). Slope estimates for a group effect were positive with confidence intervals narrowly including zero ($\hat{\beta} = 1.3$, SE = 0.8, 95% CI = -0.4, 2.8 on a logit scale). The remaining three models with ΔAIC_c values < 2 received 0.44 of support from the data (Table 2.4). Only a model with a constant daily survival was estimated precisely enough to permit reliable inference ($\hat{\beta} = 3.3$, SE = 0.3, 95% CI = 2.6, 4.0 on a logit scale); the models including a quadratic time trend or an additive effect model with status and a linear time trend had confidence intervals that largely overlapped zero. Model averaging of all candidate models in Program MARK yielded similar DSR for broods of resident ($\hat{S} = 0.96$, SE = 0.1, 95% CI = 0.86, 0.99) and translocated females ($\hat{S} = 0.97$, SE = 0.03, 95% CI = 0.87, 0.99) and increased with day of season (Fig. 2.3).

Fledging success was higher for translocated females than resident females (Table 2.2). Similarly, the proportion of fledglings per chicks hatched was higher for translocated females (46.0%, 23 of 50, 8 nests) than resident females (18.6%, 16 of 86,

13 nests); however, the number of fledgling per chick hatched (F/C) for resident and translocated females did not differ ($t = 0.36$, $df = 9$, $P = 0.73$).

Apparent Female Survival.---We monitored seasonal survival of females during the nesting and brood-rearing period for 26 female ptarmigan (13 resident and 13 translocated) and found survival during these periods was 100% for resident and translocated female ptarmigan if they survived a two-week post-release acclimation period. In 2006, to help assess over-winter female survival, we attempted to relocate females radio-marked in 2005. Of the 16 hens, 37.5% (6 of 16) were detected alive, 31.3% (5 of 16) were found dead, and 31.3% (5 of 16) were not relocated. The six hens that survived from 2005 to 2006 showed strong site fidelity and nest locations in two consecutive years were an average of 123 m (SD = 75.6, range = 54 – 251 m, $n = 5$) apart.

We searched all female territories in 2006 and expect that our best estimate of annual survival is 0.38 if missing females died and radios were not recovered. However, if undetected females survived and dispersed elsewhere on the island, female survival could be as high as 0.75. Of the five known mortalities, 60.0% (3 of 5) were females translocated in 2005.

Synthetic Estimates.---The unbiased estimate of fecundity per nest (F_n) that controlled for variation for nest exposure was 2.18 for resident females and 1.79 for translocated females. We calculated the rate of population change (λ), assuming annual female survival rate of 0.38 ($S_{female} = S_{breed} * S_{winter}$), and using a juvenile survival estimate (S_{juv}) of 0.53 for Willow Ptarmigan (Holder and Martin 2006). Using these parameter estimates, the rate of population change is 1.54 for resident ptarmigan and 1.33 for translocated ptarmigan and indicates an increasing population. If we assume a stationary rate of population change ($\lambda = 1$), then the minimum rate of juvenile survival needed would be 0.28 for offspring of resident females and 0.35 for offspring of translocated females.

DISCUSSION

This research is the first comprehensive study of the effects of translocation and reintroduction on the reproductive success of a reintroduced island ptarmigan population and provides the first estimates of demographic parameters for Evermann's Rock Ptarmigan. This study also provides the first comparison of daily survival rates of nest and brood survival between a recently translocated group and a resident population of ptarmigan. Our major conclusions were three-fold: 1) we found that translocation (capture, holding, transport, and subsequent handling) had minimal impact on female survival and reproduction after release; 2) translocated and resident females had high nest survival, moderate brood survival, and produced the same number of fledgling per chick hatched; and 3) seasonal survival of females during nesting and brood-rearing was 100% for resident and translocated female ptarmigan. Contrary to our predicted outcome, translocated females exhibited better reproductive performance than the recently restored resident population. However, our two years of intensive monitoring revealed that reproductive success can vary markedly between years, mainly as a direct effect of adverse weather coinciding with the first week after hatching when chick mortality is the highest. Nonetheless, we found that translocation of Rock Ptarmigan using wild-caught birds released at a coastal site on Agattu was a viable means to reestablish an extirpated population in the Aleutian Islands.

Reproductive effort, timing, and success.---Reproductive rates of ptarmigan on Agattu show that resident and translocated hens exhibit breeding success similar to values reported for other Rock Ptarmigan studies (Table 2.5). Clutch initiation dates were earlier on Agattu than dates reported for other Holarctic populations in Alaska (Table 2.5), likely due to Agattu's lower latitude, maritime climate, and lower snowfall compared to more northern study areas. Clutch sizes of translocated females, though containing fewer eggs than those of resident females, were within the range reported for mainland populations (Table 2.5). Hatching success for resident and translocated females on Agattu was greater than rates reported for other Rock Ptarmigan populations, and is likely attributed to the lack of terrestrial predators on Agattu. Indeed, the only cause of nest failure was due to egg predation; no monitored nests failed due to predation of the female despite the presence of a small avian predator population (Peregrine Falcon, Snowy Owls). Females

that lost their nests in the final week of incubation and did not renest, may be due to the brevity of the breeding season and the amount of investment already put into the first nest. Two of the five resident females with depredated or abandoned nests laid smaller replacement clutches, similar to results reported from the Northwest Territory (NWT), Canada (Brodsky 1986, Cotter 1999).

Previous research on reproductive success of precocial birds have suggested that larger eggs produce larger chicks that have better survival than chicks from small eggs (Ankney 1990, Bolton 1991, Grant 1991, Christians 2002). Translocated females laid eggs of similar volume compared to resident females. In response to translocation, females may lay smaller clutches, but this did not affect overall reproductive success.

Seasonal declines and group (resident versus translocated) were important predictors of daily nest and brood survival (Table 2.3, 2.4). Nest survival on Agattu was linear during the early part of the breeding season followed by a decrease during the final weeks of incubation (Fig. 2.2). This pattern may be a result of female condition (Throgmartin and Johnson 1999) or increased predator density. We speculate that the decrease in daily nest survival rates over the progression of the breeding season coincided with the hatching period of Cackling Geese (*Branta hutchinsii*) and may have had an influence on ptarmigan nest success, as well as brood survival immediately after hatching. The gull density throughout the Aleutian Archipelago is artificially high due to the outflow of fisheries processing plants at sea (V. Byrd, I. Jones, personal communication). At our study site, large flocks (15-20 individuals) of Glaucous-winged Gulls forage inland and prey upon the eggs and young of Cackling Geese. While female ptarmigan are attentive and prudent parents, the density of gulls may have a negative affect on the breeding success of ptarmigan and other breeding bird species on Agattu.

Our top models also included a quadratic time trend effect and may have been due to the effects of weather variables, such as daily ambient temperatures and precipitation. With regard to brood survival, the first week after hatching is the most critical period in chick survival (Erikstad and Andersen 1983, Hannon and Martin 2006) with young relying on females for thermoregulation (Steen and Unander 1985, Holder & Montgomerie 1993, Scherini et al. 2003). Indeed, poor weather conditions (low temperature and high precipitation) during the period around hatching on Agattu in 2006

may have caused the failure of many broods. An increase in the daily survival probabilities of broods as the season progresses (Fig. 2.3) is attributed to the acquisition of thermoregulatory (Aulie 1976) and flight abilities over time (Bergerud and Gratson 1988). Contrary to our prediction, translocated hens had higher rates of brood success than resident hens. The induced reproductive delay due to translocation, and thus a later mean hatching date of nests of translocated females, may have favored their reproductive success by avoiding an intense period of severe weather. Steen and Unander (1985) suggested that in some years on Svalbard, hens laying later had better reproduction since unfavorable weather occurs more frequently earlier in the breeding season. Our comparisons of daily mean temperature and total daily precipitation using weather data collected on Shemya detected a significant difference between the two years for the later time period (8 -16 July) as well as the overall time period (28 June – 16 July; Table 2.1); no differences between the two years were detected for total precipitation. We suspect that the weather on Agattu was more severe (particularly with regard to precipitation) than recorded for Shemya during 2006. This may be due to Shemya's overall lower elevation, its location relative to the mountainous Attu and Agattu (rain shadow-effect) or a combination of these factors.

Apparent female survival.---It is unclear why, on Agattu, a few females showed high site fidelity between the two years, while other females either dispersed to other parts of the island or suffered overwinter mortality. Of the six females that were philopatric in 2006, five nests had successfully hatched young and three had successfully fledged chicks in 2005. However, four other radio-marked females with successful nests in 2005 did not return in 2006 (fate unknown).

If we exclude deaths of translocated ptarmigan during the 2-week acclimation period, survival of radio-marked females during the 21-day incubation and 15 to 25-day brood-rearing periods was 100% for resident and translocated birds. Therefore, all mortalities occurred during the fall and winter seasons on Agattu. This is higher than values reported from Windy Lake, NWT (Cotter 1999), where survival during the breeding season was 87% for females; however, the Windy Lake study area has terrestrial and avian predators to contend with during the breeding season. Our estimate of annual female survival between 2005 and 2006 ranged from 0.38 to 0.75 due to unknown fates

of five translocated females. For arctic and alpine Willow Ptarmigan (*Lagopus lagopus*), Sandercock et al. (2005) reported apparent survival rates of 0.37 and 0.43, respectively. Overall, Sandercock et al. (2005) concluded that predation of breeding females may be an important determinant of life history variation in ptarmigan, similar to results reported for forest grouse (Jönsson et al. 1991).

Raptors are an important predator of breeding females throughout the geographical range of ptarmigan (Nielson 1999, Smith and Willebrand 1999, Thirgood et al. 2000) and may be an important determinant of life history variation in the genus *Lagopus* (Sandercock et al. 2005). Currently, a small population of Snowy Owls and Peregrine Falcons are the primary predators capable of killing an adult ptarmigan on Agattu. Our observations of no female mortality during the incubation or brood-rearing periods emphasizes a major difference between mainland and island population dynamics; fall and winter survival rates have a greater influence on population size than spring and summer survival rates. Raptors on Agattu may have preyed more heavily on ptarmigan during the non-breeding season when prey is less abundant, then shift their spring and summer diets to take advantage of breeding seabirds located at coastal and inland colony sites.

We cannot separate possible effects of radio collars from those of translocation as a cause of mortality. Radio transmitters may have influenced the first week of survival of Gray Partridge (*Perdix perdix*) released in North Dakota (Carroll 1990). While radio-collars likely have a greater impact on daily survival immediately after release, the careful selection of a release location which provides shelter, food, and preferably a low raptor density, the effects of transmitter packages on post-release female survival can be minimized.

Effects of translocation on female reproduction and survival.---Physical conditions of female ptarmigan prior to the breeding season may be an important factor determining chick production. During the egg laying period, female Svalbard Rock Ptarmigan may lose up to 16 % (100 g) of their body mass followed by an additional loss of 21% (130 g) during the incubation period (average female body mass = 634 ± 117 ; Steen and Unander 1985). Wiebe and Martin (2000) found that White-tailed Ptarmigan (*Lagopus leucura*) breeding during an extremely harsh weather year (late thaw, inclement

weather) initiated egg laying later and improved body condition with increased time off the nest. They found this strategy allowed larger than expected clutch sizes given the calendar date. We might have expected translocated females to require longer incubation periods than resident females, as they initiated laying on Agattu with poorer body condition compared with resident females and therefore might attempt to recoup condition by increasing time off the nest. Instead, we observed similar incubation times between resident and translocated females, but a decreased clutch size compared to resident hens. Smaller clutch sizes may be due to poor body condition at the onset of egg laying on Agattu or caused by an interruption during the egg laying period on Attu resulting in the laying of continuation clutches on Agattu (Sowles 1955, Sandercock 1993). However, female body condition at the onset of egg laying may have additional costs.

The short lifespan of Rock Ptarmigan (Holder and Montgomerie 1993) likely selects for high rates of fecundity regardless of biotic and abiotic factors leading to a tradeoff between survivorship and reproduction. At our island site, an environment with a low rate of nest predation, greater investment in egg production could have lowered translocated female's overwinter survival through the added strain of decreased body condition due to capture, holding, and transport, followed by a cost of reproduction. This could ultimately lead to a poor body condition prior to the onset of winter conditions on Agattu (Wiebe and Martin 2000, Martin and Wiebe 2004).

Management Implications.---We believe that translocation of Rock Ptarmigan using wild-caught birds freed at coastal release locations can be a viable means to re-establish or augment island Rock Ptarmigan populations endemic to the Aleutian Archipelago. For a high level of success, we recommend a rapid capture-release turnover time and provisioning of melon as a source of food and moisture for captive birds. To expedite the breeding process and improve reproductive success, birds should be released in proximity to nesting habitats, if known. Carefully planned release sites may also reduce the amount of time spent by females in search of suitable habitat, and thus the amount of time that released ptarmigan are exposed to danger. Captures should begin just before the onset of egg laying, but after pairing has occurred because territorial males

greatly aid in locating females. Furthermore, mated females may be more likely to nest after translocation than if captured prior to mating.

Our observations of unmarked yearlings in 2005 and 2006 confirm the success of prior translocations. Our two years of intensive monitoring revealed that reproductive success can vary markedly between years, mainly as a direct effect of adverse weather coinciding with the one week period around hatching when chick mortality is the highest. We advise future monitoring of the Agattu population to help determine whether translocation of Rock Ptarmigan is a useful management tool. A future challenge will be to examine age-specific variation in the demography of translocated ptarmigan in island environments, and to identify those life history parameters that have the greatest impact on rates of population change.

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Table 2.1 Average daily temperature (Celsius) and total precipitation (cm) values measured from the weather station on Shemya Island, approximately 30 km northeast of Agattu Island during the hatching period of Evermann's Rock Ptarmigan on Agattu. Values are presented for the early or resident hatching period (28 June - 7 July), and late or translocated hatching period (8 - 16 July), and overall hatching period for 2005 and 2006; data are means \pm SD (with number of days in parentheses).

| Parameter | Date | 2005 | 2006 | <i>t</i> | df | <i>P</i> |
|-------------------------------|-------------------|---------------------|--------------------|----------|----|----------|
| Average temperature (Celsius) | | | | | | |
| | 28 June - 7 July | | | | | |
| | | 8.8 \pm 0.6 (10) | 8.1 \pm 0.9 (10) | 0.37 | 18 | 0.71 |
| | 8 - 16 July | | | | | |
| | | 9.3 \pm 1.0 (9) | 8.3 \pm 0.5 (7) | 2.50 | 14 | 0.03 |
| | 28 June - 16 July | | | | | |
| | | 9.1 \pm 1.0 (19) | 8.2 \pm 0.7 (17) | 3.16 | 34 | 0.003 |
| Total precipitation (cm) | | | | | | |
| | 28 June - 7 July | | | | | |
| | | 8.2 \pm 1.3 (10) | 6.2 \pm 1.1 (10) | 0.37 | 18 | 0.71 |
| | 8 - 16 July | | | | | |
| | | 2.5 \pm 0.6 (9) | 1.7 \pm 0.3 (8) | 0.88 | 14 | 0.40 |
| | 28 June - 16 July | | | | | |
| | | 10.7 \pm 1.0 (19) | 7.8 \pm 0.9 (18) | 0.94 | 34 | 0.35 |

Table 2.2 Demographic rates of resident and translocated Evermann's Rock Ptarmigan on Agattu Island, Aleutians, Alaska, 2005-2006. Data are means \pm SE or proportions (with *n* in parentheses).

| Parameter | Resident | Translocated | <i>t</i> | df | X^2 | <i>P</i> |
|----------------------------------|------------------------|-------------------------|----------|----|-------|----------|
| Clutch initiation date | 8 June \pm 1.48 (14) | 16 June \pm 1.03 (10) | 4.24 | 22 | | 0.001 |
| Total clutch laid (no. eggs) | 8.1 \pm 0.2 (16) | 6.8 \pm 0.3 (10) | 3.61 | 25 | | 0.001 |
| Probability of nest success | 0.722 (18) | 0.800 (10) | | 1 | 0.22 | 0.64 |
| Renest / Total (no. failures) | 2 of 5 failures | 0 of 2 failures | | | | |
| Chicks per egg laid (%) | 81.1 \pm 10.7 | 69.1 \pm 16.4 | 2.57 | 18 | | 0.02 |
| Probability of fledging success | 0.31 | 0.88 | | 1 | 10.7 | 0.001 |
| Fledglings per chick hatched (%) | 18.6 (13) | 46.0 (8) | 0.36 | 9 | | 0.73 |

Table 2.3 Summary of model selection results for daily survival rates (DSR) of nests of resident and translocated female Evermann's Rock Ptarmigan on Agattu Island, Aleutians, Alaska, 2005-2006. Analysis performed in Program MARK. Model fit is described by Deviance, the number of parameters (K), the difference in Akaike's Information Criterion corrected for small sample size from the best-fit model (ΔAIC_c), and AIC_c weight (w_i), which indicates the relative likelihood of each model given the candidate model set and sum to 1. Models are listed beginning with the best-fitting model and sorted by ΔAIC_c . Model structure estimated apparent survival (S). Model effects include: group (resident, translocated), linear time trend, quadratic time trend, constant, and included an additive model (+) of main effects.

| Model | K | Deviance | AIC_c | Delta AIC_c | w_i |
|-----------------------|-----|----------|---------|---------------|-------|
| S linear | 2 | 51.08 | 55.13 | 0.00 | 0.25 |
| S group | 2 | 51.19 | 55.24 | 0.12 | 0.24 |
| S constant | 1 | 54.00 | 56.01 | 0.89 | 0.16 |
| S quadratic | 3 | 50.10 | 56.20 | 1.07 | 0.15 |
| S group + linear | 3 | 50.42 | 56.52 | 1.39 | 0.13 |
| S group + quadratic | 4 | 49.53 | 57.70 | 2.58 | 0.07 |

Table 2.4 Summary of model selection results for daily survival rates DSR of broods accompanied by resident and translocated female Evermann's Rock Ptarmigan on Agattu Island, Aleutians, Alaska, 2005-2006. Analysis performed in Program MARK. Model fit is described by Deviance, the number of parameters (K), the difference in Akaike's Information Criterion corrected for small sample size from the best-fit model (ΔAIC_c), and AIC_c weight (w_i), which indicates the relative likelihood of each model given the candidate model set and sum to 1. Models are listed beginning with the best-fitting model and sorted by ΔAIC_c . Model structure estimated apparent survival (S). Model structure estimated apparent survival (S). Model effects include: group (resident, translocated), linear time trend, quadratic time trend, constant, and included an additive model (+) of main effects.

| Model | K | Deviance | AIC_c | Delta AIC_c | w_i |
|-----------------------|-----|----------|---------|---------------|-------|
| S linear | 2 | 51.08 | 55.13 | 0.00 | 0.25 |
| S group | 2 | 51.19 | 55.24 | 0.12 | 0.24 |
| S constant | 1 | 54.00 | 56.01 | 0.89 | 0.16 |
| S quadratic | 3 | 50.10 | 56.20 | 1.07 | 0.15 |
| S group + linear | 3 | 50.42 | 56.52 | 1.39 | 0.13 |
| S group + quadratic | 4 | 49.53 | 57.70 | 2.58 | 0.07 |

Table 2.5 Comparison of reproductive parameters among populations of island and mainland Rock Ptarmigan.

| Parameter | Mean | n | Location | Reference |
|-------------------------------------|------------------------|-----|-------------------|--|
| Initiation Date | | | | |
| | 8 to 16 June | 24 | Agattu Island | This study |
| | 9 June | 34 | Windy Lake, NWT | Cotter 1991 |
| | 11 June | 28 | Sarcpa Lake, NWT | Brodsky 1988 |
| | 12 June | 1 | Bathurst Is., NWT | MacDonald 1970 |
| | 15 June | 52 | Ungava Penn., PQ | Oplinski 1986 |
| Clutch Size (1st nests) | | | | |
| | 5.8-8.4 | 25 | Svalbard | Steen and Unander 1985 |
| | 6.6 | 178 | Scotland | Watson 1965 |
| | 6.8 ± 0.3 | 15 | Italy | Scherini et al. 2003 |
| | 6.8 ± 0.3 to 8.1 ± 0.2 | 26 | Agattu Island | This study |
| | 7.1 ± 0.1 | 101 | Alaska | Weeden 1965 |
| | 8.7 ± 0.2 | 38 | Windy Lake, NWT | Cotter 1991 |
| | 8.8 ± 0.5 | 20 | Sarcpa Lake, NWT | Brodsky 1988 |
| Hatching Success (%) | | | | |
| | 50.0 | 24 | Italy | Scherini et al. 2003 |
| | 63.8 | 47 | Windy Lake, NWT | Cotter 1991 |
| | 67.0 | 101 | Alaska | Weeden 1965 |
| | 72.2 -80.0 | 28 | Agattu Island | This study |
| Fledging success (%) | | | | |
| | 31-88 | 28 | Agattu Island | This study |
| | 53 | 47 | Windy Lake, NWT | Cotter 1991 |
| | 60-77 | 101 | Alaska | Weeden unpubl. data, cited in Johnsgard 1973 |
| | 63 | 178 | Scotland | Watson 1965 |
| No. young fledged/successful clutch | | | | |
| | 1.2-6.2 | 153 | Scotland | Watson 1965 |
| | 3.3-4.0 | 11 | Agattu Island | This study |
| | 4.5-8.9 | 63 | Svalbard | Steen and Unander 1985 |
| | 5.3 | 208 | Alaska | Weeden 1965 |
| | 7.0 | 26 | Windy Lake, NWT | Cotter 1991 |

Figure 2.1 Study site and release locations for translocations of Evermann's Rock Ptarmigan, Agattu Island, Near Islands group, Alaska 2003-2006. The black points represent the release sites. The border outlines the mountainous section of the island.



Figure 2.2 Daily survival rates of Rock Ptarmigan nests of resident and translocated females on Agattu Island, Aleutians, Alaska, 2005-2006 ($n = 27$). We based estimates on model averaged results from candidate models in Program MARK. The nesting period was composed of 63 exposure days. Rock Ptarmigan incubation is 21 days.

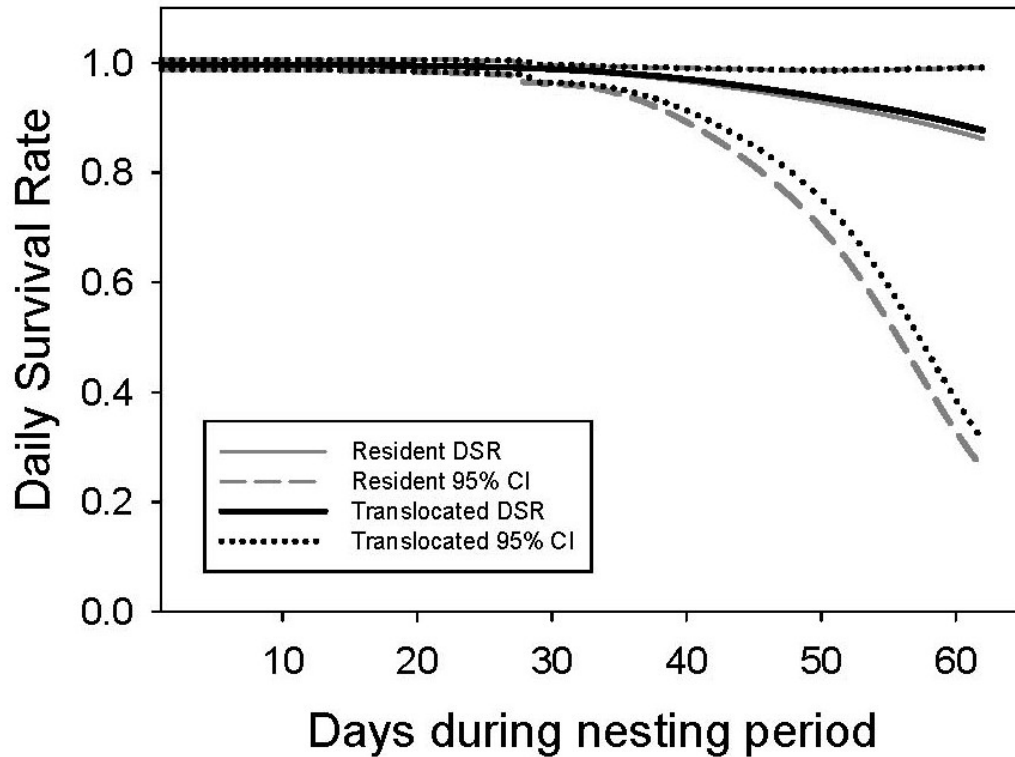
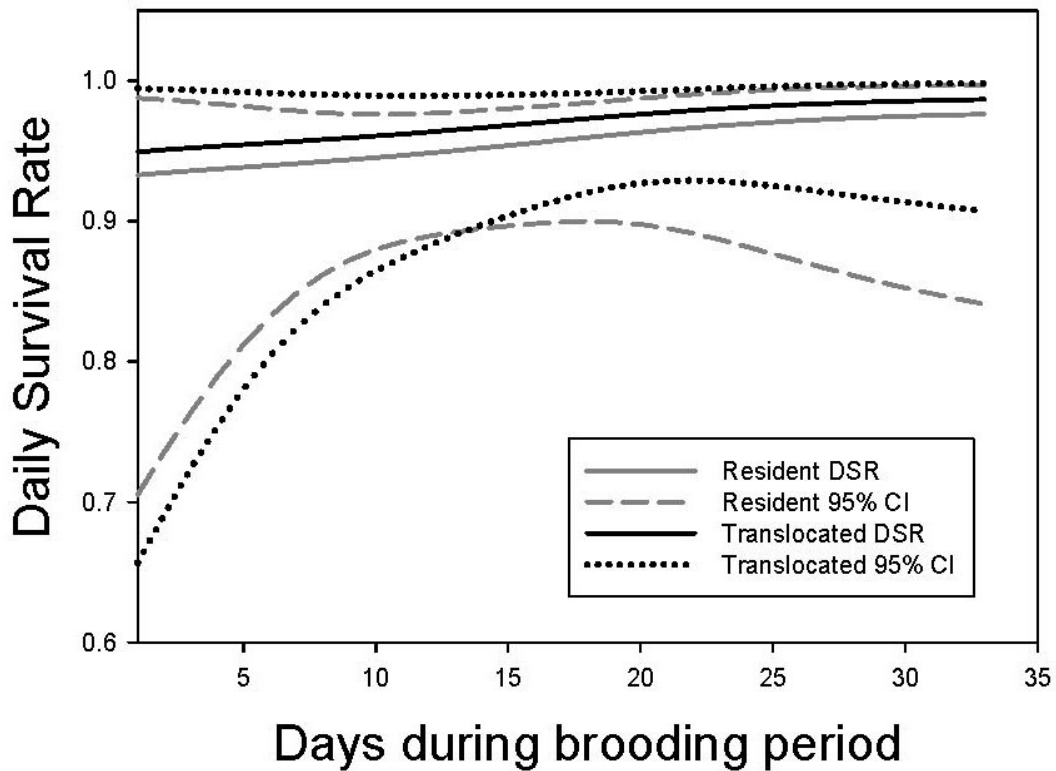


Figure 2.3 Daily survival rates of Rock Ptarmigan broods of resident and translocated females on Agattu Island, Aleutians, Alaska, 2005-2006 ($n = 21$). We based estimates on model averaged results from candidate models in Program MARK. The brood rearing period was composed of 34 exposure days. Chicks were considered fledged at 15-25 days of age.



CHAPTER 3 - NEST SITE SELECTION AND MOVEMENTS OF A RECENTLY TRANSLOCATED ISLAND PTARMIGAN POPULATION

Robb S.A. Kaler and Brett K. Sandercock

ABSTRACT

Translocations were used to reestablish a breeding population of Evermann's Rock Ptarmigan (*Lagopus mutus evermanni*) on Agattu Island in the western of the Aleutian Archipelago, Alaska. We translocated 75 ptarmigan from Attu to Agattu during 2003-2006. During 2005 and 2006 we used radio-telemetry to monitor the post-release movements, seasonal survival, and reproductive success of 35 females (15 resident and 20 translocated). We compared performance of recently translocated birds to resident birds that were the result of previous translocations. Nest sites of translocated females were located an average distance of 4.2 km from their release locations and were not different from nest locations of resident females with regard to topographical features or nest cover. Female nest site selection was influenced by percent composition of rock and forb coverage but was unaffected by slope, aspect, or general habitat. After leaving the nest, broods of both resident (mean +62 m \pm 21.8 SD) and translocated (+108 m \pm 25.3 SD) females moved to higher elevations. Brood home range sizes were similar for resident (3.6 ha, SE = 1.6) and translocated (6.7 ha, SE = 2.4) females, distances traveled between the nest site and the arithmetic center of the brood home range were greater for translocated females. Overall, we conclude that translocations are an effective technique for reestablishing island populations of Rock Ptarmigan. Our results provide baseline estimates of translocation success which will benefit future projects to reestablish endemic populations of ptarmigan and landbirds elsewhere in the Aleutian Islands.

INTRODUCTION

Translocations of wildlife to establish new populations or supplement existing populations (IUCN 1987; 1995), provides a powerful tool which can expedite the restoration of degraded ecosystems (Griffith et al. 1989, SER 2002, Austin 2004). In the simplest circumstances, restoration of an ecosystem consists of limiting or removing a specific disturbance, which in turn permits an independent and natural ecosystem recovery (Dobson et al. 1997, Austin 2004). In other situations, despite worthwhile interventions, damaged ecosystems may require direct mitigation to aid in restoring lost biodiversity. For example, the isolated nature of insular ecosystems makes their plant and animal species more vulnerable to habitat degradation and more difficult to restore (Craig 1990, Serena 1995). The release of exotic mammals, both deliberate and accidental, has had devastating effects on the native flora and fauna of many oceanic islands (Savidge 1987, Williams et al. 2003, Croll et al. 2005).

Historically, the Aleutian Islands had no native terrestrial mammals west of Umnak Island. Many island populations of native birds were dramatically impacted by the deliberate introduction of Arctic (*Alopex lagopus*) and red foxes (*Vulpes vulpes*) by Russian fur farmers during the 18th and 19th centuries (Bailey 1993, Williams et al. 2003). Depredation of eggs, young and breeding birds by foxes led to population declines and local extirpation of seabird and waterfowl populations on many islands. By 1936, Evermann's Rock Ptarmigan (*Lagopus mutus evermanni*), a unique dark plumaged subspecies that is endemic to the Near Islands, had been extirpated from all islands in the Near Islands group except Attu (Murie 1937, 1959). In 1968, the US Fish and Wildlife Service (USFWS) began removing foxes from Agattu and by the late 1970's foxes were no longer present (Bailey 1993, Ebbert and Byrd 2002). Although migratory elsewhere in Alaska, Rock Ptarmigan in the Aleutian Islands are resident (Holder and Montgomerie 1993). However, recent offshore observations of Willow Ptarmigan (*Lagopus lagopus*) landing and taking off from the ocean surface provide some insight into patterns of dispersal (Zimmerman et al. 2004). Nonetheless, despite distances between islands being less than those than those covered by migrations of inland ptarmigan, no ptarmigan dispersed across the 28-km channel from Attu Island to reestablish a population on Agattu Island after fox removal.

Restoration of natural biodiversity following removal of introduced predators is a primary objective of the US Fish and Wildlife Service (USFWS). Beginning in 2003, Alaska Maritime National Wildlife Refuge (USFWS) initiated a four-year reintroduction program to restore Evermann's Rock Ptarmigan to Agattu by translocating individuals from a source population on Attu Island (Appendix A). Translocations have been widely used as a management tool for grouse populations in North America (Griffith et al. 1989, Toepfer et al. 1990, Musil et al. 1993). For example, translocations of White-tailed Ptarmigan have been used to introduce new breeding populations of White-tailed Ptarmigan (*Lagopus leucurus*) in the Sierra Nevada of California (Clarke and Johnson 1990), the Uinta Mountains of Utah (Braun et al. 1978), and the Rocky Mountains of Colorado (Hoffman and Giesen 1983).

Because of the success of the above introductions, we examined whether translocations could serve as a viable option for the reintroduction of Rock Ptarmigan to its historic range in the Aleutians. In particular, we studied differences between recently translocated and resident females to determine: 1) whether nest site selection by translocated Rock Ptarmigan was different than resident females and if selection was based on differences in habitat, topography, or ground cover composition; and 2) whether site fidelity and brood home range varied between recently translocated and resident female Rock Ptarmigan. If released ptarmigan dispersed widely and outside of suitable habitat or experience high mortality rates following release while searching for suitable habitat, then other methods for reintroduction may be warranted.

METHODS

Study Area.---We monitored nest site selection and brood movements of recently translocated and resident Evermann's Rock Ptarmigan during two field seasons from May to August 2005 to 2006, on Agattu Island (52.43° N, 173.60° W). Agattu is part of the Near Islands group found farthest west in the Aleutian Archipelago (Fig. 2.1) and has an area of 22,474 ha, the majority of which is below 230 m elevation and is dominated by maritime tundra. A mountain range composed of seven sub-massifs lies along the north side and extends from Armeria Bay eastward to Krugloi Point (Fig. 2.1). The

westernmost sub-massif is composed of five peaks that extend to 518 - 630 m, and includes the highest point on the island (630 m).

Agattu Island is comprised of five major habitats. At elevations above 350 m, fellfields and scree slopes on the exposed ridges and summits are interspersed with dwarf shrub mats of crowberry (*Empetrum nigrum*) and decumbent willows (*Salix arctica*). Middle elevations (250 to 350 m) are dominated by upland dwarf shrub mats composed of dwarf willows and heaths (e.g., crowberry is joined by hardy shrubs [*Phyllodoce aleutica*, *Salix arctica*, *Cassiope lycopodioides*] and forbs [*Saxifraga* spp., *Geum calthifolium*]). The lower (150 to 250 m) sloping hillsides of the massif are dominated by two plant community types: tall forbs (*Geranium erianthum*, *Anemone narcissiflora*, *Geum calthifolium*), and dwarf shrub meadows characterized by crowberry/lichen tundra (*Empetrum nigrum*, *Cladina* spp.). Small, isolated patches of willow (*S. rotundifolia*) uncommonly occur in sheltered areas found at the base of the slopes. Below 150 m elevation, wet meadow communities are found in sheltered valley bottoms and are dominated by sedges (*Carex* spp.) and Alaska cottongrass (*Eriophorum russeolum*) with numerous wetlands, ponds, lakes, and streams. Last, the lower beach strand plant community forms a narrow fringe around the island. These areas are dominated by beach rye (*Leymus arenarius*), beach fleabane (*Senecio pseudo-arnica*), and beach greens (*Honckenya peploides*).

Temperatures are characteristic of a maritime environment and exhibit limited daily and annual variation. A weather station on Shemya Island, approximately 30 km to the northeast, reported a mean annual temperature of approximately 3.9° C with precipitation occurring on >200 days each year, averaging 80.6 cm per year (1949 to 1995; Western Regional Climate Center). Wind velocities average 42 kilometer per hour on Shemya; gusts of 165-200 kilometers per hour are not uncommon.

Field Methods.---We captured Evermann's Rock Ptarmigan at Attu Island using noose poles and ground nets and conducted five batches of releases at Agattu: four during late-May 2003-2006 and one during September 2003. In May through August 2005-2006, we remained at Agattu and conducted a radio-tracking study to monitor seasonal survival, reproductive success of translocated ptarmigan, nest site selection, and brood movements of recently translocated ptarmigan (Chapter 2). Resident birds were also captured and

simultaneously monitored via radio telemetry. Age-class (yearlings [1 year] and adults [2+ year]) of all captured individuals were assigned based on shape and pigmentation: primaries 9 and 10 were pigmented and tapered in yearlings, but white and rounded in adults (Weeden and Watson 1967, Parker et al. 1985).

During the two-year radio-tracking study, translocated ptarmigan were transported and released at one of two coastal beach sites to minimize handling. In June 2005, birds were released on the south side of Agattu Island (Fig. 2.1, Karab Cove). In 2006, after determining ptarmigan preference for the montane strata of the island, we released birds closer to the mountains from a release location at Binnacle Bay on the north side of the island. Prior to release, all ptarmigan were uniquely color banded and each female was fitted with either a bib-style radio collar (2005: 15 g, Telemetry Solutions, Concord, CA), or a necklace-style radio collar (2006: 6 g, Holohil Ltd., Carp, Ontario, Canada) with a battery life of 12-18 months. Radio collars were equipped with mortality switches to facilitate detection of dropped transmitters or mortality events.

We began radio-tracking ptarmigan movements immediately after release using a 3-element Yagi antenna and portable radio receiver (R2000, Advanced Telemetry Systems, Isanti, MN). Nest and brood locations were monitored using the “loudest signal method” (Appendix B; Springer 1979). Females on nests or with broods were tracked and circled at a distance of 30 to 50 m to reduce location error (Hupp and Ratti 1983, Garrott et al. 1986). We avoided flushing ptarmigan while obtaining their locations during the early brood rearing stage (<15 days post-hatch). Older broods (15-25 days old) were located and counted to determine fledging success rates (Chapter 2); if observers were unable to obtain an accurate brood count from ≥ 50 m (i.e., obscured by vegetation), then broods were flushed. However, brood flushing was rarely employed (<5 flush events during the two-year radio telemetry study). All nest and brood locations were recorded in Universal Transverse Mercator (UTM) coordinates using a hand held Global Positioning System receiver (GPS; Garmin GPSmap 76; Garmin International Inc., Olathe, KS). Locations were downloaded using DNR Garmin Version 5.1.1 software (Minnesota DNR, 2001) and later entered into Geographical information System (GIS) using ArcView GIS 3.2a software (Environmental Systems Research Institute, Inc.).

Nest site characteristics were measured after termination of nesting. For each nest, we collected vegetation data at the nest site and four dependent non-use plots placed at 50 m from the nest in each of the four cardinal directions (Figure 3.1). Using a 25-m radius plot at each nest, or non-use point, we estimated percentage classes of each general vegetation type present with the classification system of Viereck et al. (1992). Topography data (Appendix C) were also recorded for each 25-m vegetation plot. Using a 5-m radius plot centered around the nest, or non-use point, ground cover data was collected using a scoring system to classify estimated percentages into eight groups (Appendix B). Data were converted to the median point of each group (e.g., for a score of 5, the value 38 was used in the analysis [$26+50/2=38$]). To maintain consistency across plots, a single observer estimated all measurements.

Home Range and Habitat Use.---To calculate minimum convex polygon (MCP) home ranges and movement statistics for resident and translocated ptarmigan, we used the animal movement extension (Hooge and Eichenlaub 1997), designed for use with ArcView GIS software. We quantified brood home range size using MCP based on points collected during a 5-week period (30 June to 9 August). We excluded points collected within the first three days after hatching because most females remained in the nest area during this time period. Because all locations receive equal weight using MCP methods, estimates of home range values may be biased high (Jennrich and Turner 1969, Barg et al. 2005). We estimated an arithmetic center point of each brood home range and calculated straight-line distances between arithmetic center points and the respective nest location. In the case of translocated females, we also calculated straight-line distance between the release site and each female's nest location. Change in elevation between nest site and brood home range was calculated based on the average elevation of collected points subtracted from the nest elevation.

We conducted systematic searches of the montane strata on Agattu to calculate a minimum population size and determine the amount of available habitat. An observer searched suitable habitat for ptarmigan (vocalizing males, visual sightings) or signs of ptarmigan (fecal pellets, molted feathers). Criteria used to classify a male as territorial included flight song displays, rattle calls, paired walking, and defense of females (MacDonald 1970, Holder and Montgomerie 1993). In addition to recording GPS

locations for all sightings and signs of ptarmigan, observations of suitable habitat were plotted on topographic maps (scale 1:25,000). Non-territorial males and females may not have been detected during these surveys (Braun et al. 1973, Frederick and Gutiérrez 1992). However, winter feces of ptarmigan persist for long periods if they contain coarse woody fibers, and permit assessment of habitat use for up to two years (Braun 1993).

Statistical Analysis.---To help determine habitat characteristics associated with Rock Ptarmigan nest sites, we used discriminant function analysis (DFA) to compare nest plots and non-use plots. A stepwise discriminant analysis with 10 (25-m radius plots) and eight (5-m radius plot) habitat characteristics (Appendix C) was used to assess which measured characteristics best discriminated between nest sites and non-use sites (Johnson 1998). A significance level of $\alpha = 0.5$ was used for parameter entry into the analysis while an $\alpha = 0.2$ significance level was used for parameter retention (Johnson 1998). We then used DFA on the resulting significant habitat characteristics to discriminate between the two populations. A cross-validation procedure was used to determine misclassification rates for nest and non-use sites (Johnson 1998). Analyses were conducted using Proc STEPDISC and Proc DSCRIM (SAS Institute, 2005). Prior to our analysis, we arcsine-transformed all vegetation variables collected as percentages of coverage to better meet the assumptions of normality.

Differences in brood home range size between resident and translocated ptarmigan were compared using t-tests (Proc TTEST, SAS Institute 2005). All means are presented with standard errors (SE) unless otherwise noted. We used a significance level of $\alpha \leq 0.05$.

RESULTS

We radio-tracked movements of 11 recently translocated female ptarmigan (nine in 2005, two in 2006) and 17 resident birds (six in 2005, 11 in 2006; four females were followed in both years) during the two-year radio telemetry study. One resident female was censored due to harness failure. Due to nest failures ($n = 5$) and brood loss ($n = 10$), our analysis of brood home range and distance moved between nest sites and the arithmetic center of the brood home range was calculated for six resident and eight translocated females. Average number of locations for MCP calculations was 4.4 (SE =

0.3, range 3 to 6, $n = 14$) and yielded one location per week during the first 5-weeks of the brood rearing period (30 June to 9 August). Our analyses were conducted for resident and translocated ptarmigan from a total of 52 and 40 points, respectively.

Nest Distance from Release Site.---We calculated straight-line distances from release locations to nest sites for all 11 translocated females. Nest sites of translocated females averaged 4.2 km from their respective release location (SE = 0.7, range 0.7 to 7.6 km, $n = 11$). Average distance of release location to nests sites was greater for the nine females released in 2005 on the south side of the island than the two females released in 2006 close to high elevation areas (2005: mean distance 5.1 km, SE = 1.9, range 0.7 to 7.6 km, $n = 9$; 2006 Binnacle Bay: mean distance 2.7 km, SE = 1.6, range 1.1 to 4.3 km, $n = 2$).

Nest-site characteristics and selection.---We detected no difference between nests of resident and translocated female nests based on elevation (Table 3.1). Thus, we pooled resident and translocated nest data. Nests were simple 3-5 cm deep scrapes with eggs usually laid on a thin layer of vegetation and a few ptarmigan breast feathers. Most nests were well concealed; 50% (14 of 28 nests) were placed beneath a large rock or boulder (>30 cm diameter) and 46.4% (13 of 28 nests) were found among vegetation. Translocated females nested more often below rocks (60.0%, 6 of 10) than among vegetation (30%, 3 of 10); one translocated female nested in a depression (depth = 15 cm) in the open with no coverage. Resident nests were associated with rocks (44.4%, 8 of 18 nests) nearly as often as vegetation (55.5%, 10 of 18 nests).

An additional 112 non-use plots were used with the 28 nest site plots in the discriminant function analyses (DFA) at two scales: 5-m radius plots using eight variables to quantify ground cover composition and 25-m radius plots using 10 variables describing general habitat types and topographic features. At the 5-m scale, three of the eight habitat characteristics were selected in the stepwise procedure that best discriminated between nest sites and non-use sites. The significant parameters retained in the analysis ($P < 0.2$) were rocks >20 cm ($F_{1, 138} = 8.33$, $P = 0.005$), forbs ($F_{1, 138} = 8.48$, $P = 0.058$), and rock <20 cm ($F_{1, 138} = 1.91$, $P = 0.169$). DFA with all eight habitat characteristics correctly classified nest sites 46.4% (13 of 28) and non-use sites 68.8% (77 of 112) of the time. When only the three selected habitat characteristics were used,

the ability to discern between site types marginally increased. The DFA procedure using the subset had poor success and correctly classified nest sites 67.9% (19 of 28) of the time; sites without nests were correctly classified 65.2% (73 of 112) of the time. The proportion of rocks >20 cm diameter and amount of forbs present were the most important habitat characteristic in differentiating between Rock Ptarmigan nests and non-use sites (rock <20 cm: $F_{1, 138} = 8.33, P = 0.005$; forbs: $F_{1, 138} = 8.48, P = 0.058$). Nest locations could not be differentiated from non-use plots at the 25-m radius scale. The stepwise procedure selected two variables that best discriminated between nest plots and non-use plots (open low scrub: $F_{1, 138} = 20.17, P < 0.001$; mesic forbs, $F_{1, 138} = 1.95, P = 0.165$); however, the DFA procedure using the subset of variables did not improve classification (21.4%, or 6 of 28, nests were correctly classified with or without using the subset of variables). These results indicated that birds may be selecting for measured habitat features in their nest site selection; however, these features seem to have little to do with slope, aspect, or general habitat and instead are influenced by percentages present of particular ground cover characteristics.

Brood Home Range.---Home ranges of female ptarmigan with broods were twice as large for translocated females (6.7 ha, SE = 2.4, range 0.5 to 16.6 ha, $n = 7$) than resident females (3.6 ha, SE = 1.6, range 0.5 to 10.0 ha, $n = 5$) but did not differ significantly ($t = -0.89, df = 10, P = 0.40$). Mean home range size when translocated and resident females were pooled was 5.5 ha (SE = 1.6) and ranged from 0.5 to 16.6 ha ($n = 12$). After departing the nest area, all broods moved to higher elevations. Changes in elevation between resident (+62 m \pm 21.8, range 15 to 157 m, $n = 6$) and translocated (+108 m \pm 25.3, range 34 to 233 m, $n = 9$) were not significantly different ($t = -1.40, df = 13, P = 0.19$).

Brood Movement.---Translocated females with broods moved an average distance of 845 m (SE = 243.2) and ranged from 171 to 2185 m ($n = 8$) from their nest site to the arithmetic center of the brood home range; movements for resident females averaged 190 m (SE = 65.2) and ranged from 47 to 394 m ($n = 6$). These estimates of distances between a female's nest site and the arithmetic center of the brood's home range differed between resident and translocated females ($t = -2.27, df = 12, P = 0.04$).

Population and Habitat Surveys.---During systematic surveys of the montane strata and the lowland plateau between Karab Cove and the massif running along Agattu's northeast side, we located 20 territorial males in 2005, and 24 territorial males in 2006. These totals did not include translocated males ($n = 9$), because they were unable to establish territories in the same year they were released. Radio-marked males ($n = 7$) exhibited unpredictable movements and remained transient throughout the reproductive period after release on Agattu. The results of our survey indicated that most of the breeding habitat in the montane strata was suitable, but was unoccupied or loosely defended by males. In some areas of the montane strata with south-facing aspects, boundaries of male territories were continuous (i.e., bordered by neighboring males); however, we never observed any aggression between females, and only once observed a direct male-male interaction. Otherwise, territory behaviors of males were restricted to flight song displays, rattle calls, and defense of females.

With the exception of one translocated female, which nested in a riparian area 700 m from the southern release location, we detected no use, or signs of use, in the lowland areas between Karab Cove and the mountains. The area was traversed daily in 2005 (15 June – 7 August) and walks ranged from 4.5 to 10 km, one direction. The lower elevation areas on Agattu are similar to habitats on Attu, where the source population was captured prior to translocation. Nevertheless, nearly all ptarmigan observations and signs of use were found in areas above 150 m, with the majority occurring above 200 m elevation and generally on slopes with south-facing exposure. Small (4-10 ha), isolated patches of potential breeding habitat were identified on the north and east sides of the montane strata, but we did not detect any breeding activity by ptarmigan. These areas may be sub-optimal or marginal breeding habitats, perhaps due to spatial variation in timing of snow melt or food availability.

DISCUSSION

This research is the first comparative study examining differences between nest site selection and brood movements of a recently translocated and resident Rock Ptarmigan and provides insight into the life history of an island ptarmigan species. Our major conclusions were three-fold: 1) translocated females quickly left the release site

and moved to high elevation areas, where they were able to find suitable nesting and brood rearing habitat; 2) nest site selection and brood home range size of recently translocated and resident females were similar with regard to topographical features and nearly all were found in the montane strata of the island; and 3) preferred habitat for breeding ptarmigan on Agattu appears to be at higher elevations on sloping south-facing hillsides which provide sufficient cover and food for nesting and brooding rearing females. For birds that survived a 2-week acclimation period, we found a 100% seasonal survival rate for translocated female ptarmigan on Agattu (Chapter 2). Most females moved to higher elevations shortly after release on the island, presumably because females were searching for suitable nesting areas (Bergerud and Graston 1988). Centers of brood-use areas were farther from respective nest sites of translocated female than nest sites of resident females, but brood home range sizes were similar between the two groups. Our results indicate that the montane habitat of Agattu, were preferred and were capable of supporting a ptarmigan population with demographic characteristics that are representative of other viable populations (Chapter 2). Overall, our results support the use of translocation as a viable means to restore island ptarmigan populations in the Aleutians.

Post-release Movement and Nest Site Selection.---During our two-year study, we located ptarmigan from all five batches of releases (2003-2006). These results indicate that the three coastal release locations were suitable for successful release of translocated ptarmigan during the initial acclimation period on Agattu. Ptarmigan ranged widely, but quickly settled in preferred habitats. Karab (2003, 2005) and McDonald Coves (2004) provided habitat similar to the grassy valley bottoms where the source population was found breeding on Attu. Binnacle Bay was chosen as a release site in 2006 because of its proximity to higher elevation areas on the island where ptarmigan were found breeding in 2005. Aside from the preliminary movements of released birds, we detected no sign or sightings of ptarmigan below 100 m elevation in the lowland area between Karab Cove and the mountains with one exception (see Brood Home Range). We conclude that lower areas (<100 m elevation) are able to sustain translocated ptarmigan, and provide the resources needed to nest and rear a brood; however, higher elevation areas (>150 m elevation) were preferred by translocated and resident ptarmigan.

In order for successful reproduction to occur, female ptarmigan require food and a suitable nest site, preferably one which provides protection from weather, concealment, and fewer predators (Bergerud and Gratson 1988). In our comparisons of translocated and resident female nest sites on Agattu, we found no differences in topographic features or amount of nest cover. The majority of ptarmigan nested on south-facing slopes, more frequently on the lower third of the hillside. The results of our vegetation and habitat analysis at two scales (5-m and 25-m radius) weakly suggests that upon locating a larger area of suitable nest habitat, female ptarmigan may be selecting a nest site based on a suite of finer resolution characteristics. Nest plots compared to dependent non-use plots varied in the percent composition of rock and forb cover, both of which provide nest concealment. Although there were subtle differences between nest and non-use plots with respect to percentage of cover types, these plots were too similar to detect differences in nest site selection; however, nest concealment is probably the most important factor driving nest site selection.

Gardarsson (1988) reported that while typically nesting among good cover, nest locations of Rock Ptarmigan in Iceland were often associated with preferred foods (*Vaccinium* spp., *Salix herbacea*). The mean distance between 18 nests and female feeding location in Iceland was 131 ± 14 m. Our observations of nest locations on Agattu may also have been influenced by access to food, as females were occasionally observed feeding within 100 m of nests, often in moist depressions associated with late snow melt which contained ericaceous food species (*Empetrum nigrum*, *Vaccinium* spp.). In our analysis we were unable to examine vegetation of foraging areas. Nonetheless, the proximity of areas with good nest concealment (rocks, shrubs, forbs) to preferred feeding locations may be an important cue to identifying optimal Rock Ptarmigan nesting habitat. Furthermore, preferred feeding areas and timing of snow melt in areas may further elucidate optimal nesting areas of ptarmigan on Agattu.

Clutch initiation is highly synchronized among Rock Ptarmigan females and has been associated with the amount of snow covering nesting areas (Watson 1965, Weeden 1965a, Steen and Unander 1985, Brodsky 1988, Cotter 1999). Due to the maritime climate of Agattu, snow accumulation on our study area was minimal with only isolated patches remaining at the onset of clutch initiation (early June); however, breeding

chronology on Agattu may still be associated snow melt. Female ptarmigan may time hatching of clutches with plant phenology, which would benefit chick growth and survival. Additionally, if females synchronized clutch initiation with snow melt in areas near nests, females could minimize time off the nest by reducing travel time between foraging areas and nest sites, limiting their exposure to predators and expediting the incubation period.

Brood Home Range and Site Fidelity.---We observed a greater range of movement from nest site to brood rearing habitats for translocated females. Bergerud and Graston (1988) point out that greater movement distances by females with broods may be a result of nest site selection without considering the location of suitable brood habitat. In some cases, available nest sites or nest spacing or both might also cause females to nest in inferior habitats. We do not believe this is the case on Agattu; instead, movements of translocated females, which ranged higher and farther from nest areas than resident females, appeared to continue ascending in elevation until upward movement was no longer possible, at which point the brood became sedentary. Resident broods made upward movement, but never to the windswept summits. Translocated females were likely searching for areas with adequate cover, food, and few predators; we speculate that alpine habitats on Agattu met these requirements. We do not know why resident broods did not exhibit the same rate of increase in elevation as translocated females, but familiarity with the area may be a factor. Another possibility might be the variation in timing of hatching. Translocated broods left nests two weeks later than resident broods. Following their first week after hatching, chicks gradually shift their diet from animals to plants (Spidsø 1980); the delay in hatching may have caused translocated females to make more rapid uphill movements to locate insect prey during the early stage of chick development. Additionally, these movements may have been because nutritional value of plants at lower elevations had declined due to a combination of age and temperature factors (Van Soest 1968). After our departure from Agattu, resident broods may have continued to move to higher elevations might have eventually reached the upper portions of the montane areas.

Compared to values of home range size reported from studies of Rock (Steen and Unander 1985), Willow (Bergerud and Huxter 1969, Erikstad 1985, Bergerud and

Gratson 1988), and White-tailed Ptarmigan (Schmidt 1988), our mean brood home range pooled over both groups was considerably smaller (Table 3.2). Two possible explanations may explain the differences in home range size of broods on Agattu and elsewhere. First, food quality and quantity may be high on Agattu because of the lack of terrestrial herbivores, such as ptarmigan and geese, during the past 100 years. Without regulation by grazing pressures, plant density is likely to increase rapidly, particularly if relief from grazing continues for an extended time period. Broods on Agattu may be exhibiting minimal movement patterns compared to other areas because food is uncommonly abundant. A similar pattern was described for introduced reindeer herds to islands in the Bering Sea. Initially, reindeer populations increased in size from 29 animals to 6,000 in <20 years; however, numbers crashed the following winter to <50 individuals and was attributed to the interaction between climatic factors and food supply (Scheffer 1951, Klein 1968).

Our second explanation is based on the small size of the ptarmigan population on Agattu. Broods exhibiting wide ranging movements are more likely to experience higher chick mortality (Erikstad 1985), thus females should minimize movements whenever possible. A low brood density on Agattu permits females with broods to remain more stationary once adequate resources are found because competition with other broods is minimal. Furthermore, potential predators would be less likely attracted to preferred brood-rearing areas if prey sources are relatively low. Brood densities reported from other studies were considerably higher than levels observed on Agattu, including descriptions of chick swapping among females (Gardarsson 1988). However, Bergerud and Huxter (1969) reported observing no evidence of density affecting brood movements of Willow Ptarmigan in Newfoundland. Erikstad (1985) thought the lack of overlap in brood home range may be a spacing behavior, but his observations were mainly of broods in lower-quality habitats. We conclude that the small home ranges of ptarmigan broods, along with the upward movements observed, was not correlated with brood density, but rather part of a food searching behavior. Upon locating suitable habitats, brood movement decreased such that chicks could spend more time feeding and less time traveling.

Most studies of Rock Ptarmigan brood home ranges from mainland areas report patterns of uphill movements from the nest area 1-2 days after hatching with little regard to territorial boundaries of males (Weeden 1965b, Bergerud and Graston 1988). On the Norwegian Island of Svalbard, Steen and Unander (1985) found the opposite; broods usually moved downhill after hatching, where the vegetation was denser at lower elevations; however, these areas also contained the preferred plants of the chick's diet (*Polygonum* spp., *Salix* spp., *Saxifraga* spp.), and thus provided both food and cover for the larger adult female and the rapidly growing young. Preferred brood-rearing areas on Svalbard were often used by several broods at one time, covered an area of 50 ha, and were approximately 200 m below their original territories (Steen and Unander 1985). Indeed, several studies reported common brood area-use and exchanges of chicks in areas of high brood density are common (Weeden 1965b, Bergerud and Huxter 1969, Steen and Unander 1985, Gardarrson 1988). On Agattu, we observed some overlap among brood ranges, but never observed any interaction among broods.

One translocated female, who eluded detection until the early brood-rearing period, was discovered in a riparian area 700 m inland and at 30 m elevation. This female, who successfully reared her brood to the 15-25 day period, moved to the highest elevation area in the vicinity (120 m), then continued moving north toward the montane strata of the island. Nonetheless, this observation provides support that lower elevation areas of Agattu provide ptarmigan breeding habitat, though not preferred.

A gradient of habitat quality likely occurs on Agattu, with south-facing slopes above 150 m elevation being preferred by males and females. Unander and Steen (1985) described flat homogenous areas, like valley bottoms, plateaus and areas adjacent to the sea, to be not well suited for nesting due to late thaw and predator risk. Intriguingly, the source population on Attu (and much of the Aleutian Archipelago) breeds on grassy hills along the coastal plane of an otherwise mountainous island. Release from intraspecific competition for resources with Willow Ptarmigan, found where their ranges overlap in other parts of Alaska, may allow Rock Ptarmigan to broaden their use of habitats (Weeden 1969). The restoration of Rock Ptarmigan on Agattu helps elucidate the life history traits (habitat selection, behavioral adaptation, and breeding biology) of this unique Aleutian subspecies and provides an area warranting further study.

Management Implications.---Using movement patterns and habitat selection by translocated ptarmigan, we determined that translocation of Rock Ptarmigan provides a viable option for restoring and augmenting other populations in the Aleutians. Translocated female ptarmigan exhibited high rates of survival while moving from coastal release locations to higher elevation nesting habitats. Our translocated females had brood movement patterns similar to resident females, but ranged farther from nest locations with their broods and to higher elevations. Lack of familiarity with the area by translocated females did not reduce brood success, as females exhibited chick production rates similar to resident hens (Chapter 2). While coastal release locations appear to be sufficient, we recommend the use of areas closer to breeding habitats, if known, to reduce exposure to predators and expedite the nesting process.

Restoration of Evermann's Rock Ptarmigan to Agattu was successful using wild birds held for up to 48 hours. Should need arise to translocated birds from populations of the other six endemic subspecies found breeding in the Aleutian Islands, then our methods will expedite the re-establishment or augmentation of these populations. Our results provide insight in the life history traits of Rock Ptarmigan as well as the factors which potentially govern reintroduction success. With the continued removal of foxes from other islands in the Aleutians, our results provide critical information needed for establishing reintroduction objectives, guidelines, and benchmarks by which to assess program status.

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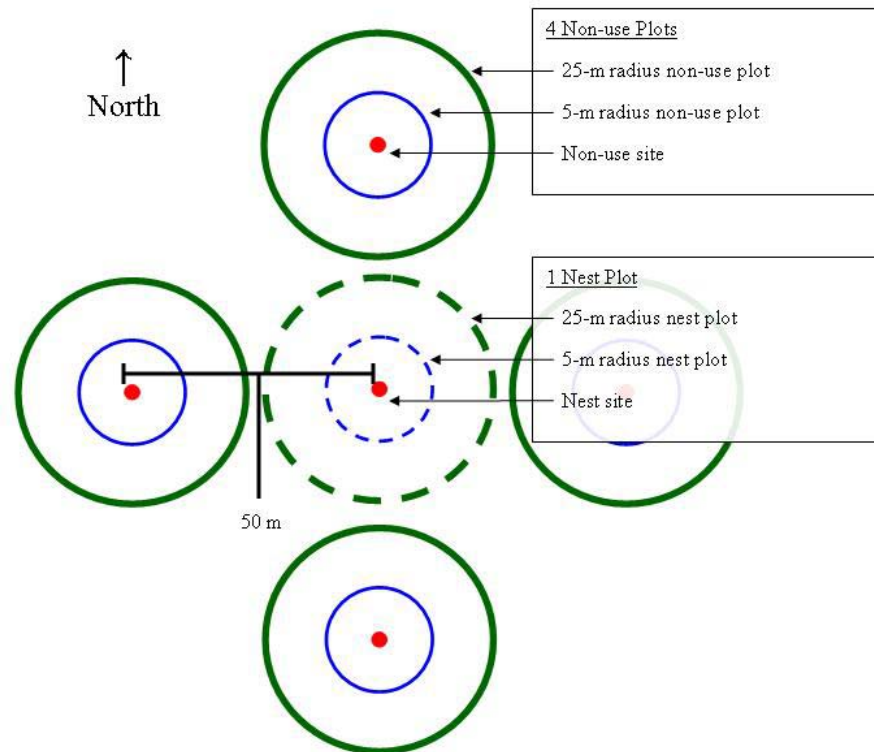
Table 3.1 Topographic and nest cover measurements of resident and translocated Evermann's Rock Ptarmigan nests on Agattu Island, Alaska, 2005-2006. Values are means presented with SD and sample sizes in parentheses.

| Parameter | Resident | Translocated | Pooled | <i>t</i> | df | <i>P</i> |
|-----------------|----------------|---------------|---------------|----------|----|----------|
| Elevation (m) | 237 ± 120 (18) | 251 ± 43 (10) | 242 ± 73 (28) | -0.5 | 26 | 0.65 |
| Slope (degree) | 35 ± 57 (18) | 27 ± 10 (10) | 32 ± 34 (28) | -0.6 | 25 | 0.59 |
| Aspect (degree) | 140 ± 73 (18) | 176 ± 45 (10) | 153 ± 62 (28) | -1.5 | 25 | 0.15 |
| Nest Cover (%) | 90 ± 26 (18) | 82 ± 37 (9) | 84 ± 25 (27) | 0.75 | 25 | 0.46 |

Table 3.2 Average home ranges (ha \pm SE) of female ptarmigan during the brood rearing cycle.

| Species | Mean | Location | Reference |
|------------------------|---------------------|-----------------------------|---------------------------|
| Rock Ptarmigan | | | |
| | 5.5 \pm 1.6 (12) | Agattu Island | This study |
| | 50 (7) | Svalbard, Norway | Steen and Unander 1985 |
| Willow Ptarmigan | | | |
| | 14.3 \pm 2.0 (15) | Tranøy, Norway | Erikstad 1985 |
| | 27.0 \pm 5.4 (18) | Not specified | Bergerud and Gratson 1988 |
| | 27 (9) | St. Shotts, Newfoundland | Bergerud and Huxter 1969 |
| | 25.1 (3) | Portugal Cove, Newfoundland | Bergerud and Huxter 1969 |
| White-Tailed Ptarmigan | | | |
| | 70 (8) | Rocky Mountain NP, Colorado | Schmidt 1988 |

Figure 3.1 Nest and non-use vegetation plots. The nest plot was located at the center and consisted of a 5-m radius plot for estimation of percent ground cover and a 25-m radius plot for measuring topographical features and estimating percent of habitat cover (Viereck et al. 1992). Four non-use plots were located 50 m from the nest site in the four cardinal directions.



CHAPTER 4 - CONCLUSIONS

Restoration of natural biodiversity following removal of introduced predators is an important part of ecological restoration. In cases where animals fail to recolonize parts of their historic range, other measures should be practiced in order to help propel the ecosystem back toward its historic trajectory. Using translocations of wild-caught Evermann's Rock Ptarmigan, our objective was to restore this endemic island ptarmigan to part of its historic range while examining factors influencing translocation success. In particular, we studied differences between recently translocated and resident female to 1) determine the effects of translocation on reproductive rates of female ptarmigan, 2) quantify demographic rates, and 3) examine nest site selection and brood home range movements.

Our population count of territorial Evermann's Rock Ptarmigan males on Agattu increased, albeit slightly, during our study period. We acknowledge these counts were conducted during a time of additional translocations to the population; however, recently translocated males did not increase our total count. Our results using nest survival models in Program MARK produced similar estimates of reproductive performance between resident and recently translocated females for the nesting and brooding period. Seasonal survival during this time was 100% for both translocated and resident females; over-winter survival or emigration from the study site may have the most influence on our estimates population recruitment, followed by chick mortality due to severe weather conditions during the first week after hatching.

We recommend additional monitoring of the restored population as it is still relatively small and potentially vulnerable to stochastic processes. Continued censuses of the island population every two consecutive year out of five during the early breeding season (early June) would provide insight into the population's status and viability, and would reveal habitat use patterns which would help elucidate ptarmigan life history traits for comparative purposes elsewhere. Furthermore, the information gathered will provide data necessary to develop and guide decisions about future reintroduction for other

extirpated or decreasing island ptarmigan populations, especially the remaining six subspecies of Rock Ptarmigan in the Aleutians.

Appendix A - Timeline of Evermann's Rock Ptarmigan Reintroduction project, Agattu Island, Aleutian Archipelago, Alaska, 2003-2006.

| | | |
|------|------|---|
| 2003 | JUNE | First spring translocation: 12 ♀♀, 8 ♂♂ released at the east side of Agattu at McDonald Cove. |
| | SEPT | First and only fall translocation: 1 ♀♀, 3 ♂♂, 2 juveniles of unknown sex released at the east side of Agattu at McDonald Cove. |
| 2004 | JUNE | Second spring translocation: 16 ♀♀, 11 ♂♂ released at the south side of Agattu at Karab Cove. |
| 2005 | JUNE | Year 1 of post-release monitoring at Agattu Island. Third spring translocation: ten ♀♀, four ♂♂ released at Karab Cove. One translocated ♀ drowned 2-days after release. Ptarmigan from the 2003 and 2004 translocations and their offspring found nesting at higher elevation areas (>100 m) on Agattu. |
| | JULY | Twenty territorial males detected during census of montane strata. Captured unbanded resident ptarmigan: five ♀♀, four ♂♂ |
| | AUG | Recaptured ptarmigan: two ♀♀, two ♂♂ (2003 ♀, 2004 ♀, 2003 ♂, 2004 ♂). Resighted ptarmigan: one 2003 ♂, one 2003 ♀. |
| 2006 | JUNE | Year 2 of post-release monitoring at Agattu Island. Fourth spring translocation: three ♀♀, five ♂♂ released at the north side of Agattu at Binnacle Bay. One translocated ♀ found dead 1-week after release. Captured resident ptarmigan: six ♀♀, one ♂. Recaptured ptarmigan: one 2003 ♀, one 2004 ♂, six 2005 ♀♀. |
| | JULY | Twenty four territorial males detected during census of montane strata. |
| | AUG | Resighted ptarmigan: two 2004 ♂♂, one 2005 ♂. |
| | | |

Appendix B - Geographic coordinates of nests located on Agattu Island, Aleutian Archipelago, Alaska, 2005-2006. Information included year, group (translocated or resident females), band number, nesting attempt (1st or 2nd), latitude and longitude (datum = WGS84, decimal degrees), and elevation (m).

| Year | Group | Band No. | Nesting Attempt | Latitude | Longitude | Elevation |
|------|--------------|----------|-----------------|----------|-----------|-----------|
| 2005 | Resident | 13 | 1 | 52.44066 | 173.57214 | 280 |
| 2005 | Resident | 115 | 1 | 52.46260 | 173.63742 | 237 |
| 2005 | Resident | 116 | 1 | 52.47747 | 173.67239 | 162 |
| 2005 | Resident | 117 | 1 | 52.43764 | 173.58347 | 242 |
| 2005 | Translocated | 102 | 1 | 52.43876 | 173.58164 | 292 |
| 2005 | Translocated | 105 | 1 | 52.43714 | 173.58526 | 235 |
| 2005 | Translocated | 107 | 1 | 52.45159 | 173.57181 | 317 |
| 2005 | Translocated | 110 | 1 | 52.43685 | 173.58650 | 231 |
| 2005 | Translocated | 111 | 1 | 52.44207 | 173.56722 | 272 |
| 2005 | Translocated | 112 | 1 | 52.46151 | 173.64490 | 156 |
| 2005 | Translocated | 113 | 1 | 52.45057 | 173.61114 | 234 |
| 2005 | Translocated | 114 | 1 | 52.43809 | 173.55728 | 205 |
| 2006 | Resident | 102 | 1 | 52.43822 | 173.58250 | 269 |
| 2006 | Resident | 102 | 2 | 52.43658 | 173.58216 | 227 |
| 2006 | Resident | 111 | 1 | 52.44227 | 173.56794 | 292 |
| 2006 | Resident | 116 | 1 | 52.47772 | 173.67607 | 132 |
| 2006 | Resident | 118 | 1 | 52.47249 | 173.66201 | 149 |
| 2006 | Resident | 119 | 1 | 52.43921 | 173.57811 | 296 |
| 2006 | Resident | 121 | 1 | 52.45919 | 173.60825 | 240 |
| 2006 | Resident | 121 | 2 | 52.45155 | 173.60885 | 292 |
| 2006 | Resident | 132 | 1 | 52.47271 | 173.66543 | 118 |
| 2006 | Resident | 133 | 1 | 52.44975 | 173.58275 | 253 |
| 2006 | Resident | 134 | 1 | 52.43782 | 173.58314 | 248 |
| 2006 | Resident | 135 | 1 | 52.45356 | 173.60459 | 488 |
| 2006 | Resident | 136 | 1 | 52.46637 | 173.65240 | 173 |
| 2006 | Resident | 137 | 1 | 52.46028 | 173.63358 | 161 |
| 2006 | Translocated | 124 | 1 | 52.44163 | 173.54981 | 265 |
| 2006 | Translocated | 129 | 1 | 52.46960 | 173.60370 | 246 |

Appendix C - Habitat variables estimated for 5-m and 25-m radius plots. Cover values were estimated for 5-m radius circle centered around nest or satellite point. Percentages were estimated using score values as follows: <<1%=0, <1%=1, 1-4%=2, 5-10%=3, 11-25%=4, 26-50%=5, 51-75%=6, 76-90%=7, 91-95%=8, 96-100%=9. General habitat categories were estimated for 25-m radius plots. Categories were ericaceous dwarf scrub, open low scrub, willow dwarf scrub, mesic forb, mesic graminoid herbaceous, and bare (Vioreck et al. 1992).

| Variable | Explanation |
|----------------------------|--|
| 5-m radius | |
| Percent soil cover | Estimated percentage of plot covered by mineral soil. |
| Percent rock cover | Estimated percentage of plot covered by stones <20 cm in diameter. |
| Percent boulder cover | Estimated percentage of plot covered by stones >20 cm in diameter. |
| Percent forb cover | Estimated percentage of plot covered by perennial forbs. |
| Percent grass cover | Estimated percentage of plot covered by graminoids. |
| Percent shrub cover | Estimated percentage of plot covered by wood shrubs. |
| Percent mosses | Estimated percentage of plot covered by moss and moss-like plants. |
| Percent lichen cover | Estimated percentage of plot covered by bryoids. |
| 25-m radius plot | |
| Elevation | Elevation above sea level measured with GPS and confirmed on topographic map. |
| Slope | Slope angle measured in degrees with a clinometer. |
| Aspect | Slope orientation measured to nearest 10 degrees with hand held compass. |
| Topography | Categorized as cliff, crest, slope (upper, middle, or lower 1/3), mound, or valley bottom. |
| General habitat categories | Following Vioreck et al. (1992). |