ECOLOGY OF NORWAY RATS (RATTUS NORVEGICUS) IN RELATION TO CONSERVATION AND MANAGEMENT OF SEABIRDS ON KISKA ISLAND, ALEUTIAN ISLANDS, ALASKA 2005-2006

by

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ABSTRACT

Historical invasions by introduced species into formerly pristine ecosystems present a case where damage and change must often be measured indirectly. Long-term monitoring of demographic parameters has been used to infer trends of the auklet colony at Sirius Point, Kiska Island Alaska in relation to predation by introduced Norway rats (*Rattus norvegicus*). In 2001 and 2002 the auklet colony experienced the lowest reproductive success ever recorded for auklets. Norway rats have been suggested as the cause for auklet reproductive failure due to anecdotal evidence and incidental sign collected at the colony. The first part of my study was to investigate Least Auklet population trends post reproductive failure at Kiska. I found that annual adult local survival estimates for 2002-2005 steadily declined to below 0.8 while reproductive success rebounded to normal levels (54% in 2006). Overall productivity was significantly lower at an island with rats (Kiska) as compared to islands without rats (Kasatochi: $z = 7.24$, $df = 6$, $P < 0.0001$, Buldir: $z = 5.58$, $df = 6$, $P < 0.0001$).

The next part of my study aimed to go beyond the previous approach centered on auklet monitoring and focus on Norway rat activity at the auklet colony as well as estimate rat density and develop a method to measure relative abundance. In 2006 radio tracking was used to quantify Norway rat home ranges and movements located near the center of the auklet colony. Rat home range estimates varied from an average of 7713 ± 1978 m^2 for male rats to 3169 ± 244 m^2 for female rats. Compared to other islands, home ranges were smaller and density estimates, 12.75 rats/ha, were higher at Sirius Point, with

rats living largely underground in the lava dome or tunneling through grass. Rat distribution was patchy – not all habitat types were used equally.

Three non-invasive index methods (chew sticks, wax blocks and tracking tunnels) were tested to measure Norway rat abundance. Rats were attracted to all indexing methods tested in 2005 and 2006. Fortunately, the most successful method tested, peanut butter flavored wax blocks, also was an easy and inexpensive method to apply in the terrain at Sirius Point, Kiska Island. This method will likely prove to be a good choice to monitor fluctuations in rat populations annually at seabird colonies. Taken together, the results of my thesis work showed that Norway rat activity, while difficult to track and monitor, can be measured using novel methodology that will ultimately contribute to management and conservation of Aleutian Island ecosystems.

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AICc	Akaike's Information Criterion
Av. D	Average Diameter
AMNWR	Alaska Maritime National Wildlife Refuge
CTI	Corrected Trap Index
ETA	Effective Trap Area
GPS	Geographical Positioning System
H	Bandwidth (Smoothing Parameter)
LSCV	Least-Squares Cross Validation
MCP	Minimum Convex Polygon
P	Recapture Rate
QAICc	Quasi-Akaike's Information Criterion
Φ	Survival rate

CHAPTER ONE

INTRODUCTION

Among island bird species extinctions, predation by rats (*Rattus* spp.) has been implicated in the greatest number of cases (54 percent; King 1980). Nevertheless, some researchers argue that evidence of rats causing bird population decreases is often circumstantial, and that few data are available to conclude that rats are solely responsible for some bird extinction events (Courchamp et al. 2003). More recently, Towns et al. (2006) provocatively questioned the evidence for harm caused by rats, but in the end concluded that the effects of rats have not been exaggerated and that growing literature points to pervasive effects. Most researchers agree that in order to understand island ecosystems and the complicating factors at play within them, it is crucial to monitor impacts from invasive species to ensure endemic species are not lost. In the case of rats on islands with nesting seabirds, there is an urgency to know their density and movements which lead to effective methods of control or eradication.

Rats have reached ~ 90% of the world's islands and are among the most successful invasive mammals, yet their effects on native species and ecosystems are not always easy to characterize or quantify (Parker et al. 1999). Most of the evidence is from anecdotal reports of species declines and circumstantial evidence of the effects of the introduced species believed to be responsible (Courchamp et al. 2003). For example, in a review on the effects of invasive rats on seabirds, Jones et al. (2008) reported that seventy-three percent of studies cited direct observations of rat predation. Missing from these studies was data that quantified the effects of predation which would provide causation for the seabird declines. Furthermore, few publications describe the benefits of the numerous completed rodent eradications especially in New Zealand (Simberloff 2001). However, Jones et al. (2008) also documented dramatic effects such as 10 unequivocal cases of seabird population extirpations following rat introduction. Improved field studies are needed to provide rigorous data because sensible conclusions can only be reached by using several sources of corroborating evidence.

Most deliberate and accidental introductions of alien mammal species to islands have been failures (i.e., the introduced species did not persist; deVos and Petrides 1967). The "10's rule" was termed to refer to the generalization that approximately 10% of introductions succeed and approximately 10% of those will cause significant ecological damage (Williamson and Fitter 1996). However, this has not been true for all groups of introduced species. Introduced mammals such as rats have reportedly caused more problems than any other vertebrate group (Ebenhard 1988; Lever 1994). Ebenhard (1988) recorded 644 mammal introductions on islands alone. Introduced species may successfully establish themselves on islands because there are more abundant resources, scarcer natural enemies, lack of competitors and advantageous physical environments (Shea and Chesson 2002). In particular, rats succeed on islands due to the absence of native mammals (Atkinson 2001). Unfortunately, these successes are soon followed by impacts to native species such as: effects on individuals, on genetics, on population dynamics, on community composition and functioning, and on ecosystem processes (Parker et al. 1999).

In recent years, it has been recognized that understanding the mechanisms governing interactions among introduced and native species can improve management decisions (Kiesecker et al. 2001). The common techniques currently used to assess impacts caused by introduced species are: predictions from studies in other geographical locations, correlational analysis of abundance data, dietary analysis, demographic and behavioral studies, and experimental removal or exclusion of the introduced species (Park 2004). Often data from a combination of the techniques mentioned above are needed to understand the interactions and how they can be managed. In the case of the population decline of breeding seabirds at Langara Island, Queen Charlotte Islands, British Columbia, Canada, dietary analysis along with predictive and anecdotal data identified rats as a major cause in the decline of Ancient Murrelets (*Synthliboramphus antiquus*) (Hobson et al. 1999). Therefore, using data from a predictive technique, dietary analysis and a demographic study together provided more evidence than data from a predictive technique alone. The benefit of predictive techniques is that they can be inexpensive and can be the first step in considering the effects of an introduced species on an ecosystem. Currently, comprehensive reviews of existing data from around the world are being developed to prioritize future eradications as well as controls for invasive species (e.g. Jones et al. 2008). These prioritizations are based on knowledge from different geographical areas and can then be applied to other areas of concern.

The Alaska Maritime National Wildlife Refuge (AMNWR) encompasses over 2,500 islands off the coast of Alaska, most lying in the Aleutian Island Chain. Native people inhabited these islands for many years, but land mammals are believed to have been introduced to the Aleutian Islands west of Umnak only after Vitus Bering's 1741 discovery voyage (Bailey 1993). The first deliberate introductions occurred in 1741 when Arctic foxes (*Alopex lagopus*) and red foxes (*Vulpes vulpes*) were introduced (Bailey 1993). Norway rats (*Rattus norvegicus*) were first accidentally introduced to an Aleutian Island in 1780, to Rat (Hawadak) Island in the similarly named Rat Island group (Brooks 1878; Black 1984). The second wave occurred during WWII when several islands were occupied by Japanese, United States' and Canadian armed forces (Murie 1959). Today a major priority of AMNWR is to restore native biological diversity by removing introduced predators and preventing accidental introductions. AMNWR biologists, managers and collaborating scientists have been successful at eradicating alien foxes from most islands and are now beginning to focus more effort on eradicating Norway rats.

Norway rats are ecological generalists and omnivores that have colonized a wide range of island habitats. For example they are found in habitats ranging from tussock grass communities on the Falkland Islands in south-western Atlantic Ocean to tropical islands dominated by coconut palms such as on Fregate Island in the Seychelles (GISD 2008). They have also been introduced to at least 16 islands within the AMNWR (Bailey 1993). Aleutian Island weather is cold, foggy and rainy but the islands provide an array of food for Norway rats including vegetation, intertidal invertebrates, fish, and shore-land-birds and seabirds (eggs, chicks and adults) (Major and Jones 2005). Out of the 27 seabird species world wide known to be preyed on by Norway rats (Moors and Atkinson 1984) at least 10 breeding species in AMNWR are thought to have been affected:

Leach's Storm-petrel (*Oceanodroma leucorhoa*), Fork-tailed Storm-petrel (*Oceanodroma furcata*), Pigeon Guillemot (*Cepphus columba*), Ancient Murrelet (*Synthliboramphus antiquus*), Least Auklet (*Aethia pusilla*), Crested Auklet (*A. cristatella*), Whiskered Auklet (*A. pygmaea*) and Parakeet Auklets (*A. psittacula*), and Tufted (*Fratercula cirrhata*) and Horned Puffin (*F. corniculata*; IL Jones personal communication). Norway rats were thought to be implicated in the near-total reproductive failure of the Least Auklet colony at Sirius Point, Kiska Island in 2001 and 2002 (Figure 1.1; Major 2004, Major et al. 2006), and rats were noted as a predator of Least Auklets at the Sirius Point auklet colony in 1988 and 1996 (AMNWR, unpubl.data). A recent review on the severity of the effects of invasive rats on seabirds (Jones et al. 2008) concluded that small seabirds--those that have all life stages preyed on and those that nest in burrows (e.g. Least Auklet) -- are most susceptible to invasive rat predation (Moors and Atkinson 1984). Furthermore, Least Auklets only breed once a year and only lay one egg. For these reasons long-term research on this matter began in 2001 to assess the effects of Norway rats on the auklet colony. The results of four different approaches to assessment of rat impacts used at Kiska are summarized below:

1. Predictive Technique: Anecdotal evidence of rat depredated adult Least Auklets, eggs and chicks as well as rat caches with 100's of bird carcasses were found in the early 2000's (Major and Jones 2005). Taking into consideration the size of the bird and known high rates of predation by rats it was concluded that with ongoing predation it is not likely the auklet colony will persist.

2. Dietary analysis: Stable isotope analysis of rat tissue indicated that auklet flesh was the main food source for Norway rats at Sirius Point during the auklet breeding season (Major et al. 2007).
3. Demographic studies and population-viability analysis: Reproductive success and adult survival of Least auklets were compared between an island with rats (Kiska) to two islands without rats (Buldir and Kasatochi). In 2001 and 2002 the Kiska Island auklet colony experienced almost complete reproductive failure (Major & Jones 2005) – persistent conditions similar to 2001-2002 lead to predicted steep declines in colony size.
4. Experimental Removal: In 2004 a bait efficacy trial (Witmer et al. 2006) was conducted. The rodenticide bait was apparently effective in reducing the Norway rat population however, the rats proved very difficult to detect and capture. Least Auklet productivity in baited area was the highest recorded at Kiska.

The above findings suggest that the auklet colony at Sirius Point, Kiska Island faces rat effects of conservation concern. Major and Jones (2005) results indicate that predation and disturbance by Norway rats can be very destructive. Yet, Witmer et al. (2006) suggested that stronger evidence that rat populations are large enough to limit auklet reproductive success may be needed before control measures are implemented. This was further underlined by the improvement in auklet reproductive success and decreased rat incidental sign at Sirius Point during 2003 and 2004 (Major et al. 2006). Since the evidence from isotopic ratios suggested rats at Sirius Point primarily feed on auklets, are there normally enough rats to cause an additive impact to the large colony of

Least Auklets at Sirius Point? Or is predation compensatory, only taking what the natural mortality rate would be (i.e. scavenging)?

Increased understanding of the behavior and ecology of the Norway rat at Sirius Point will help us understand what may limit the abundance of Norway rats as well as benefit the design of practical applications in control operations and more effective monitoring techniques. Therefore, the main objective for my research at Kiska Island during 2005-2006 was to increase our understanding of Norway rats at Kiska Island by specifically addressing the following questions:

1. After the almost complete reproductive failure in 2001 and 2002 have there been any cases of decreased auklet reproductive success and inter-annual survival at Kiska that may have been caused by Norway rat predation?
2. What are the home range size, social organization and movement patterns of Norway rats at the Sirius Point auklet colony?
3. What is the most effective way to monitor Norway rat activity at Sirius Point to accompany the on-going Least Auklet productivity and survival monitoring?

Here I address the questions about auklet demography (1, above) in Chapter Two, describe my investigation of rat movement, behavior and social organization (2, above) in Chapter Three, and present my novel rat index-monitoring method (3, above) in Chapter Four. Finally, in Chapter Five, I summarize the results of my study and outline important topics for future research.

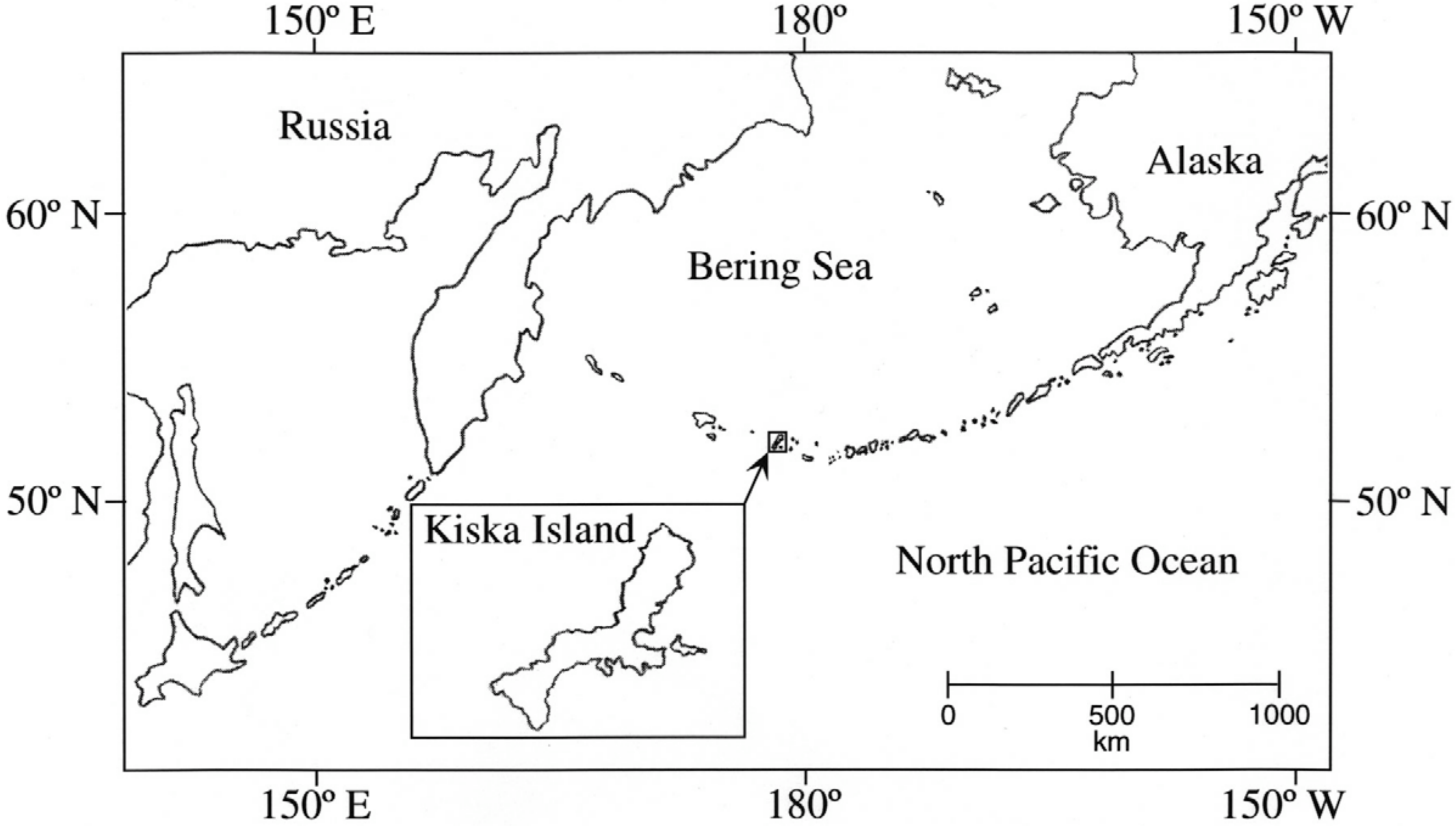


Figure 1.1 Map of the North Pacific showing the location of Kiska Island, Aleutian Islands, Alaska

CHAPTER TWO

DEMOGRAPHY OF LEAST AUKLETS (*AETHIA PUSILLA*) ON ALEUTIAN ISLANDS WITH AND WITHOUT INTRODUCED NORWAY RATS (*RATTUS NORVEGICUS*)

2.1 INTRODUCTION

Long-term monitoring is required to understand the natural cycles, declines, or recoveries of populations. In the Aleutian Island chain, Alaska, monitoring seabird populations can be difficult, dangerous and challenging. Most seabird species have multiple colonies on several islands that utilize cliffs, burrows or lava flows for nesting habitat. In addition, most of the islands have been exposed to different pressures due to different non-native predators. Therefore, monitoring a representative population of a particular seabird species in the Aleutians should include monitoring colonies at more than one island. AMNWR biologists first started long-term monitoring of Least Auklet productivity and adult survival on two rat-free islands, Buldir Island and Kasatochi Island during the 1990's. Unfortunately, estimates from these predator-free islands alone would misrepresent the population as a whole because there are other known islands with larger populations of Least Auklets that are being impacted from introduced predators such as Norway Rats. In 2001, Kiska Island was added as an additional long-term monitoring site.

Remote island avifauna is highly susceptible to extinction. In 1978 the rate of avian extinction was estimated at one island species or subspecies every 3.6 years (King

1980). Introduced predators pose the greatest threat and have caused the extinction of 42% of the world's island avifauna. Furthermore, rats (*Rattus* spp.) have been implicated in the greatest number of extinctions due to predation (54 percent, King 1980). Nevertheless, some still argue that evidence of bird population decreases and their causes is often circumstantial, and that few data are available to conclude that rats were solely responsible for some bird extinction events (Courchamp et. al. 2003). Therefore, in order to understand an island ecosystem and the complicating factors at play within it, it is important to monitor interactions between invasive predators and native species before populations become threatened.

In a three-year study (Major et al. 2006), Norway rats (*Rattus norvegicus*) were implicated as a possible threat to the Least auklet colony at Sirius Point, Kiska Island, Aleutian Islands, Alaska. The impact of rats on the auklet population would occur only by decreasing adult survival (seabirds' most crucial demographic parameter), or by reducing productivity. Hundreds of rat-depredated auklet eggs, chicks and adults have been noted since the initial sightings of Norway rats at the Sirius Point Colony in the late 1980s. Incidental signs of rats were particularly high in 2001 and 2002, when overall reproductive success of the Least Auklet was the lowest ever recorded anywhere in Alaska, but more years of monitoring was needed to answer questions about the fate of the colony at Sirius Point and the survival of the population as a whole (Major et al. 2006). Norway rats are widely known to predate seabirds (Courchamp et al. 2003, Moors & Atkinson 1984) and Least Auklets are especially susceptible to predation by the Norway rat because of their small size (Moors & Atkinson 1984). The objective of my study was to use three additional years' data (2004-2006) to discern if the presence of Norway rats at Kiska Island was significantly correlated with decreases in auklet reproductive success and inter-annual survival after the almost complete reproductive failure in 2001 and 2002.

2.2 METHODS

2.2.1 Auklet Productivity

From the end of May to the beginning of August of 2004-2006 Least Auklet breeding crevices have been monitored at Kiska to assess hatching, fledging and overall reproductive success. Approximately 200 crevices were located, marked and monitored each year, distributed among three study plots representative of the different habitat types present at Sirius Point. The first productivity study plot New Lava (centered at 52°08.038'N 177°35.780'E, Figure 2.1) was located on the top and east side of the most recent lava dome, which was created during the last eruption of Kiska volcano during 1965-69 (Miller et al. 1998). All of the crevices on this plot were within 60 m of the coastline, at an elevation of 25 - 30 m a.s.l. in an area sparsely vegetated with lichens. The second productivity study plot Old Lava Low (centered at 52°07.813'N 177°35.724'E, Figure 2.1) was located in the valley between the 1965-69 lava dome and Bob's Plateau (52°07.803'N 177°35.731'E). All of these crevices were within 520 m from the coast at an elevation of 190 m a.s.l. This second plot was in an area densely vegetated with *Carex* sp., *Calamagrostis* sp. and fern overgrowing basalt blocks. The third plot Old Lava High (centred at 52°07.704'N 177°36.139'E, Figure 2.1) was located at the top of Bob’s Plateau close to the base of a steep talus slope of blocky lava on the northern face of Kiska volcano. These crevices were within 800 m of the coast at an elevation of 180 m a.s.l. The Old Lava High productivity plot was moderately vegetated with *Carex* sp. and ferns (Major et al. 2006).

Each study crevice was monitored every 4 to 5 days. When breeding failed, the causes were classified as abandonment, disappearance or predation of the egg or chick. A chick was considered fledged when the nest was empty ≥ 25 days after hatching. Similar protocols are used in long term monitoring of productivity ongoing at rat-free Main Talus, Buldir Island (52°23.266' N 175°55.029' E, 10+ years) and Thundering Talus, Kasatochi Island (52°10.751' N 175°31.183' W, 7 years) as part of a long-term seabird monitoring program by AMNWR. Productivity at the three Kiska study plots was compared to productivity at samples of crevices widely scattered over the auklet colonies at Buldir and Kasatochi. To compare hatching, fledging and reproductive success between islands and years I used log-linear analysis, testing for interactions using a binary logistic regression using Minitab, version 14.1 (Minitab Inc., State College, PA).

2.2.2 Auklet Adult Survival

Resighting of colour banded adult Least Auklets was conducted at Sirius Point from 2001-2006 to estimate adult survival. In 2001-2003 auklets were captured at the beginning of the breeding season (May) using noose carpets tied to the surface of rocks at a single study plot located in the New Lava Flow (centered at 52°08.038'N 177°35.780'E). At initial capture adult auklets were banded with a numbered stainless steel leg band and three Darvik plastic colour bands in unique combinations for individual identification. The precise age of adults was unknown but they were distinguished from subadults (not marked) using criteria described by Jones (1993b; Jones and Montgomerie 1992). The same procedures were used at similar study plots at Buldir and Kasatochi Islands to compare survival estimates.

Throughout the auklet breeding season (beginning of May to early August) during peak activity periods (0900h – 1400h; 2200h – 0030h) banded birds were sighted from a bird blind. The study plot encompassed an area 15 m out from the blind. All banded birds sighted were recorded daily and tabulated annually (capture history for each individual banded bird 2001-2006).

Local adult annual survival (ϕ) and recapture (p) rates were estimated using methods described in Lebreton *et al.* (1992) and Burnham and Anderson (1998), with the program MARK (White and Burnham 1999). I began by defining a global model for each island (Burnham and Anderson 1998, Anderson and Burnham 1999a) where recapture rates were allowed to vary over time (i.e., the years of this study). Since the marking technique used is known to catch both non-breeding and breeding adult birds, I expected that some individuals might show lower site fidelity, and hence lower local survival rates, after their first capture (Pradel et al. 1997, Prévot-Juilliart et al. 1998, Bertram *et al.* 2000). To account for this, survival rates in the year after the initial capture were modeled independently of survival in subsequent years. Structurally, this approach is similar to age-based models (Lebreton et al. 1992). In this model, apparent survival after first year of capture is a combined estimate of true survival and permanent emigration rates (because the sample of marked individuals includes transient birds), while survival in subsequent years (of resident individuals) is a better approximation of true survival (Pradel et al. 1997).

In summary, the global model incorporated time dependence (year) in both the survival and recapture models. The goodness-of-fit of this global model to the data was determined using a parametric bootstrap approach, based on 100 bootstraps, described in Cooch and White (2001). From these bootstraps, the mean of the model deviances and ĉ were extracted. ĉ is a measure of over-dispersion, or extra-binomial variation, in the data. It arises when some model assumptions are not being met, such as heterogeneity in survival or recapture rates among individual animals (Burnham and Anderson 1998).

The candidate models were restricted to the global model, plus a series of reduced parameter models, including Cormack-Jolly-Seber (Lebreton et al. 1992) models (time and age structure). I used the approach described by Lebreton et al. (1992) by first modeling recapture rates to determine the best structure for recapture rates and then modeling survival rates. Resighting effort often varied between years at the different islands. To account for this variation, recapture rate was divided into two categories, high and low. For example, at Kiska in 2005 resighting effort was substantially lower than all other years. Heterogeneity in resight rate is known to create problems in estimating survival rates (Martin et al. 2000, Prevot-Juilliard et al. 1998). Therefore recapture rate for all years were grouped together with the exception of 2005 for the Kiska Island adult survival model to account for the level of resighting effort, which was known to vary between years.

Relationships among factors were indicated using standard linear model notation. Model selection was based on comparison of the Quasi-Akaike's Information Criterion (QAICc), where the models with lowest QAICc values suggest the best compromise between good fitting models and models with relatively fewer explanatory variables (i.e. parsimonious; Burnham and Anderson 1998, Anderson and Burnham 1999a). QAICc, instead of Akaike's Information Criterion (AICc) was used to rank models, as an acknowledgment of the extra-binomial variation in the data set, represented by c-hat (Burnham and Anderson 1998, Anderson and Burnham 1999b). QAICc weights were also calculated, as they provide a relative measure of how well a model supports the data compared with other models (Anderson and Burnham 1999a).

2.3 RESULTS

2.3.1 Auklet Productivity

Overall productivity (reproductive success) was significantly lower at an island with rats (Kiska) as compared to islands without rats (Kasatochi: $z = 7.24$, $df = 6$, $P < 0.0001$, Buldir: $z = 5.58$, $df = 6$, $P < 0.0001$). Productivity was not significantly different between years 2001 and 2002 ($z = -1.38$, $df = 6$ $P = 0.167$), years with lowest productivity. However, there were significant differences in productivity in the following years; 2003 ($z = 5.05$, $df = 6$, $P < 0.001$), 2004 ($z = 5.06$, $df = 6$, $P < 0.001$), and 2006 ($z = 6.13$, $df = 6$, $P < 0.001$) when compared to productivity in 2001.

Overall hatching success at Kiska was significantly lower when compared to Buldir ($z = 3.39$, $df = 6$, $P = .001$) but was not significantly different from Kasatochi (z =

0.62, df = 6, P = 0.538). Hatching success did not differ significantly between years in relation to 2001 (2002: z = -1.72, df = 6, P = 0.085, 2003: z = 1.92, df = 6, P = 0.054, 2004: z = 1.90, df = 6, P = 0.057, 2006: z = 1.25, df = 6, P = 0.211)

The odds of an auklet successfully fledging from Kiska significantly differed from Buldir (z = 8.02, df = 6, P < 0.001) and Kasatochi (z = 4.67, df = 6, P < 0.001) in 2001 through 2006 (no data was available for 2005 from Kiska). It was 3.09 times more likely for a Least Auklet to fledge from Kasatochi and 1.93 times more likely to have successfully fledged from Buldir compared to Kiska. Similar to productivity and hatching success, fledging success was also lowest in 2002 (0.14). Fledging success in 2003 (z = 4.61, df = 6, P < 0.001), 2004 (z = 4.74, df = 6, P < 0.001) and 2006 (z = 6.35, df = 6, P < 0.001) were significantly different in relation to 2001 and 2002.

2.3.2 Auklet Adult Survival

Kiska data showed the best fit to a model with time dependence in survival rates (t) and time dependence in recapture rates (t) (Table 2.2). From the parametric bootstrap ĉ was 1.76, suggesting the presence of some overdispersion. To correct for the magnitude of this extra variation I adjusted the c-hat to compare QAICc values for all models. From preliminary results of recapture probabilities I was able to make refinements to improve the global model. Two categories (low and high) were established for recapture probabilities (lumped) (High: > .60, Low: < .60) estimated from the global model. I found no evidence for a difference in survival rate in a two-age class (2a) survival model with time dependence in both the year after initial capture and in subsequent years. Therefore, the best fit model for Kiska data had time dependent survival (t) and recapture rate that varied between years of high and low resighting rate (lumped).

The parametric bootstrap ĉ was 1.36 for Buldir, the lowest of all three islands modeled, suggesting minimal over-dispersion. Recapture rate was best modeled in two categories high and low (lumped) (Table 2.3). Models with constant survival (.) and two-age structure (2a) were well supported by the data and ranked higher than models with time dependent rates (t). Therefore the best fit model (ϕ(.) p(lumped)) was only 1.67 times better than the next model (ϕ(2a) p(lumped)) which was then 10.95 times better supported by the data compared to the next best models, which had a constant rate for the survival and constant recapture rate.

At Kasatochi data fit to Clobert-Jolly-Seber assumptions was less good (Table 2.4). From the parametric bootstrap ĉ was calculated at 2.457 the largest of all three islands. This c-hat was used to adjust all QAICc values. The best model in the final candidate model had a constant rate of survival after the initial capture (2a) and recapture rates grouped into high and low categories (lumped). This model (ϕ(2a) p(lumped)) was 2.78 times (.70684/.25377; Table 2.4) better supported by the data than the next most parsimonious model. The second best model had time dependent recapture rates.

Buldir had the lowest constant survival rate (86.7%). Kasatochi's Least Auklet survival was only a little higher at 88.8%. The estimates for auklet survival at Kiska ranged from 94.6% to a low of 72.1% during 2004-2005.

2.4 DISCUSSION

When determining the trends of Least Auklets in the Aleutian Islands, long-term monitoring at Kiska Island is essential. Although it is infested with introduced Norway Rats, a known predator of Least Auklets, Sirius Point at Kiska still remains one of the largest auklet colonies in Alaska. Thus impacts to the Sirius Point colony would greatly effect the overall Alaskan auklet population. After six years of monitoring auklet reproductive success at Kiska, 2001 and 2002, still remain the lowest ever recorded for Least Auklets anywhere. Additional years of monitoring for adult survival showed a decline following years of lowered reproductive success.

The auklet colony at Kiska has unique issues that need to be better understood. One significant difference between Kiska and the other islands studied is the presence of rats. Unfortunately, nest predation, a direct measure of impact to auklet reproductive success, is hard to quantify due to: 1) the complex rock structures the auklets choose to nest in, hampering visibility to human observers; and 2) rats' predation behavior involving the removal of egg/chick/adult from crevice while leaving no trace. These challenges have made an exact estimate of rat predation on auklets difficult, and led to many nest failures caused by rats to be labeled as 'unknown' (Major et al. 2006). Methods must be developed to monitor rat abundance as well as determine habitat preferences of Norway Rats throughout the Sirius Point Colony. Also, more auklet nests may need to be monitored to represent a larger portion of the population at Sirius Point.

2.4.1 Auklet Productivity

Natural fluctuations in reproductive success at a seabird colony are normal over time (Cairns 1987). Buldir and Kasatochi, islands that have been studied for over 10 years, both show fluctuations in reproductive success in a cyclical pattern (Table 2.1, Figure 2.2). However these fluctuations never reached below 34%. The lowest reproductive success at Buldir and Kasatochi, respectively were 34% (2005, an anomalously low figure) over an 11 year period and 39% (2003) over a 16 year period. In comparison, Kiska Island's lowest estimated reproductive success was by far the lowest of all islands at 9% in 2002 (16% in 2001) over a 6 year period. Furthermore, Kiska's auklet colony experienced two consecutive years of the lowest recorded estimates of reproductive success, a result unprecedented in auklet productivity monitoring.

In large numbers, rats have the ability to cause mass destruction at seabird colonies especially at colonies where the seabirds are significantly smaller in size. White-chinned petrels *Procellaria aequinoctialis* nesting in the Crozet archipelago (mean of 1200 g adult body mass; Jouventin et al. 2003) and Cory's Shearwater *Calonectris diomedea* nesting in the Spanish Chafarinas Islands (mean of 950 g adult body mass; Igual et al. 2006) both experienced extremely low reproductive success similar to that found for auklets at Kiska, the cause being rat predation on chicks. Studies showed that these populations were affected by increased rat abundance and therefore increased rat predation (Igual et. al. 2006, Jouventin et. al. 2003). Due to the lack of precise data on rat abundance and predation rates it was hard to prove that rats were the sole cause for auklet reproductive failure seen in 2001 and 2002 at Sirius Point. This doesn't exclude the possibility that rats may have acted in conjunction with other environmental effects to cause the observed failures. Buldir Island and Kiska Island are relatively close and birds are assumed to be feeding in similar areas. This would eliminate the theory that poor reproductive success was caused by lack of food availability since it was only lowered at Kiska.

Fledging success was significantly different between islands and it was chick loss that had the most drastic effect on the reproductive success. More specifically the majority of failed nests in 2001 and 2002 at Kiska were due to dead chicks. This is about twice the average frequency found at Buldir and Kasatochi. One hypothesis that could explain the increase in dead chicks is effects to adult auklet incubation. Fates of all nests were recorded but often the direct cause of failure was not ascertained. For example, the disappearance of chicks without trace accounted for a lot of chick loss, while confirmed rat predation (dead predated chick found in the nest site) only accounted for < 1%. The disappearance of chicks and eggs were not reported as rat predation because we could not confirm if they had been taken by a rat or just naturally fallen down into the complex rock structures of the lava flow and disappeared. This may lead to underestimates of rat predation. Therefore, our estimates of rat nest predation are very conservative and may not be able to be used as a good indicator of the full impact of rats at the Sirius Point auklet colony.

2.4.2 Auklet Adult Survival

Alarmingly, the annual adult local survival estimates of Least Auklets at Kiska for 2002-2005 steadily declined to below 0.8. Survival rates for Least Auklets in these years were lower than required for a stable population (Major et al. ms submitted). However, these results need to be interpreted cautiously because we are operating only a single survival monitoring plot at Sirius Point (located in a dense and apparently typical part of the colony). Nevertheless, the data do suggest there may be cause for concern. Most interesting was the observation that years with high inter-annual adult survival followed years of breeding failure and high apparent early season rat abundance. With only five years of data it was impossible to confirm a statistically significant negative correlation but if one in fact exists then this would be consistent with a reproductive tradeoff (high reproductive success and investment incurring a survival cost). An explanation linking low auklet survival to rat predation is less plausible, because auklets are most vulnerable to rats during the incubation period when they are in their crevices for long periods of time. None of the years with low adult survival had low hatching success or apparently abundant rats early in the breeding season. Further survival monitoring at Kiska based on a larger sample of marked birds (no new birds were marked in 2004, 2005 or 2006) is required for more reliable results.

Another cause of concern for the Least Auklet colony at Sirius Point involves another predator. A significant part of the Glaucous-winged Gull (*Larus glaucescens*) diet at Buldir and Kasatochi has been seabirds, including Least Auklets, which comprise 20-60 percent volume of the pellet contents examined 1997-2006 (AMNWR, Orben et al.

2006). At Sirius Point the presence of Glaucous-winged Gulls has increased over the six years (2001-2006) of monitoring (ILJ, HLM, CJE, personal observations). These gulls prey upon auklets leaving the colony. Furthermore, the first Glaucous-winged Gull nest at Sirius Point was recorded in 2006 with one successful fledgling. The increasing number of gulls at Sirius Point is likely the result of decreased predation following the eradication of foxes from Kiska in 1987-1988.

Taken together, my data combined with the previously reported information (Major et al. 2006) provide a complex picture of the relationship between introduced rats and the breeding auklet population at Kiska. The only way to better understand this relationship is to study the rat population directly as well as look for other causes of reduced productivity. Baseline abundance estimates as well as a long-term monitoring program should accompany the on-going Least Auklet monitoring. Lack of recent breeding failure years is a hopeful sign for auklet conservation. However, the recent low survival rates are alarming, if this is reflective of the entire colony it is certain to indicate decline, whatever the cause.

Table 2.1 Summary of Least Auklet productivity and causes of breeding failure at Kiska, Kasatochi and Buldir Islands 2001-2006.

	Kiska						**Kasatochi**						**Buldir**					
Year	**01**	**02**	**03**	**04**	**05**	**06**	**01**	**02**	**03**	**04**	**05**	**06**	**01**	**02**	**03**	**04**	**05**	**06**
No. nests (a)	190	195	201	197	-	180	85	97	110	91	93	77	65	50	83	81	73	84
Hatched (b)	149	127	164	167	-	154	65	80	95	75	64	55	55	43	75	71	62	75
Dead adult	1	0	2	0	-	1	0	0	0	0	0	0	0	0	0	0	0	0
Egg abandoned	17	27	19	20	-	12	11	14	5	11	15	13	5	3	4	4	7	4
Egg broken	1	10	1	1	-	1	5	1	6	5	9	4	0	0	2	3	0	0
Egg disappeared	21	30	9	8	-	4	4	2	4	0	5	5	5	4	2	3	4	10
Egg displaced	1	1	0	0	-	1	0	0	0	0	0	0	0	0	0	0	0	0
Egg predated	0	0	6	0	-	5	0	0	0	0	0	0	0	0	0	0	0	0
Crevice collapsed	0	0	0	0	-	2	0	0	0	0	0	0	0	0	0	0	0	0
Fledged (c)	31	18	100	103	-	98	47	50	80	48	36	34	36	30	28	43	44	63
Chick disappeared	32	33	40	20	-	46	14	20	4	19	12	14	15	10	39	19	15	10
Dead chick	86	69	20	44	-	8	4	10	11	8	16	7	4	3	8	9	3	2
Dead chick injured	0	6	5	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0
Dead chick predated	0	1	0	0	-	2	0	0	0	0	0	0	0	0	0	0	0	0
Hatching success (b/a)	0.78	0.65	0.82	0.85	-	0.85	0.77	0.83	0.86	0.82	0.69	0.71	0.85	0.86	0.9	0.88	0.85	0.89
Fledging success (c/b)	0.21	0.14	0.61	0.62	-	0.63	0.72	0.63	0.84	0.64	0.56	0.62	0.65	0.7	0.37	0.61	0.71	0.84
Reproductive success (c/a)	0.16	0.09	0.5	0.52	-	0.54	0.55	0.52	0.73	0.53	0.39	0.44	0.55	0.6	0.34	0.53	0.6	0.75

USFWS AMNWR unpublished data; (-) data is not available for 2005 at Kiska Island.

Table 2.2 Summary of the seven best models of Least Auklet survival at Kiska Island during 2001-2006 (ĉ adjusted to 1.763). The best fit model for Kiska data had time dependent survival (t) and recapture rate that varied between years of high and low resighting rate (lumped).

Model	QAICc	Delta QAICc	QAICc Weight	Number of Parameters	Deviance
ϕ(t) p(lumped)	0.00	566.885	0.69827	7	30.765
ϕ(t) p(t)	2.71	569.590	0.18052	9	29.379
ϕ(2a*t) p(t)	3.68	570.569	0.11066	9	30.358
ϕ(.) p(t)	9.16	576.048	0.00715	6	41.965
ϕ(2a) p(t)	10.65	577.533	0.00340	7	41.413
ϕ(t) p(.)	42.46	609.349	0.00000	6	75.266
ϕ(.) p(.)	73.08	639.965	0.00000	2	113.979

Table 2.3 Summary of the seven best models of Least Auklet survival at Buldir Island (Jones *et al.* 2006) during 1990-2006 ($\hat{c}$ adjusted to 1.359). Models with constant survival (.) and two-age structure (2a) were well supported by the data and ranked higher than models with time dependent rates (t).

Model	QAICc	Delta QAICc	QAICc Weight	Number of Parameters	Deviance
ϕ(.) p(lumped)	0.00	2163.687	0.69693	3	828.343
ϕ(2a) p(lumped)	1.67	2165.354	0.30290	4	828.000
ϕ(.) p(.)	18.28	2181.968	0.00007	2	848.632
ϕ(.) p(t)	18.97	2182.654	0.00005	17	818.932
ϕ(2a) p(.)	19.64	2183.331	0.00004	3	847.987
ϕ(t) p(.)	24.30	2187.991	0.00000	17	824.269
ϕ(t) p(t)	27.34	2191.026	0.00000	31	798.411

USFWS AMNWR unpublished data;

Table 2.4 Summary of the eight best models of Least Auklet survival at Kasatochi Island during 1996-2006 (ĉ adjusted to 2.457). The best model in the final candidate model set had a constant rate of survival after the initial capture (2a) and recapture rates grouped into high and low categories (lumped).

Model	QAICc	Delta QAICc	QAICc Weight	Number of Parameters	Deviance
ϕ(2a) p(lumped)	0.00	1798.960	0.70684	4	515.330
ϕ(2a) p(t)	2.05	1801.009	0.25377	12	501.268
ϕ(2a*t) p(lumped)	6.15	1805.106	0.03271	12	505.365
ϕ(2a*t) p(t)	11.45	1810.411	0.00231	20	494.456
ϕ(.) p(t)	11.49	1810.452	0.00226	11	512.731
ϕ(.) p(.)	12.74	1811.698	0.00121	2	532.079
ϕ(t) p(.)	13.52	1812.478	0.00082	11	514.756
ϕ(t) p(t)	18.17	1817.128	0.00008	19	503.205

USFWS AMNWR unpublished data

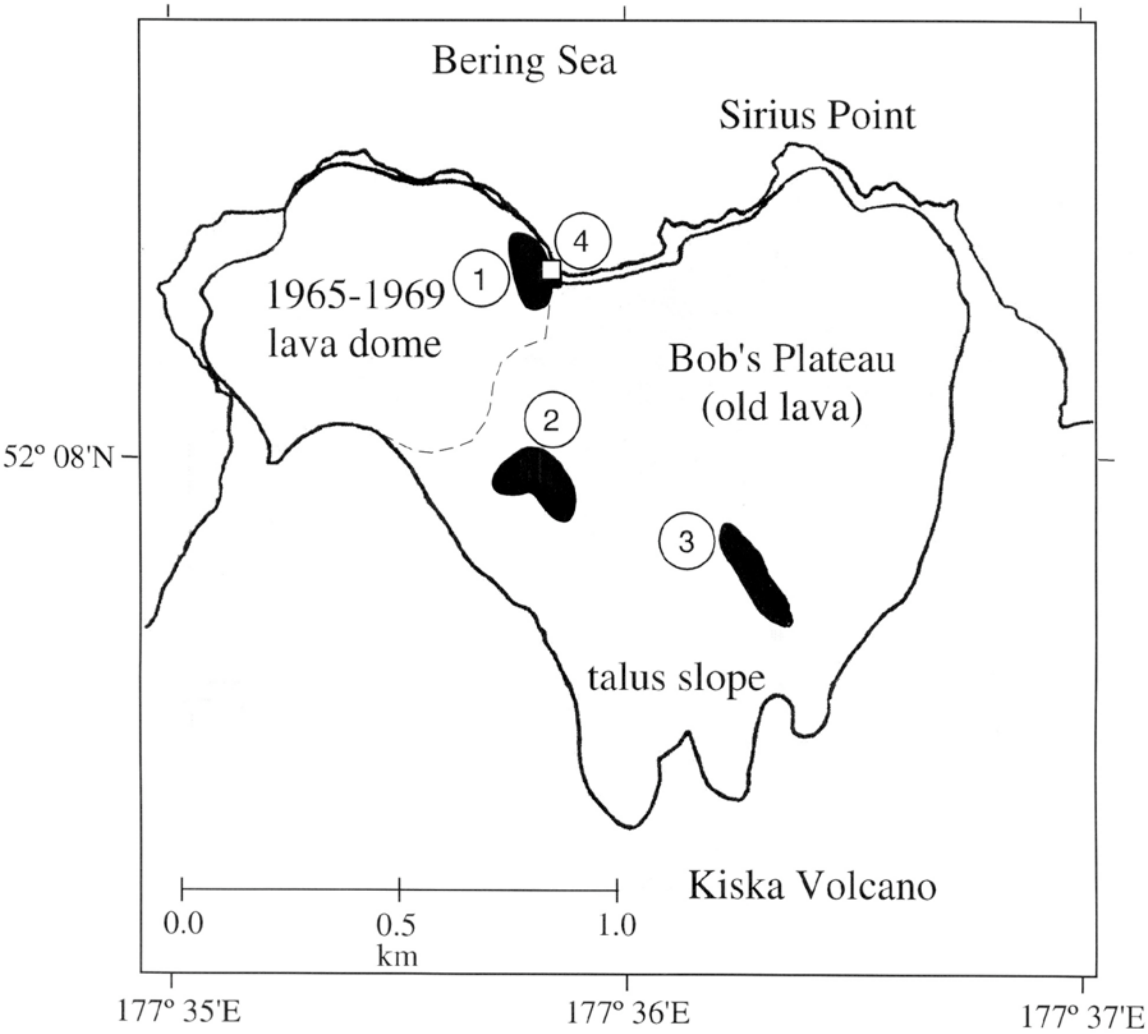


Figure 2.1 Map of Sirius Point showing the Least Auklet colony boundaries and the locations of the three productivity monitoring plots (1 – new lava, 2 – old lava low, and 3 – old lava high) and the banding plot (4).

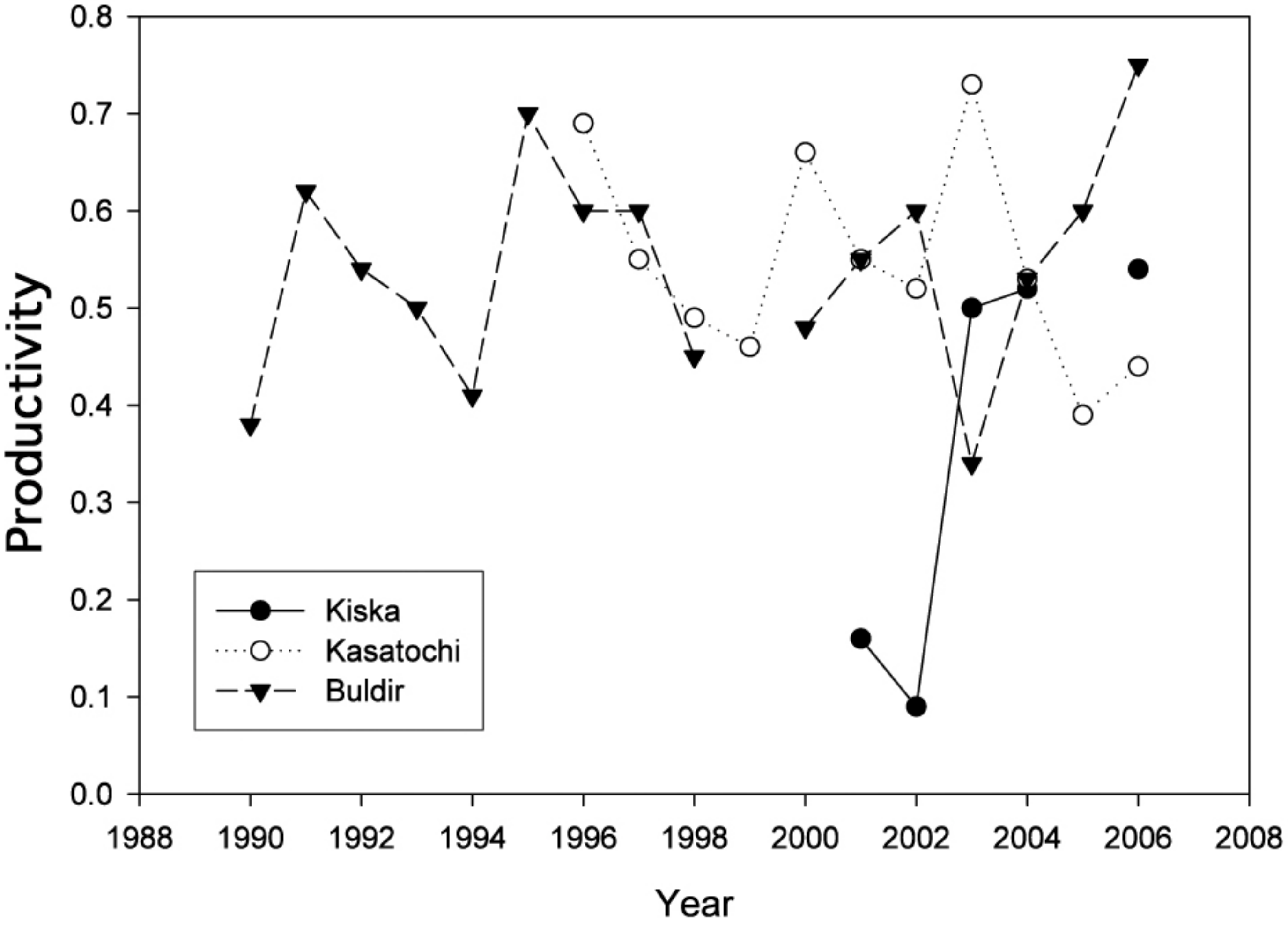


Figure 2.2 Comparison of the annual estimates of Least Auklet reproductive success (percent of nests that survive to fledge) at Buldir (USFWS AMNWR unpubl. data), Kasatochi (USFWS AMNWR unpubl. data) and Kiska Islands during 1988 – 2006.

CHAPTER THREE

NORWAY RAT HOME RANGE, SPATIAL RELATIONSHIPS AND HABITAT USE AT A SEABIRD COLONY

3.1 INTRODUCTION

Over 80% of the world's oceanic islands have been invaded by non-native rats (Shrader-Frechette 2001). With an abundance of resources and a lack of pressure from natural enemies, rats are able to thrive on remote island ecosystems and have become one of the most successful invasive mammals (Atkinson 1985; Martin et al. 2000, Donlan et al. 2003). Unfortunately, due to the relatively low diversification, simplified trophic webs, high rates of endemism and lack of behavioral and other forms of resistance to predators, island ecosystems often suffer from the effects of such invasive species (Chapuis et al. 1995). For example, within two years, black rats (*Rattus rattus*) introduced in 1964 to Big South Cape Island, New Zealand caused the local loss of three endemic birds, and the complete extinction of two other species as well as one bat species (Bell 1978). Another set of isolated islands that have not escaped accidental introduction of rats is the Aleutian Islands, Alaska, USA (Jones and Byrd 1979). The earliest recorded accidental mammal introduction was prior to 1780 when Norway rats (*Rattus norvegicus*) became established on Rat Island following a Japanese shipwreck (Brooks 1878; Black 1984). Within the last 200 years, Norway rats have become established on at least 16 other islands within the Alaska Maritime National Wildlife Refuge (AMNWR, Ebbert 2000; Bailey 1993), of which the Aleutian Islands are a major component.

AMNWR has designated invasive species management as a top priority due to the large amount of critical habitat the refuge provides for many breeding seabirds. Kiska Island, home to one of the largest auklet colonies in Alaska but otherwise depauperate of cavity nesting seabirds, has introduced Norway rats that invaded after WWII (Murie 1959). Rats at Kiska received little attention from biologists until after the removal of introduced Arctic foxes in 1986 (Deines and McClellan 1987). Results from demographic studies have implicated Norway rats as a threat to Least Auklets breeding at Kiska due to near-failure of reproductive success in 2001 and 2002 followed by a decline in adult survival in 2003 and 2004 (Major et al. 2006). However, little is known about population dynamics of Norway rats living in seabird colonies, let alone in such a complex lava flow present at Sirius Point, Kiska Island.

Nocturnal, secretive, subterranean and adaptable, Norway rats are very hard to observe at Kiska Island, especially in lava flows. For the first five years of recent monitoring at Kiska the presence of rats was documented anecdotally mostly by feces and prey caches found throughout the auklet colony site (Major and Jones 2005). Behavioral data obtainable by radio-tracking (the distances they move, their home range areas, and social organization) are essential prerequisites of any effective management strategy and may facilitate the design of more efficient control operations (Hooker and Innes 1995). Home range varies seasonally between sexes and with population density (Davis et al. 1948). For example, increased productivity of an island with breeding seabirds may allow the Norway rat to gain resources required to survive over a smaller area and allow higher densities of rats to be supported (McNab 1963, Stapp and Polis

2003). This study was an investigation of the home range size, social organization, and movement patterns of several male and female Norway rats at Sirius Point, using radio tracking to provide baseline data relevant to possible control and eradication options in the future.

3.2 METHODS

3.2.1 Study Site

Norway rats were studied at Sirius Point, Kiska Island, Aleutian Islands, Alaska, USA (Figure 3.1). The auklet colony at Sirius Point (52º08'N 177º37'E) is situated on two lava domes at the base of Kiska Volcano, encompassing an area of 1.8 km^2 (Figure 3.2). This colony was occupied in 2001 by more than 1 million Least and Crested (*A. cristatella)* auklets (I.L. Jones unpubl. data). The study plot encompassed four main habitat types with nesting auklets: 'New Lava' (52°08.049′N 177°35.789′E) was sparsely vegetated with lichens, 'Old Lava' (52°07.803′N 177°35.731′E) was heavily vegetated with *Carex* and *Calamagrostis* sp. and fern overgrowing basalt blocks, 'Large Boulders' (52°08.014′N 177°35.898′E),was composed of boulders larger than 4m in circumference with little to no vegetation cover, and 'Beach'(52°08.038′N 177°35.886′E) was covered with smaller rounded boulders which ranged from the intertidal area to the base of blocky lava flows with no vegetation. The terrain at Sirius Point was rugged with steep cliffs rising to jagged ridges. The highest density of breeding auklets occupy the New Lava habitat which consists of relatively un-vegetated undulating and complex lava formations from a 1966-1969 eruption of Kiska volcano. Mean temperature at Sirius Point from June to August 2006 was 5°C and rainfall and wind > 30km/h were frequent.

3.2.2 Rat Capture and Processing

To evaluate the feasibility of capturing live rats, a trap grid of 36 Tomahawk live traps (Tomahawk Live Trap Co., model 201), each 10 m apart, was laid out within the New Lava during late May 2006 where rats had been previously observed in 2005 (Figure 3.2). Traps were set open for three weeks before being pre-baited. Traps were pre-baited with peanut butter, honey and oats for three days before being set. A single rat was captured over the two week period following setting of the traps. Due to this unsuccessful first attempt at trapping rats in the New Lava an alternate method of trapping was then instituted. Areas were located that were in active use by Norway rats (presence of fresh feces and caches). Four traps were placed near areas where fresh rat sign was observed. Traps were neither set open or pre-baited before being set. A rat was caught during the first night traps were set. Between 13 June 2006 and 9 July 2006 traps were set at dusk 2100 h and checked at 0700 h. The health of rats can be compromised if left in traps for prolonged periods of time while wet or cold; therefore, traps were not set in rain or winds exceeding 50 km/h.

Captured rats were anaesthetized in a plastic bag using cotton balls soaked in isoflourane, and then sexed, weighed, measured and radio collared within 3 minutes (unpublished protocol developed by Island Conservation researchers). A 4 to 4.5 g radio transmitter was attached to rats of body mass > 140 g (transmitters weighing > 3 % of body mass have adverse effects; Kenward 2001). Transmitters were attached around the neck with a nylon collar (ATS, Michigan).

At the end of the study, rats in the study area were removal trapped (killed) to obtain a density estimate. A trap grid of 20 snap traps (Victor Professional Expanded Trigger Rat Trap) at 20 m spacing was laid out through the central portion of the study site (Figure 3.2). Rats were kill trapped from August 3 to August 11, 2006, after auklet activity at the colony site had begun to die down with the departure of most fledglings. This provided a minimum count of rats exposed to the trapping site, from which an estimation of density was calculated. First, it was necessary to estimate the effective trapping area (ETA). The area of exposure to trapping was expected to differ for males and females because males have larger home ranges and so are more likely to encounter traps. These areas were calculated by adding a border of one-half of the mean home range diameter to the trapping grid, representing the average distance outside the grid included within the ranges of the trapped animals (Dice 1938). This was estimated by a parameter Av.D. (average diameter), the average of the range length and width from the minimum convex polygon (MCP) estimates (Hooker and Innes 1995). Range length is the longest possible straight line inside the range, and range width is the length of the line at right angles to this and measured at the midpoint.

The mass of each rat killed was measured to the nearest 1 g using a Pesola 500 g spring scale. Body and tail lengths were measured to the nearest 1 mm using a steel ruler. Stomach contents were also examined. Food items were placed into broad diet categories: bird (composed of seabird related items flesh, feathers, and egg), invertebrates, vegetation and trap bait. In the field I quantified the percentage composition by volume of the different foods per total stomach contents (small <10%, 10%< med >50%, and large >50%).

3.2.3 Radio-tracking

Radio locations (position fixes for individual rats) were determined by homing (White and Garrott 1990), using a hand held antenna (ATS three-element yagi) and ATS FM-100 receiver from 14 June 2006 - 29 July 2006. Locations were marked with a flag and coordinates were obtained from a hand held GPS unit (Garmin GPSmap 76S) (Appendix A). The habitat type, time, and movement of rats were recorded at each location. Two locations were obtained per 24 hour period; one location during the day (0600-2200 h) and one location at night (2201-0559 h). Night sessions were further divided into two sessions: 2200-0300 h and 0300-0600 h. Night location was alternated between sessions each 24 hour period so that locations could be considered independent. Radio location error was estimated by measuring observer accuracy. Ten transmitters attached to the neck of painted water bottles were placed within the study area unknown to the observer. Using the homing technique transmitters were located and then compared to the actual location.

3.2.4 Home Range Analysis

Radio tracking data were analyzed using the software program ArcView (Environmental Systems Research Institute, Redlands, CA, version 3.3) and the ArcView home range extension (Version 1.1). Data for each rat was standardized according to equal number of days sampled prior to data analysis. Borger et al. (2006) found that the number of days sampled was more critical than an equal number of detected locations. Therefore, at Kiska, seventeen days was the fewest number of days a rat was tracked so in order to standardize the radio tracking data for all rats I only used locations over the first seventeen days of tracking for each rat. Home-range size was calculated using 100% and 95% MCP for use in comparative studies since this is still the most frequently used technique (Mohr 1947, Seaman et al. 1999). MCP estimates were used to compare home range size using all tracking locations obtained for each rat and standardized tracking data as explained above. Ninety and eighty percent kernel home range estimates were also calculated for a more detailed understanding of the rats' home range use (Seaman et al. 1999). Kernels provide a more biologically relevant home range by placing a probability distribution around locations, which puts more emphasis on areas with higher use. Furthermore, this method will allow for analysis of core areas inside the 90% kernels which is not possible with MCPs.

Kernel estimate accuracy is dependent on determining the correct bandwidth or smoothing parameter (h; Silverman 1986, Worton 1995). Most studies have shown that fixed kernels using least-squares cross validation (LSCV) for the smoothing parameter (bandwidth) gives the least biased results (Seaman and Powell 1996, Seaman et al. 1999, Powell 2000). In certain situations with strong autocorrelation, even though kernel analyses are less sensitive to autocorrelation than other home-range estimators, (Swihart and Slade 1997, de Solla et al. 1999) using LSCV to determine bandwidth often fails (Millspaugh and Marzluff 2001). In an exploratory analysis to determine the correct bandwidth for the Kiska data LSCV resulted in the formation of numerous small disjunct contours for some configurations of clumped data leading to inconsistent results, and underestimates of home ranges for some rats, similar to results of Blundell et al. (2001). Norway rats at Kiska, especially females, often stayed in one spot over a 2-4 day period during the breeding season causing strong autocorrelation. Seaman et al. (1999) also recognized that the use of LSCV to select bandwidths resulted in poor estimates for small sample sizes ($n<50$ locations). Therefore, it was appropriate to use a fixed kernel method with ad hoc choice of 0.4 for h (bandwidth) to determine home range for comparisons between Norway rats at Kiska (Worton 1989). I tested the difference in average home range size among male and female Norway rats using a two sample t-test.

The kernel estimator places a kernel (a probability density) over each observation point in the sample therefore, in the context of home range analysis the density at any location is an estimate of the amount of time spent there (Seaman and Powell 1996). A measure of the overlap between rats using 100 percent of the estimated area for each individual rat may be misleading if some space is used with lower than average intensity, whereas weighting area by usage as with the kernel density estimate enables the use of more accurate estimates for the probability of interaction between individuals (Smith and Dobson 1994). Therefore, percentage of home range overlap was calculated using 90%

kernel estimates between and within sexes from individuals tracked from June to July. Overlap was determined by dividing the amount of intersected area from two Norway rats by the range area of each individual.

3.3 RESULTS

3.3.1 Rat Capture and Processing

Nine adult Norway rats (5 male, 4 female) were radio collared and tracked. None of the 9 radio-collared rats died during the telemetry phase of my study. At the end of the study 28 rats were removal trapped (12 males and 16 females) within the study area. The traps did not kill non-target species, likely because trapping occurred after most auklets had departed the breeding colony. Using MCP range dimensions the average diameter (Av.D.) for males was calculated as 107 m and 68 m for females outside the trapping grid (80 m x 60 m) (Table 3.1). The ETA (effective trap area) was thus calculated to be 1.8 ha for females and 3.1 ha for males. Therefore assuming all the rats in the trapping grid were caught, the number of rats trapped divided by the ETA gave a density of 12.75 rats per hectare (8.88 females per hectare and 3.87 males per hectare).

Adult male average weight was 343.24 g (n = 9, SE = 20.38) and adult female average weight was 288.24g (n = 12, SE = 24.91). Five out of the 9 rats collared were recaptured. Percent weight change of each of the 5 rats ranged from ± 13.1 % to ± 27.7 % gaining from 45.2 g to 74.8 g over a 25 to 53 day period. Twenty-six of the 27 rats (96%) caught had auklet remains in their stomachs. Seventy percent had more than 50% auklet remains in their stomach contents (Table 3.2, Figure 3.3). Fifteen percent had a medium (between 10% and 50%) amount of auklet remains and eleven percent had a small amount (less than 10%).

3.3.2 Radio Tracking

It took the telemetry observer approximately 3 hours to get a single location for 6-8 rats each night at Sirius Point, Kiska Island. Only one rat was seen while radio tracking during the day. The observer location accuracy was estimated as an average of 0.7 ± 0.11 (SE) m. GPS accuracy was recorded at every location and averaged 8.04 ± 0.17 (SE) m. All collars stayed attached to the rats throughout the duration of the project. However, signals from transmitters attached to Rat F105 and M083 lost transmission after 29 days and 25 days respectively. Both rats were recaptured at the end of the study and antennas were extremely frayed. The antennas were damaged by fellow rats or by the lifestyle of the rats living and moving in small crevices composed of coarse lava rock. Furthermore, after 10 days of tracking rat M182, the signal could no longer be located during the day or night. Six days later the rat was located at the top of the old lava flow. It was not safe to climb above the old lava flow at night so the rat continued to be located during the day only. Due to the variance in location data and limited number of locations I could not use data collected for rat M182 in home range analysis.

3.3.3 Home Range Analysis

Home range for each rat was estimated using on average 40 radiolocations (range = 25-62, SE ± 4.27) and 30 radiolocations (range = 25-37, SE ± 1.46) when using only the first 17 days of tracking (Table 3.3). The average 90% kernel home range (±SE) estimate was 7713.06 ± 1978.93 m^2 for male Norway rats and 3169.96 ± 244.35 m^2 for female rats at Sirius Point, Kiska Island (Table 3.3). Male and female kernel home range estimates did not differ significantly ($t= 2.28$, $p = 0.11$) however, every male rat had a larger estimated home range area than any female. Average home range size of male Norway rats was 9100.75 ± 2385.87 m^2 based on 95% MCP (±SE) estimates using all locations, and 7506.00 ± 1438.64 m^2 based on 95% MCP using the first 17 days of locations (Table 3.3). Average home range areas of female Norway rats based on MCP using all locations and locations from the first 17 days only of radio tracking are both smaller than male estimates (Table 3.3).

Each of the four male rat home ranges overlapped each other (Figure 3.4). The average overlap of male home ranges was 26 % ± 6 (SE) (Figure 3.5). All female home ranges also overlapped however, some only overlapped less than 5% (Figure 3.6). If only overlapping over 5 % was considered then on average each of the females tracked overlapped an average of 2 other female home ranges per individual (Figure 3.5). The average overlap of female home ranges by other females was 19% ± 5 (SE) (Figure 3.5). Overlap between males and females did not significantly differ ($t= .84$, $p = 0.40$, $df= 22$). Two female rats (F062 and F161) were the only rats ever located together (7/16/2006, 1238) during the radio tracking study. Furthermore, each female was overlapped by an average of three males (Figure 3.7). The average male home range overlapped a female's home range by 33% ± 6 (SE). Considering females had a slightly smaller home range, the average female home range overlapped a male's home range by 16% ± 3 (SE) (Figure 3.5).

The percentage of fixes within each of the four habitats represented in the tracking study area is shown in Table 3.5. The majority of fixes for each rat were made in the Old Lava except for rat M220 whose majority of fixes were made in the New Lava (Figure 3.8). The second most frequented habitat type was the New Lava. Five out of nine rats had fixes at the beach which was the least used habitat in the study (Figure 3.8). On average male rats had more fixes in the New Lava and Large Boulder habitats than female rats while more fixes for female rats were made in the Old Lava (Table 3.8).

3.4 DISCUSSION

Previous studies indicated that Norway rats are difficult to detect, monitor and capture at the Sirius Point, Kiska Island, Alaska auklet colony. At the beginning of my study I explored two areas of very different rat activity. The first site I chose to live trap proved to be unsuitable for trapping rats even with increased trapping effort. Therefore, I choose a second area that subsequently turned out to be ideal for obtaining individuals with little trap effort. The rats at the second area were neither neophobic nor seemed to be at a low density. Different densities of rats at the two areas could explain the differences in trapping success and not the ability to trap rats. The most obvious difference between the New and Old Lava Flow, the two areas trapped, was the amount of vegetation covering the lava (Figure 3.10). This difference in activity can further be explained by rat habitat preferences causing clumping of rats throughout Sirius Point which was later supported by recorded movements of the radio collared rats in my study.

Norway rats were found in all four habitats encompassed in the study plot at Sirius Point. The most rat activity, according to fixes made while radio tracking, was in the Old Lava which once again suggests rats at Sirius Point may have a preference for vegetation covered lava. Not only does vegetation serve as an important food source for rats at Kiska Island but it also makes suitable cover for nesting and burrowing. This may be crucial for survival at Kiska because low temperatures have been linked to an increase in nesting activity (Kinder 1927; Denenberg et. al 1969). For example, Denenberg (et al. 1969) showed when the temperature was lowered from 21° C to 13° C rats substantially increased the shredding of wood cylinders to provide material for nests. Since the average temperature at Kiska is well below 13° C rat nests would be expected to contain a substantial amount of nesting material and also be in close proximity to nesting material to conserve energy while making nests. Many studies testing habitat associations in rat populations have also reported higher density in increased vegetation cover (Clark 1980; Drever 1997).

Rats at Sirius Point had home ranges that overlapped both within and between sexes. All rats in the study area were not radio collared therefore, the results for overlapping home ranges can only be assumed to have been the minimum amount of overlap. This is typically seen in high density populations where males will have access to several females within a smaller area than if the density were low (Nelson 1995).

Ostfeld (1992) suggested that if food is abundant, such as exhibited during the auklet breeding season at Kiska Island, it is not worth a female investing effort to protect the resources in her home range, and therefore more overlap may occur. This in turn determines space use by males, who are more responsive to the distribution of potential mates than to food resources (Gliwicz 1997). This is also consistent with the resource hypothesis used to explain territorial behavior of insular vertebrates proposed by Stamps and Buechner (1985) who stated that increased resource densities are primarily responsible for the changes in spacing behavior among insular territorial vertebrates. These preliminary observations using radio tracking data provide support of Sirius Point being able to accommodate a large population of rats during the auklet breeding season.

Compared to other islands, Norway rat home ranges were smaller and density estimates were higher at the Sirius Point study site. Norway rat home ranges on islands can be as large as 5.1 ha as measured on Kapiti Island, New Zealand (Innes 2001). Estimates at Sirius Point were more similar to Norway rats living in urban areas (0.8 - 2.0 ha; Recht 1988). Norway rat density estimates on New Zealand islands range from 2.6 rats/ha to 10 rats/ha (Bettesworth 1972; Lattanzio and Chapman 1980; Moors 1985). The estimate at Sirius Point was similar to rat densities measured in the intertidal zone of central Chile (14.75rats/ha; Navarrete and Castillo 1993). Once again the amount of resources available to rats at the Sirius Point auklet colony can explain the ability for rats to utilize smaller home ranges and maintain larger populations.

The low trap success rate in the New Lava indicated that there may be habitat preferences that might affect movements and therefore densities in certain areas.

However, the social structure of rats at my study site was typical of a high density population. This may have been due to pockets of rats that aggregate for winter in the less rugged parts of Sirius Point and then disperse into new areas in the spring and summer. The proportion and number of rats that survive the winter will determine the amount of activity seen during the auklet breeding season and the effect they may have on the auklet population, so more information on factors affecting rat over-winter survival at Sirius Point would be useful.

At Sirius Point, auklet productivity has been monitored at three plots thought to be representative of the auklet colony in general, but comprising less than 5% of the area of the colony (Major et al. 2006). If pockets of high rat density are widely scattered throughout the auklet colony, but don't occur in the 5% of the colony being monitored then the auklet reproductive success will not reflect the impact of rats. Thus more information of the overall distribution and patchiness of rats within the auklet colony would be useful to evaluate and improve the auklet productivity monitoring protocol.

Table 3.1 Home range measurements; length, width, and average diameter (Av.D.) (m) of Norway rats radio tracked at Sirius Point, Kiska Island in 2006. Home ranges were calculated from minimum convex polygons based on data collected during the first 17 days of tracking for each rat.

Female	length	width	Av. D	Male	length	width	Av. D.
F062	116.57	34.00	75.29	M020	96.95	59.50	78.23
F105	80.49	47.37	63.93	M083	169.19	48.78	108.99
F121	97.82	46.86	72.34	M121	166.41	74.48	120.45
F161	83.95	33.37	58.66	M220	163.45	78.61	121.03
Mean	94.71	40.40	67.55	--	149.00	65.34	107.17
SE	8.19	3.88	3.82	--	17.39	6.88	10.04

Table 3.2 Occurrence and number of rats having large (lg > 50%), medium (md = 10% - 50%) or small (sm < 10%) proportions of each food type in their stomachs, out of 27 Norway rats trapped at Sirius Point, Kiska Island Alaska in 2006 (bait proportions was not recorded in three rats).

		Auklet				Vegetation				Invertebrates				Bait			
sex	n	lg	md	sm	zero	lg	md	sm	zero	lg	md	sm	zero	lg	md	sm	zero
Female	15	10	3	1	1	1	5	7	2	1	1	10	3	1	4	1	7
Male	12	9	1	2	0	2	3	6	1	1	1	6	3	0	1	3	7
Total	27	19	4	3	1	3	8	13	3	2	2	16	6	1	5	4	14

lg = large, md = medium, sm = small

Table 3.3 Home range areas (m²) of Norway rats at Sirius Point, Kiska Island (MCP=minimum convex polygon; M=male, F=female). Ranges derived from radio-tracking data from 14 June 2006 to 29 July 2006.

	MCP				Fixed Kernel			
	All days		17 days		17 days		No. fixes	No. fixes
Rat	100%	95%	100%	95%	90%	80%	(all)	(17 days)
M020	5340.00	4109.50	5263.00	4334.00	4620.172	3441.453	62	37
M083	7654.00	6404.50	7654.00	6404.50	4345.203	2880.547	25	25
M141	14992.00	14758.00	13358.50	8154.50	9328.625	6404.406	43	30
M220	11243.00	11131.00	11243.00	11131.00	12558.23	9486.469	25	25
Mean	9807.25	9100.75	9379.63	7506.00	7713.06	5553.22	-	-
SE	2112.18	2385.87	1808.04	1438.64	1978.93	1522.00	-	-
F062	3203.50	3192.50	2586.50	2481.50	2865.109	1950.469	46	30
F105	3340.50	2543.00	3340.50	2543.00	3156.219	2319.719	39	34
F121	4463.00	4216.50	4318.50	3589.00	3864.328	2720.594	47	32
F220	3959.50	2099.50	3959.50	2225.50	2794.203	2011.953	40	29
Mean	3741.63	3012.88	3551.25	2709.75	3169.96	2250.68	40.87	30.25
SE	291.31	459.71	379.75	301.04	244.35	176.23	4.27	1.46

Table 3.4 Habitat in the radio tracking study area was divided into four categories (New Lava, Old Lava, Beach, and Large Boulders). Habitat use was based on percentage of rat locations recorded in each category. The greatest percentage of locations for both males and females was in the Old Lava.

	% of fixes				
Sex	New Lava	Old Lava	Beach	Large Boulders	*n*
Male	25.7	57.7	2.3	14.3	176
Female	14.4	72.2	6.4	6.9	174
All	20.6	64.6	4.3	10.6	350

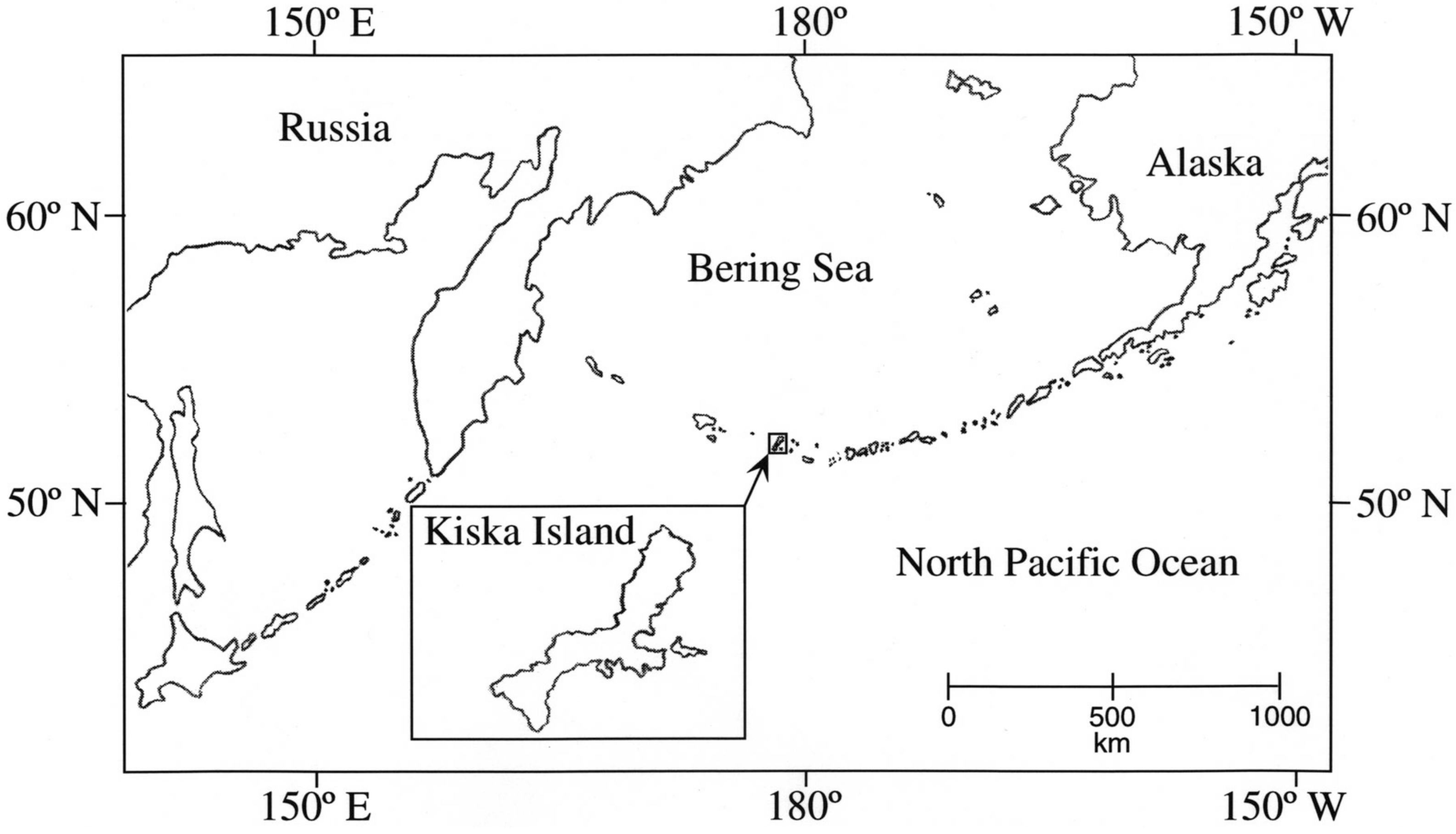


Figure 3.1 View of Aleutian Island Chain located between the Pacific Ocean and Bering Sea with an enlarged view of the outline of Kiska Island.

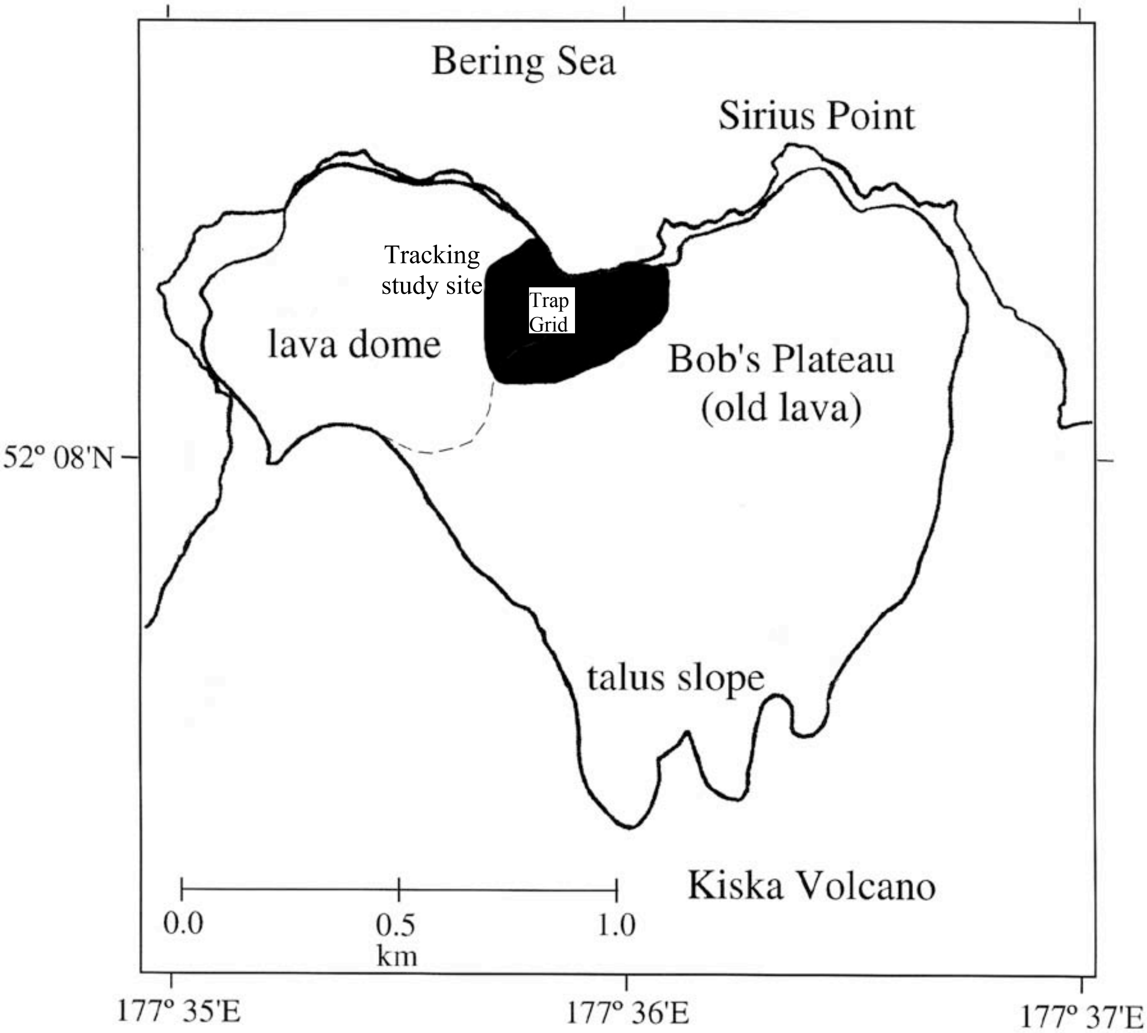
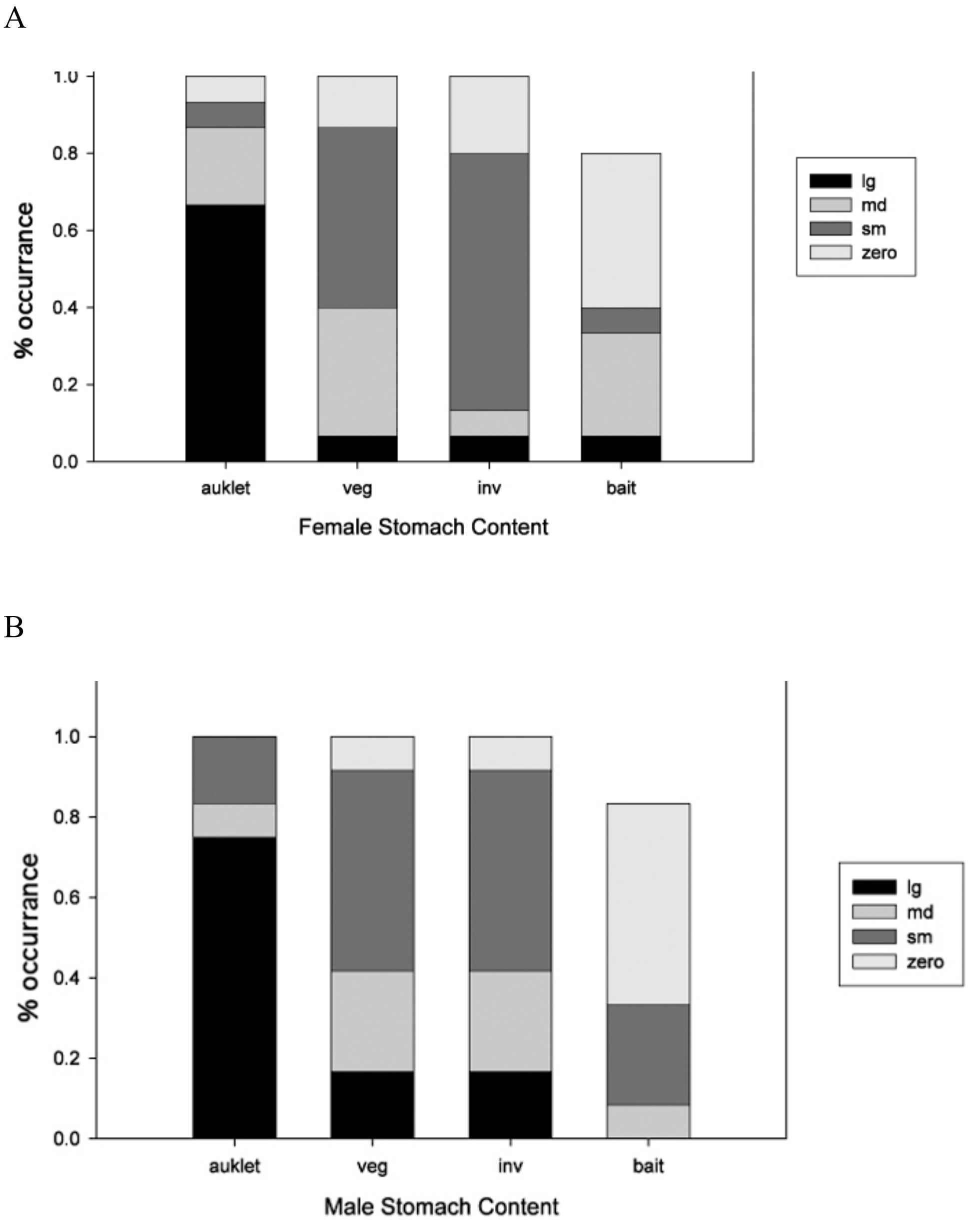


Figure 3.2 Approximate locations of radio tracking study site and snap-trap grid used to estimate the density of rats at Sirius Point, Kiska Island in 2006.



A

Figure 3.3 Percent of rats with stomach contents of each volume category (lg-large, md-medium, sm-small, and zero) of each food group in female (A) and male (B) rat stomachs collected July-August 2006 at Sirius Point, Kiska Island Alaska.

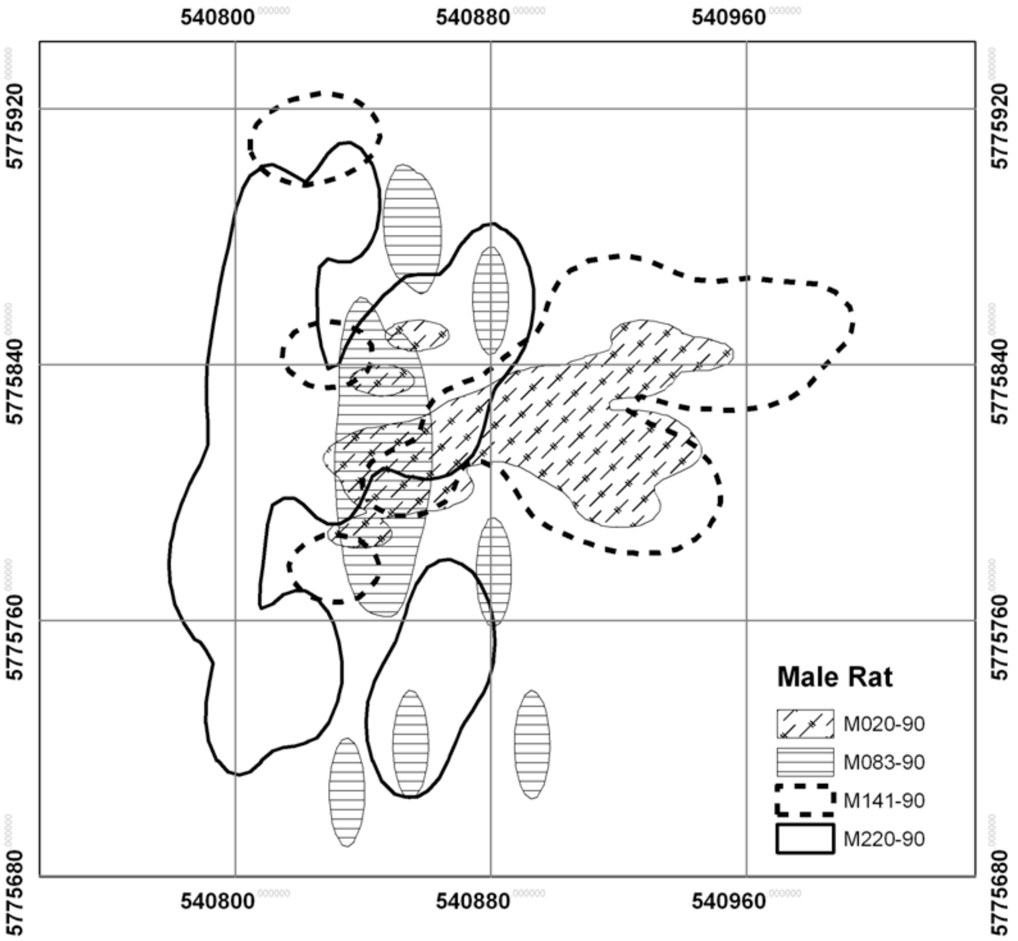


Figure 3.4 Map (UTM coordinates) showing home range overlap of four male Norway rats (M020, M083, M141 and M220) at Sirius Point, Kiska Island in 2006 (90% fixed kernel estimates).

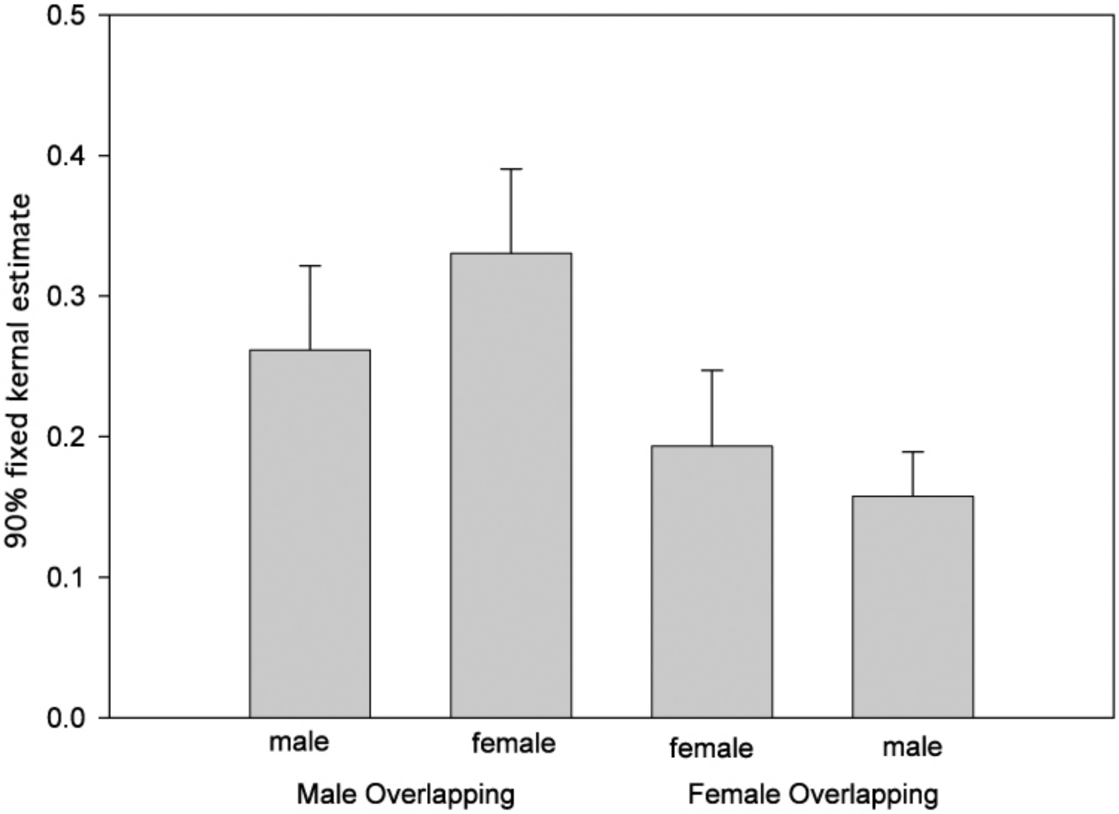


Figure 3.5 Intrasexual and intersexual home range overlap among individual Norway rats on Kiska Island (90% fixed kernel estimates). Male home ranges tended to be larger and also overlapped other male and female home ranges.

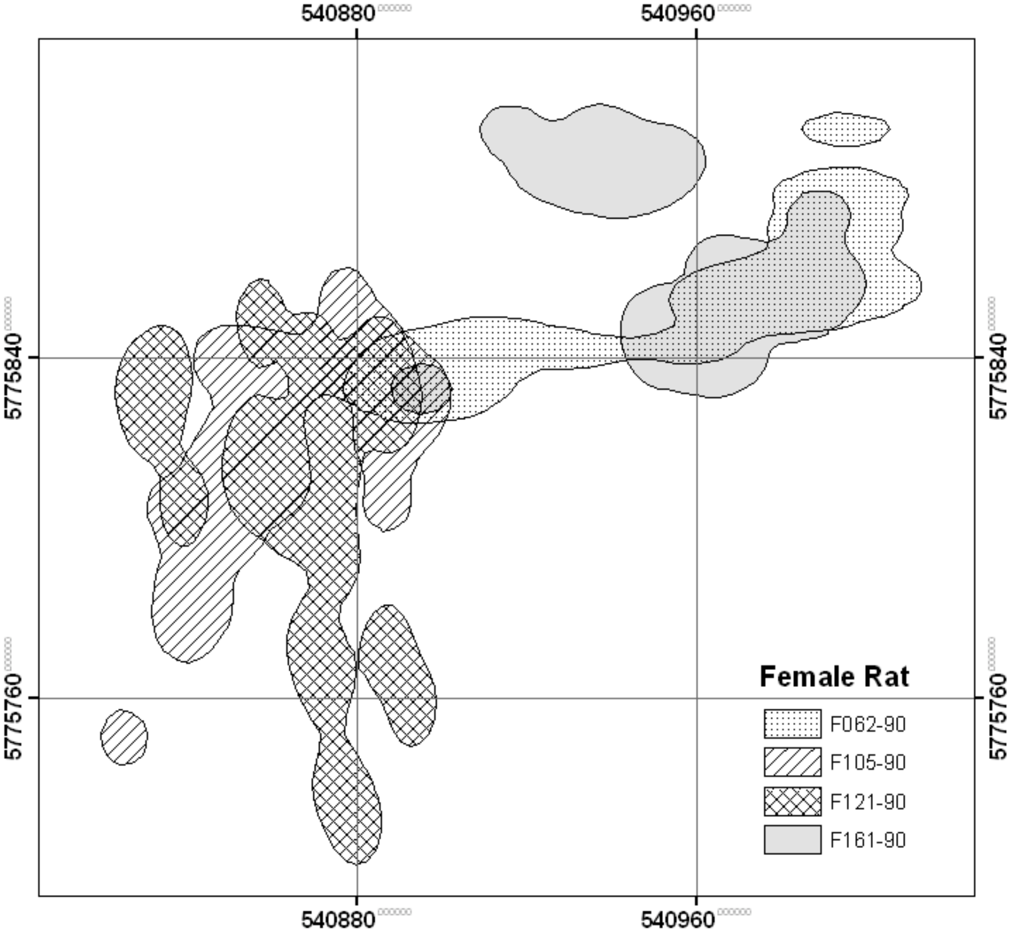


Figure 3.6 Map (UTM coordinates) showing home range overlap of four female Norway rats (F062,F105, F121, and F161) at Sirius Point, Kiska Island in 2006 (90% fixed kernel estimates).

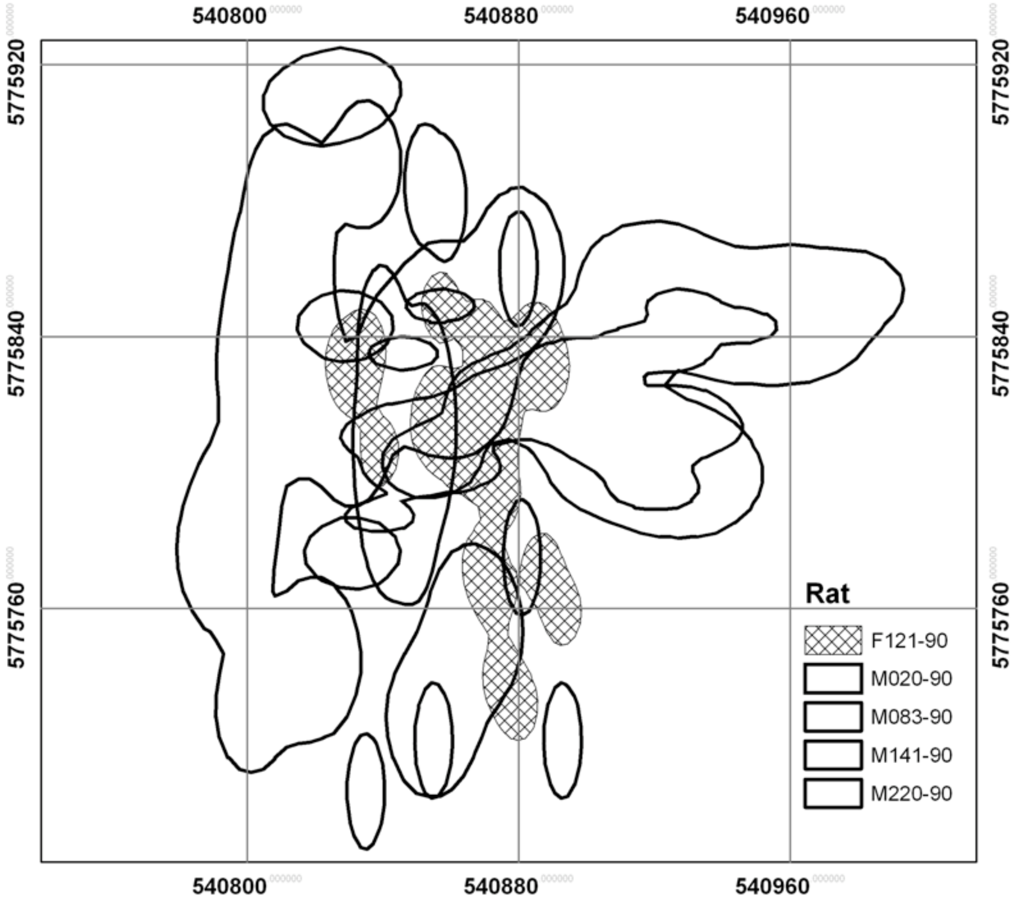


Figure 3.7 Map (UTM coordinates) showing portions of four male Norway rat (M020, M083, M141, M220) home ranges overlapping one female (F121) home range at Sirius Point, Kiska Island in 2006 (90% fixed kernel estimates).

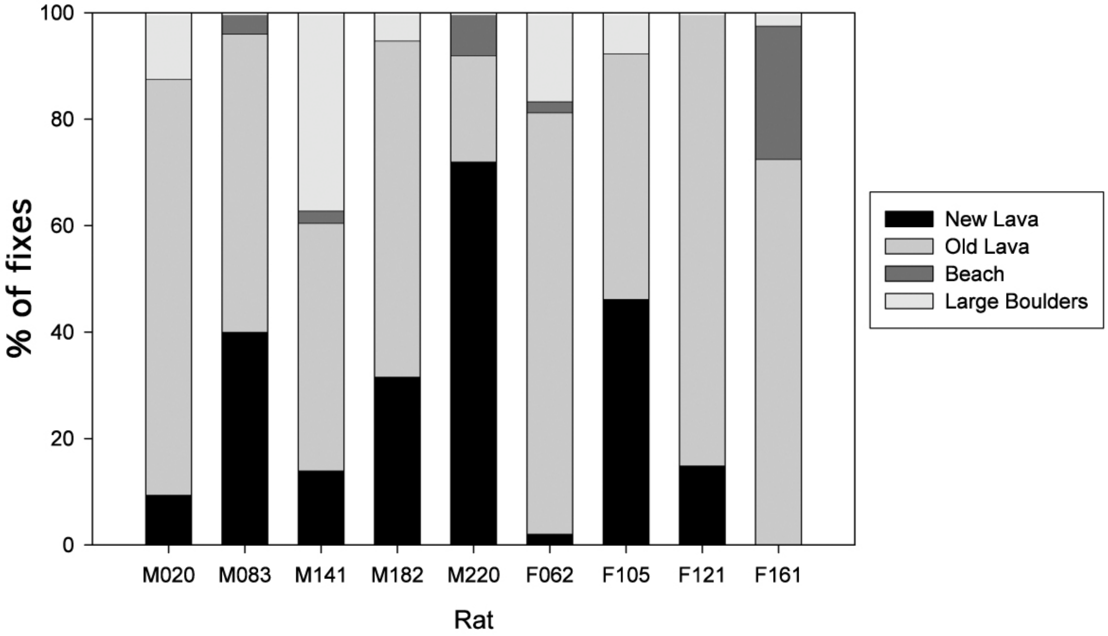


Figure 3.8 Habitat in the radio tracking study area was divided into four categories (New Lava, Old Lava, Beach, and Large Boulders). When a rat was located the habitat category was also recorded. Habitat use was determined by the percent of locations (fixes) in each category. Norway rats utilized all four categories of habitat types at Sirius Point.

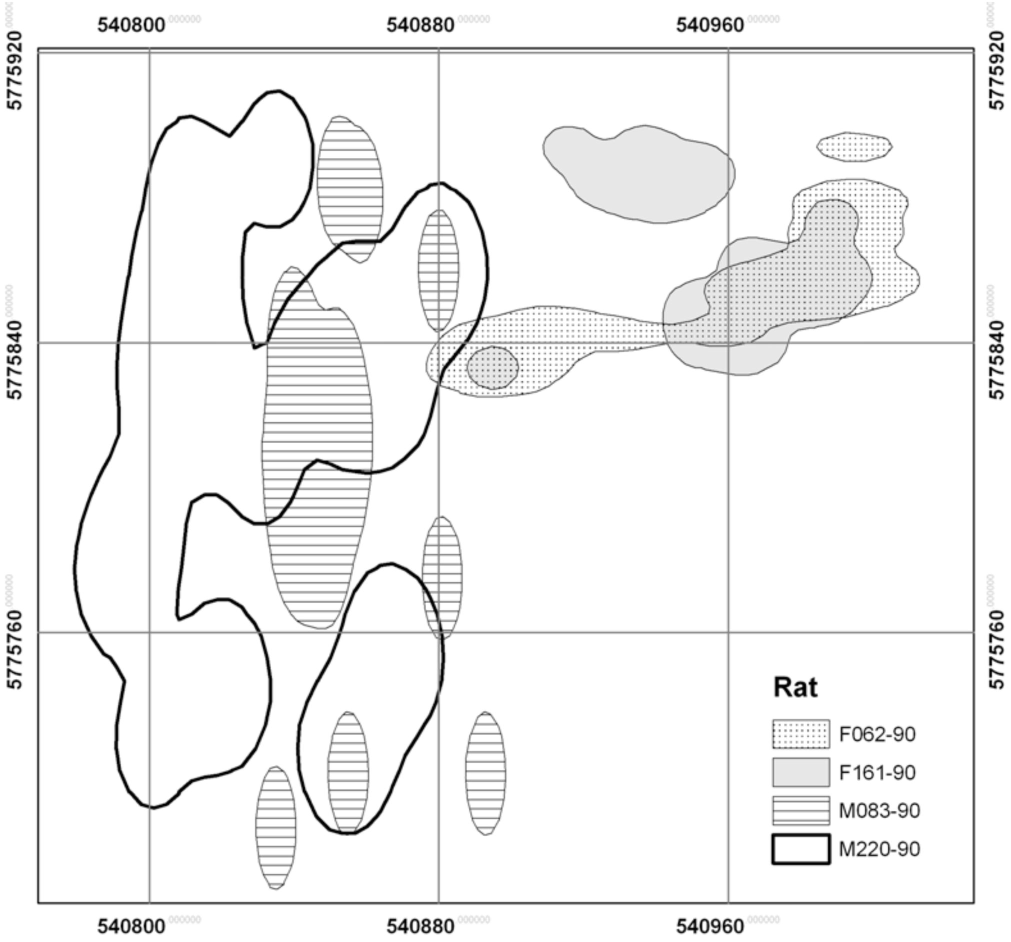


Figure 3.9 Map (UTM coordinates) showing minimum home range overlap of two male (M083, M220) Norway rats and two female rats (F062 and F161) at Kiska Island (90% fixed kernel estimates).

Figure 3.10 Vegetation cover on portions of the two lava flows, New and Old, near Sirius Point, Kiska Island, July 2006 (CE photo).

CHAPTER FOUR

A METHOD TO MONITOR INTER-ANNUAL ACTIVITY OF NORWAY RATS AT SIRIUS POINT, KISKA ISLAND ALASKA AS WELL AS INSIGHT INTO ELEVATIONAL DISTRIBUTION, AND CAPTURE RATES IN THE VICINITY OF KISKA HARBOR

4.1 INTRODUCTION

Estimating the abundance and distribution of small mammals is fundamental to the study of their population and community ecology. This information can be of particular importance when species have become introduced and established into new environments. After a relatively slow colonization period, successfully introduced small mammals often become abundant and widespread in new environments and therefore pose an increased threat to native species (Moors 1990). The increased pressure and predation on native species is usually due to the lack of defense mechanisms against these predators (Greenway 1967). Therefore, the first step in management of invasive species is to establish baseline population estimates and design monitoring protocols to increase the effectiveness of decisions related to the impact of successful introduced species.

Norway rats (*Rattus norvegicus*) are extremely adaptable and are able to survive and thrive in a multitude of environmental conditions (Olds and Olds 1979). This remarkable adaptability makes rats a major threat to a wide range of insular endemic species as well as biodiversity worldwide. Threats to insular avian fauna have been documented and in some cases such as at Langara Island (Queen Charlottes Islands, B.C., Canada) introduced rats have been implicated as the major cause of decline of breeding Ancient Murrelets (*Synthliboramphus antiques*) (Bertram 1995; Drever and Harestad 1998; Hobson et al. 1999). Norway rats were introduced as early as the 1780's too many islands within the Aleutian Island chain, Alaska (Brooks 1878; Black 1984) and were successful in maintaining populations on at least sixteen of these islands (Bailey 1993). The Aleutian Islands form the boundary between the Pacific Ocean and Bering Sea, and experience a harsh climate characterized by frequent heavy rain and strong winds throughout the year. In a study of rats experiencing an even colder climate in Nome, Alaska, Schiller (1956) found that mortality among rats living under marginal conditions during the winter was especially high. However, a high rate of reproduction during the summer resulted in a dense population by fall (Schiller 1956). Even in extreme climates rat populations can persist. The size of a population may be very important when considering the impacts on island ecosystems. Therefore, a method for indexing relative abundance would be particularly useful in studies of factors influencing the size of rat populations.

Most wild mammals are shy and adept at keeping out of sight. The majority of mammals are also nocturnal and many of the smaller forms spend the daylight hours hidden in burrows (Dice 1941). Furthermore, the habits of the various kinds of mammals vary so greatly that often a special technique must be used to quantify the population density of each species (Dice 1941). All of the traits mentioned above are true of Norway rats at Kiska Island, Aleutian Islands Alaska. Further confounding the difficulty of monitoring small mammals at Kiska Island is the likelihood of high incidental captures of seabirds due to the study site being within an extremely large breeding colony of Least and Crested Auklets (Major et al. 2006). Unfortunately, the most common monitoring techniques for rats have included live-trapping and snap-trapping which both can cause incidental captures of birds (Waldien et al. 2004). However, alternatives involving indicator baits such as wax blocks, tracking tunnels and chew sticks are non-destructive and do not impact non-target species (Quy et al. 1993). These methods can be a safe way to index population changes of small mammals at a seabird colony.

The objective of this part of my study was to determine the most effective way to monitor the Norway rats at Sirius Point, Kiska Island, Alaska. Three indicator methods - wax blocks, tracking tunnels, and chew sticks - were tested to see if rats were attracted to them, if activity was detectable, and if so whether rats had a preference for one of the methods. In addition, baseline estimates of Norway rat activity near Kiska Harbor (more than 10 km distance from the island's major seabird colony) was recorded in 2005.

4.2 METHOD

4.2.1 Study Site

Kiska Harbor is protected on both sides by long arms of rolling tundra overlain on Tertiary volcanic deposits (Coats 1947), North Head and South Head, reaching out into the Bering Sea (Figure 4.1; 4.2). The beaches rise to 300 m mountains cut by low lying valleys and as elevation increases the vegetation becomes more patchy and barren. The protected harbor at Kiska was used during WWII as an anchorage for Japanese, American, and Canadian military ships. With high ship and human traffic and a wharf constructed during WWII, Kiska Harbor was the most likely place to have been first invaded by rats on all of Kiska Island.

Norway rats were also studied at Sirius Point, Kiska Island in both 2005 and 2006 at the same time of year (Figure 4.1). The auklet colony at Sirius Point (52º08'N 177º37'E) is situated on two recent lava domes at the base of Kiska Volcano, encompassing an area of 1.8 km^2 (Figure 4.3). This colony was occupied in 2001 by more than 1 million Least and Crested Auklets (*A. cristatella,* I. L. Jones unpubl. data). The study plot encompassed four main habitat types all of which have nesting auklets: 'New Lava' (52°08.044′N 177°35.637′E) was sparsely vegetated with lichens, 'Old Lava High' (52°07.722′N 177°35.879′E) was heavily vegetated with *Carex* and *Calamagrostis* sp. and fern overgrowing basalt blocks, 'Old Lava Low' (52°07.801′N 177°35.693′E) was at a lower elevation but with similar vegetation to the high lava, and the 'Gully'(52°07.932′N 177°35.757′E) encompassed the lowest elevation and ran between the new and old lava flow. The overall terrain at Sirius Point was rugged with steep cliffs rising to ridges. Ridges flowed into undulating and unpredictable lava formations.

4.2.2 Kiska Harbor Baseline Estimate

A quantitative method using tracking tunnels to monitor rat activity was tested at Kiska Harbor (central Kiska Island, grassy lowlands) in 2005 and Sirius Point (north end, volcano) in 2006. The method for tracking tunnel installation was as described by Gillies and Williams (2004). A hill rising 300 m from the western shoreline of Kiska Harbor was chosen as a site to index Norway rat activity at three different elevation ranges (Figure 4.2). Three transect lines each traversing a different elevation range (Line TA - lowest elevation range and closest to the water, Line TB – middle, and Line TC – highest elevation range), approximately 200 m apart, contained 10 tracking tunnels, rectangular black plastic boxes (10 cm by 10 cm by 50 cm and open at each end) containing a strip of paper with an ink pad in the middle to record foot prints as rats traverse the tunnel, at approximately 50 m spacing. All tunnel locations were flagged and GPS coordinates were taken. The tracking tunnels were set up two weeks prior to pre-baiting to reduce the effects of neophobia. After pre-baiting with a mixture of peanut butter, honey and oats for three days, rat activity was indexed for two consecutive days using tracking plates with ink cards that would indicate use of the tunnel by the presence of footprint marks. After the first night and again on the second day, rat activity was recorded and ink cards with evidence of rat activity were replaced with new ink cards. Rat activity recorded included: bait gone, tracks, scratches, droppings, chewing or none. Blank cards were left in place for the next night. The tunnels were then left in position for an additional two weeks and ran again to measure rat activity using the same methodology as described above. The two trials were used to compare activity rates to test habituation. The tracking index of activity for rodents is expressed as the mean percentage of tunnels tracked by rodents per line.

Snap trap grids were used to test whether rat density was significantly different at low elevations near water supplies where food availability is greatest. Sixteen snap traps (Victor Professional Expanded Trigger Rat Trap) in a 4 trap x 4 trap grid formation, at 20 m spacing between each trap, were established at three locations on Kiska Island (Kiska Harbor North, Kiska Harbor South and Conquer Point; Figure 4.2). All grids were within 10m of a shoreline (ocean or lake). Traps were pre-baited with a mixture of oatmeal, honey and peanut butter for at least two days before being set for eight days. Rat activity at each trap was recorded each morning: bait gone, trap sprung, rat body, blood, rat droppings and movement of the trap. Each trap was then sprung, cleaned, and re-baited for the next night's activity. An index of activity for each grid was calculated per 100 corrected trap nights (Nelson and Clark 1973). I also tested whether capture rates in snap-traps varied by location using a logistic regression (binary logistic regression in Minitab, Biometry).

4.2.3. Sirius Point activity indexing

In 2006, tracking tunnels plus two additional methods, wax blocks and chew sticks, were used to index rat activity at Sirius Point. Ten indexing stations spaced 25 m apart were set up on eight different transect lines encompassing four different habitat types (two lines per habitat type) within the auklet colony at Sirius Point (Figure 4.3). Each index station contained a wax block, chew stick and tracking tunnel. Index station positions were recorded using a hand held GPS unit (Garmin GPSmap 76S) and flagged. Rocks were painted with corresponding tunnel IDs, if possible. The starting points for the eight transect lines were based on environment type and access but the transect direction was randomly chosen using a method described by Gillies and Williams (2004). However, for safety considerations, the transect lines established in the gullies were based on a safe path and could not be chosen randomly. Tunnels were set at the most suitable spot for maximum protection from severe winter weather in the Aleutians, within two meters of the 25m marker along the line. Ledges, rock crevasses, or caves were chosen in preference to flat open surface area. Also, obstruction of possible auklet nesting sites was avoided. A generalized linear model was used to test which method best detected rat presence. In addition, a generalized linear model was also used to determine if there was a significant difference in rat activity between June and July.

4.3 RESULTS

4.3.1 Kiska Harbor Baseline Estimates

Rat activity was significantly lower in transect line TB (medium elevation) and TC (high elevation) in relation to line TA (low elevation). There were no significant differences in rat activity between time period trials (df = 1, P = 0.891). There was significant variation in trapping frequency across days within each trail (df = 1, P = 0.015).

Thirty rats were trapped over 384 trap nights from all three combined trap areas for a corrected trap index (CTI) of 8.46 (Table 4.1). Kiska Harbor North had a capture rate of 7.86, Kiska Harbor South 9.2, and Conquer Point 8.26. The capture rates in the three different locations were not significantly different (G = 0.217, df = 2, P = 0.897). The odds of false sprung traps at Kiska Harbor South and Conquer Point differed in relation to Kiska Harbor North (G = 10.075, df = 2, P = 0.006). The odds of a false sprung trap were 2.8 times greater at Kiska Harbor North than at Kiska Harbor South and were 4 times greater than at Conquer Point. False sprung traps provide a measure of bias in the different trapping areas.

4.3.2 Sirius Point Activity Indexing

Norway rats had a significant preference for chewing wax blocks over gnawing on chew sticks or running through tracking tunnels ($G = 253.5$, $df = 5$, $P < 0.0001$) (Table 4.2). When activity from all methods was combined there was significantly higher rat activity in July ($G= 253.5$, $df= 5$, $P = 0.001$). The odds of rat activity in July were 6.40 times that in June. There was no rat activity in the old lava flow in June but the lower elevation transects lines did get rat activity in July. The higher elevation transects in the old lava flow only had rat activity in August.

4.4 DISCUSSION

At Kiska Harbor Norway rats were more active at lower elevations where nesting seabirds were absent. This trend in rat activity might be explained by an increase in food diversity at lower elevations. In addition to vegetation the lower elevations had better access to marine resources of the intertidal zone. The beaches surrounding Kiska provide access to living and dead intertidal organisms including kelp, fish, mollusks, and invertebrates. Rat foraging ecology studies in the Aleutian Islands observed Norway rats feeding on amphipods in the beach wrack and small invertebrates on Fucoid Algae (Kurle

2003). Furthermore, observations in 2005 confirmed daily activity of rats on the beaches (observations by CJE and ILJ 2005).

Kiska Harbor capture rates were similar to capture rates observed on Langara Island, British Columbia, Canada (8.2 C/100TN at sites without seabirds; Drever 2004) where Norway rat predation was implicated as the major cause in the decline of breeding Ancient Murrelets (*Synthliboramphus antiquus* - Bertram 1995; Drever and Harestad 1998; Hobson et al. 1999). A similar study was conducted at Langara to compare trap rates at different habitats prior to an eradication of rats in 1995, indicating that capture rates were significantly different between coastal and inland sites. Future rat trapping grids at Kiska could be improved by increasing the area trapped and number of traps used, to provide trapping rates more reflective of the entire island. Incorporating trapping grids to other habitat types would also improve existing data on the distribution of Norway rats at Kiska Island.

Norway rats were attracted to all indexing methods tested at Kiska Island, Alaska in 2005 and 2006. Fortunately, the most successful method tested in 2006, peanut butter flavored wax blocks, also was an easy and inexpensive method to apply in the terrain at Sirius Point, Kiska Island. This non-invasive method will likely prove to be a good choice to monitor fluctuations in rat populations annually at a seabird colony such as Sirius Point. Tracking tunnels worked well at Kiska Harbor but proved to be more labor intensive and more expensive to employ. Since rats at Kiska Harbor may prefer different baits it would be important to test all methods at Kiska Harbor to make any conclusions for that part of the island.

In several parts of the world, tropical and arid zone rodents show extreme population fluctuations, apparently in response to climatic factors (Madsen and Shine 1999). The Aleutian climate of Kiska Island is similarly variable and likely affects parts of the ecosystem that rats are dependent on which in turn can affect the number of Norway rats. This possibility is consistent with anecdotal observations of fluctuating rat abundance at Kiska across different years (many observers, personal observations). For this reason it will be important to quantify annual variation in rat numbers in relation to other variables within the environment. My wax block monitoring protocol will provide a method to explore this issue on Kiska and also other islands where rats and seabirds persist together in the same habitat.

Table 4.1 Index of Norway rat abundance (captures/100 ctn) at three locations at central Kiska Island, Alaska 2005.

	Kiska Harbor North	Kiska Harbor South	Conquer Point	Combined Areas
No. of trap nights	128	128	128	384
No. of trap sprung	18	7	5	29
No. of captures	9	11	10	30
Index	7.86	9.2	8.26	8.46

ctn = corrected trap nights

Table 4.2 Rat presence recorded at three treatments (w=wax blocks, c=chew sticks and t= tracking tunnel) within eight transect lines to index rat activity at Sirius Point, Kiska Island, Alaska in 2006.

	June										**July**									
	13			**14**			**15**			**Total**	**13**			**14**			**15**			**Total**
Treatment	**w**	**c**	**t**	**w**	**c**	**t**	**w**	**c**	**t**		**w**	**c**	**t**	**w**	**c**	**t**	**w**	**c**	**t**	
New 1	1	1	0	3	0	0	2	0	0	7	2	2	0	5	3	0	5	2	0	**19**
New 2	0	0	1	0	0	0	0	0	1	2	0	0	0	0	0	1	3	0	1	**5**
Gully 1	3	0	0	2	0	1	2	0	1	9	7	1	6	7	4	7	8	7	9	**56**
Gully 2	3	2	0	1	0	0	2	0	0	8	8	1	0	9	1	3	7	1	6	**36**
Low 1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2	1	0	1	**7**
Low 2	0	0	0	0	0	0	0	0	0	0	4	2	3	3	1	3	3	1	4	**24**
High 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
High 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**

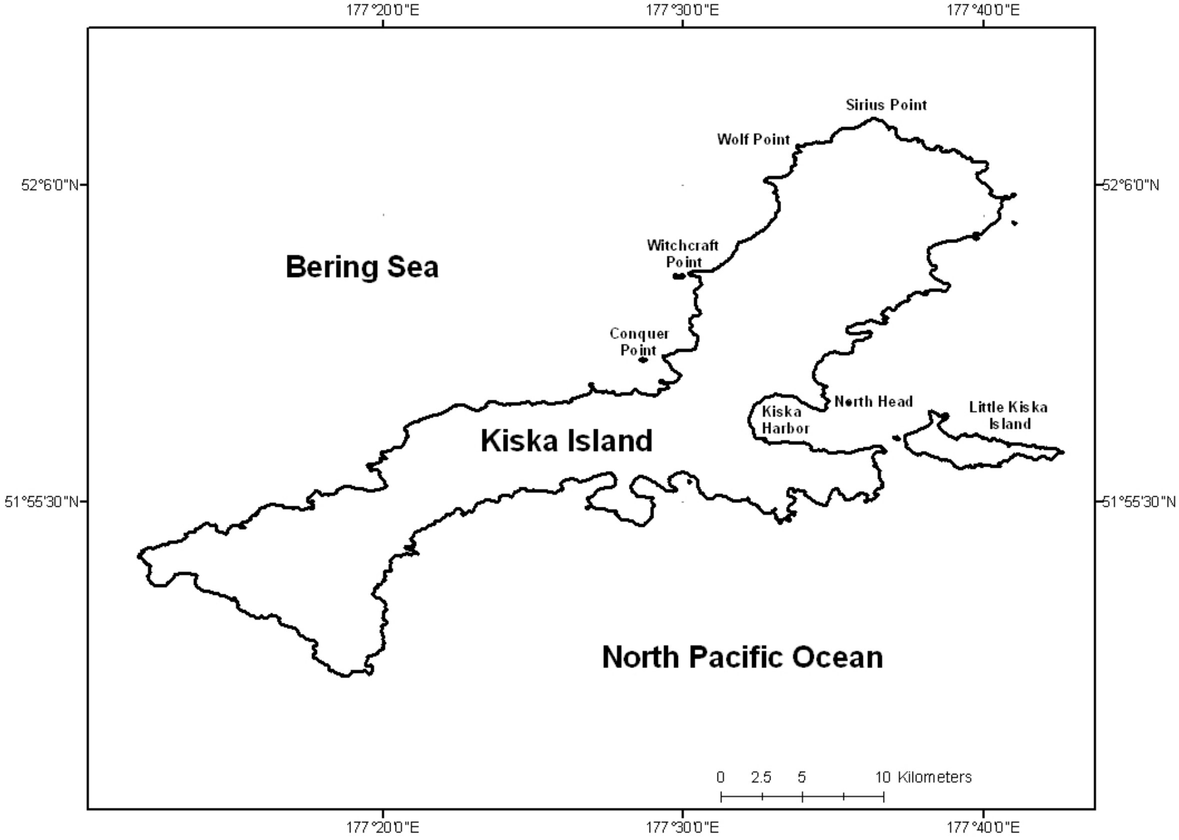


Figure 4.1 Map of Kiska Island, Alaska. The central portion of the island (Kiska harbor to Conquer Point – Figure 4.2)) was used as a study site in 2005 and Sirius Point was visited in 2005 and 2006 (Figure 4.3).

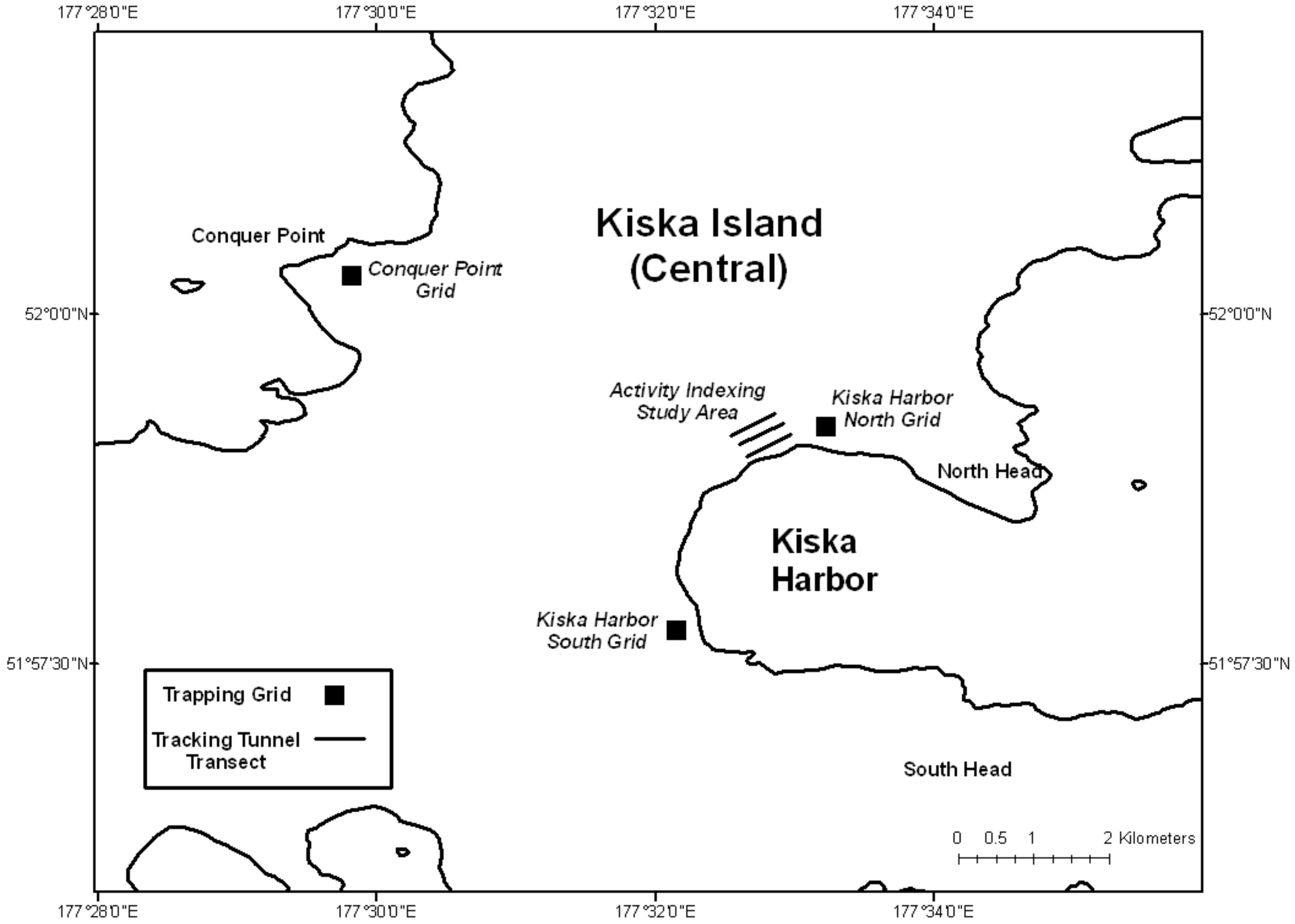


Figure 4.2 Location of rat trapping grids and rat activity indexing study area at Kiska Harbor, Kiska Island in 2005.

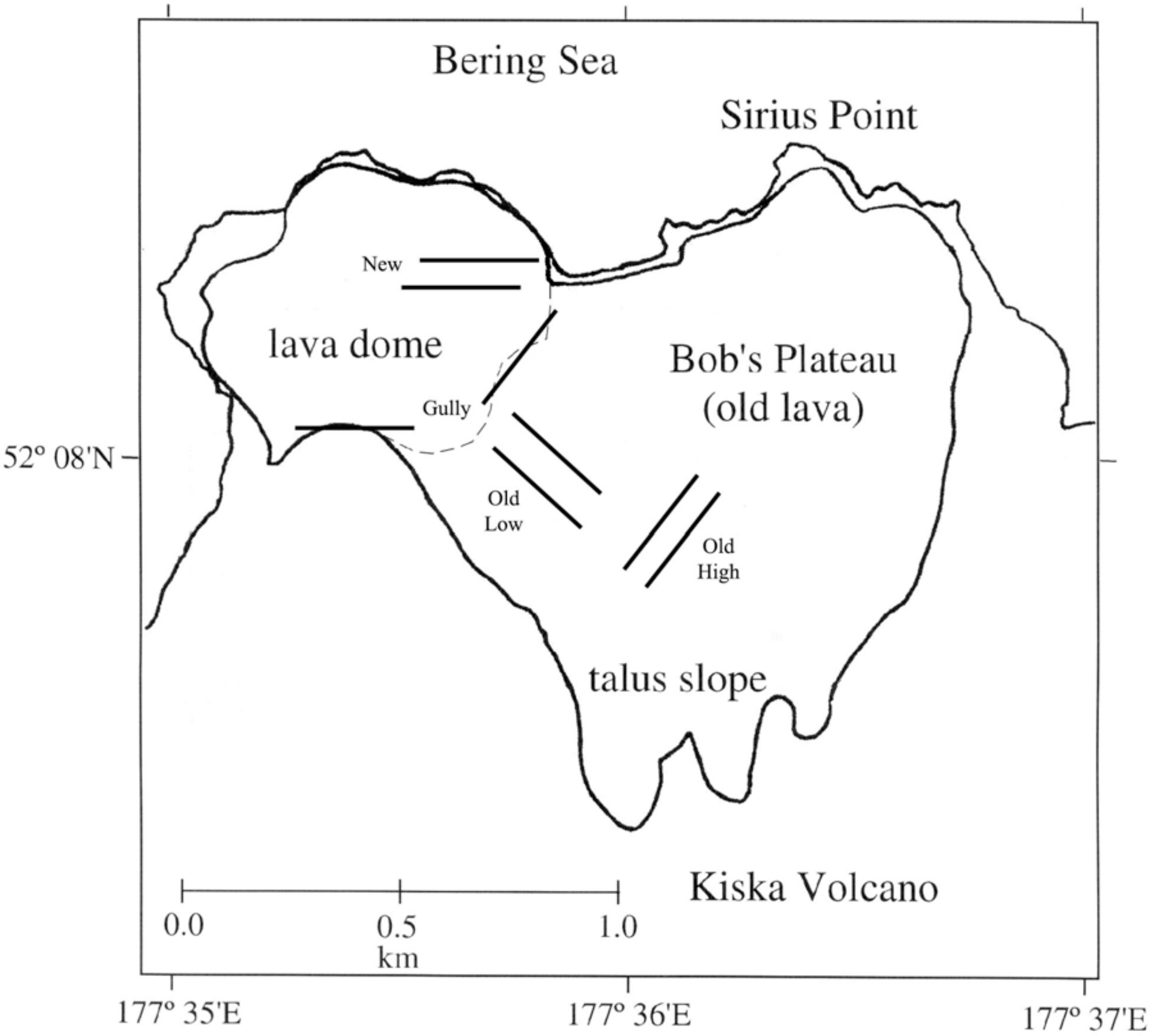


Figure 4.3 Approximate locations of activity index transect lines at Sirius Point, Kiska Island in 2006.

CHAPTER FIVE

SUMMARY

Although it is frequently infested with introduced Norway rats (*Rattus norvegicus*), a known predator of Least Auklets (*Aethia pusilla*), Sirius Point at Kiska still remains one of the largest auklet colonies in Alaska. Thus rat impacts to the Sirius Point colony would greatly effect the overall Alaskan auklet population. After six years of monitoring auklet reproductive success at Kiska, 2001 and 2002, still remain the lowest ever recorded for Least Auklets anywhere. Natural fluctuations in reproductive success at a seabird colony are normal over time (Cairns 1987). Buldir and Kasatochi, islands that have been studied for over 10 years, both show fluctuations in reproductive success in a cyclical pattern. However these fluctuations never reached below 34%. In comparison, Kiska Island's lowest estimated reproductive success was by far the lowest of all islands at 9% in 2002 (16% in 2001) over a 6 year period. Furthermore, Kiska's auklet colony experienced two consecutive years of the lowest recorded estimates of reproductive success. I found with additional years of monitoring that annual adult local survival estimates for 2002-2005 steadily declined to below 0.8 while reproductive success rebounded to normal levels (54% in 2006). Overall productivity was significantly lower at an island with rats (Kiska) as compared to islands without rats (Kasatochi: $z = 7.24$, $df = 6$, $P < 0.0001$, Buldir: $z = 5.58$, $df = 6$, $P < 0.0001$). Further survival monitoring at Kiska based on a larger sample of marked birds (no new birds were marked in 2004, 2005 or 2006) is required for more reliable results. Long-term monitoring is necessary to compare threats to different colonies in Alaska.

Norway rats used all the habitats studied at Sirius Point. The low trap rate in the New Lava indicated that there may be habitat preferences that might affect movements and therefore densities in certain areas. Yet, the social structure of rats in the study site was typical for a high density population. Furthermore, Norway rat home ranges were smaller and density estimates were higher at the Sirius Point study site compared to other islands. The limiting factor for rat explosions may be the proportion and number of rats that survive the winter. This will determine the amount of activity seen during the auklet breeding season and the effect they may have on the auklet population. More information on factors affecting rat over-winter survival at Sirius Point would be useful.

Norway rats were attracted to all indexing methods tested at Kiska Island, Alaska in 2005 and 2006. Fortunately, the most successful method tested in 2006, peanut butter flavored wax blocks, also were an easy and inexpensive method to apply in the terrain at Sirius Point, Kiska Island. This non-invasive method will likely prove to be a good choice to monitor fluctuations in rat populations annually at a seabird colony such as Sirius Point.

In several parts of the world, tropical and arid zone rodents show extreme population fluctuations, apparently in response to climatic factors (Madsen and Shine 1999). The Aleutian climate of Kiska Island is similarly variable and likely affects parts of the ecosystem that rats are dependent on which in turn can affect the number of Norway rats. This possibility is consistent with anecdotal observations of fluctuating rat abundance at Kiska across different years (many observers, personal observations). For this reason it will be important to quantify annual variation in rat numbers in relation to other variables within the environment. The wax block monitoring protocol will provide a method to explore this issue on Kiska and also other islands where rats and seabirds persist together in the same habitat.

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Appendix A. Standardized data used to estimate home range for rats radio tracked at Sirius Point, Kiska Island in 2006 (Habitat 1-New Lava, 2-Old Lava, 3-Beach, 4-Large Boulders) (UTM, Projection: NAD27 Alaska).

RAT ID	EASTING	NORTHING	TIME	DATE	HABITAT
M020	540857	5775849	10:52	6/14/2006	1
M020	540928	5775849	00:15	6/14/2006	4
M020	540946	5775843	00:35	6/15/2006	2
M020	540903	5775825	05:15	6/15/2006	4
M020	540897	5775830	18:36	6/15/2006	4
M020	540853	5775802	10:50	6/16/2006	2
M020	540920	5775809	02:55	6/17/2006	2
M020	540853	5775802	13:20	6/17/2006	2
M020	540915	5775838	23:22	6/17/2006	2
M020	540847	5775811	03:15	6/18/2006	2
M020	540897	5775830	17:20	6/18/2006	2
M020	540875	5775825	21:57	6/18/2006	4
M020	540901	5775813	06:05	6/19/2006	2
M020	540854	5775803	15:40	6/19/2006	2
M020	540895	5775833	12:20	6/20/2006	2
M020	540871	5775814	01:15	6/21/2006	2
M020	540921	5775794	12:48	6/21/2006	2
M020	540846	5775835	22:25	6/21/2006	1
M020	540847	5775815	02:00	6/22/2006	1
M020	540848	5775800	19:26	6/22/2006	2
M020	540905	5775808	05:45	6/23/2006	2
M020	540918	5775798	17:30	6/23/2006	2
M020	540839	5775787	22:31	6/23/2006	2
M020	540863	5775801	00:24	6/24/2006	2
M020	540889	5775825	19:53	6/24/2006	2
M020	540926	5775835	04:39	6/25/2006	2
M020	540892	5775815	10:44	6/25/2006	2
M020	540863	5775818	00:25	6/26/2006	2
M020	540889	5775825	15:52	6/26/2006	2
M020	540889	5775822	20:39	6/26/2006	2
M020	540839	5775810	02:40	6/27/2006	1
M020	540915	5775806	22:20	6/27/2006	2
M020	540915	5775806	00:30	6/28/2006	2
M020	540927	5775820	11:53	6/28/2006	2
M020	540931	5775812	04:46	6/29/2006	2
M020	540931	5775812	16:00	6/29/2006	2
M020	540929	5775816	05:16	7/6/2006	2
F062	540895	5775833	08:28	6/28/2006	2
F062	540994	5775879	15:51	6/29/2006	2
F062	540905	5775837	00:47	6/30/2006	2
F062	540995	5775870	02:28	6/30/2006	2
F062	540992	5775858	21:47	6/30/2006	2

F062	540959	5775843	04:28	7/1/2006	2
F062	540896	5775842	05:40	7/1/2006	4
F062	540988	5775857	19:01	7/1/2006	2
F062	540995	5775894	01:55	7/2/2006	2
F062	540994	5775879	03:04	7/2/2006	2
F062	540992	5775858	14:00	7/2/2006	2
F062	540990	5775870	05:50	7/3/2006	2
F062	540988	5775857	12:57	7/4/2006	2
F062	540988	5775857	16:27	7/5/2006	2
F062	540973	5775853	05:01	7/6/2006	2
F062	540983	5775854	06:28	7/6/2006	2
F062	540896	5775830	19:08	7/7/2006	2
F062	540912	5775846	02:03	7/8/2006	4
F062	540895	5775838	03:32	7/8/2006	2
F062	540969	5775857	18:43	7/8/2006	2
F062	540894	5775833	05:08	7/9/2006	2
F062	540988	5775857	17:41	7/9/2006	2
F062	540983	5775854	12:20	7/10/2006	2
F062	540988	5775857	12:04	7/10/2006	2
F062	540988	5775857	05:17	7/11/2006	2
F062	540988	5775857	17:44	7/11/2006	2
F062	540931	5775842	00:13	7/12/2006	4
F062	540988	5775857	17:31	7/13/2006	2
F062	540971	5775852	16:40	7/14/2006	2
F062	540988	5775857	17:40	7/15/2006	2
M083	540839	5775810	02:40	6/27/2006	1
M083	540842	5775783	12:06	6/28/2006	2
M083	540854	5775802	21:53	6/28/2006	2
M083	540849	5775779	03:46	6/29/2006	2
M083	540850	5775795	12:24	7/4/2006	2
M083	540839	5775810	17:29	7/5/2006	1
M083	540848	5775800	12:48	7/10/2006	2
M083	540841	5775793	04:25	7/11/2006	2
M083	540852	5775810	18:30	7/11/2006	2
M083	540852	5775885	01:06	7/12/2006	1
M083	540859	5775880	04:30	7/13/2006	1
M083	540839	5775810	18:11	7/13/2006	2
M083	540840	5775791	17:16	7/14/2006	1
M083	540849	5775820	18:31	7/15/2006	1
M083	540881	5775775	00:14	7/16/2006	2
M083	540845	5775794	13:40	7/16/2006	2
M083	540893	5775721	17:08	7/17/2006	2
M083	540855	5775721	17:30	7/22/2006	2
M083	540855	5775816	00:37	7/23/2006	2
M083	540880	5775860	14:34	7/23/2006	3
M083	540852	5775827	05:40	7/24/2006	1
M083	540852	5775827	18:00	7/24/2006	1
M083	540839	5775841	01:29	7/25/2006	1
M083	540835	5775706	16:53	7/25/2006	2
M083	540841	5775838	03:57	7/26/2006	1

F105	540839	5775776	12:00	6/27/2006	1
F105	540893	5775831	12:16	6/28/2006	2
F105	540893	5775831	22:02	6/28/2006	2
F105	540887	5775821	03:59	6/29/2006	2
F105	540887	5775824	05:37	6/29/2006	1
F105	540851	5775801	15:24	6/29/2006	2
F105	540840	5775787	01:11	6/30/2006	1
F105	540847	5775840	02:47	6/30/2006	1
F105	540847	5775811	19:17	6/30/2006	1
F105	540836	5775805	03:38	7/1/2006	1
F105	540860	5775818	04:57	7/1/2006	2
F105	540845	5775802	20:03	7/1/2006	2
F105	540850	5775807	01:10	7/2/2006	2
F105	540887	5775806	02:20	7/2/2006	2
F105	540855	5775816	13:19	7/2/2006	2
F105	540873	5775840	03:38	7/3/2006	2
F105	540848	5775817	05:02	7/3/2006	1
F105	540893	5775831	12:12	7/4/2006	2
F105	540842	5775783	17:21	7/5/2006	2
F105	540854	5775820	03:53	7/6/2006	2
F105	540856	5775825	05:59	7/6/2006	1
F105	540858	5775820	18:15	7/7/2006	1
F105	540825	5775751	01:20	7/8/2006	2
F105	540844	5775801	02:38	7/8/2006	2
F105	540862	5775810	18:11	7/8/2006	2
F105	540861	5775836	03:39	7/9/2006	1
F105	540854	5775839	16:54	7/9/2006	1
F105	540847	5775801	12:56	7/10/2006	2
F105	540842	5775783	03:41	7/11/2006	2
F105	540885	5775841	18:15	7/11/2006	4
F105	540861	5775836	01:29	7/12/2006	1
F105	540877	5775855	04:39	7/13/2006	1
F105	540881	5775842	18:32	7/13/2006	4
F105	540881	5775842	17:48	7/14/2006	4
F121	540857	5775849	08:28	6/28/2006	1
F121	540870	5775814	15:37	6/29/2006	1
F121	540835	5775837	00:58	6/30/2006	1
F121	540889	5775830	02:13	6/30/2006	2
F121	540856	5775814	19:33	6/30/2006	1
F121	540832	5775827	03:48	7/1/2006	1
F121	540862	5775808	05:05	7/1/2006	2
F121	540885	5775833	20:14	7/1/2006	2
F121	540870	5775814	01:18	7/2/2006	2
F121	540869	5775841	02:32	7/2/2006	2
F121	540870	5775814	13:25	7/2/2006	2
F121	540869	5775773	03:52	7/3/2006	2
F121	540870	5775814	05:12	7/3/2006	2
F121	540870	5775814	12:19	7/4/2006	2
F121	540857	5775819	17:11	7/5/2006	2
F121	540893	5775759	04:10	7/6/2006	2

F121	540870	5775814	06:06	7/6/2006	2
F121	540856	5775814	18:28	7/7/2006	2
F121	540873	5775764	01:35	7/8/2006	2
F121	540866	5775805	02:30	7/8/2006	2
F121	540887	5775772	18:28	7/8/2006	2
F121	540829	5775833	03:52	7/9/2006	1
F121	540839	5775806	17:07	7/9/2006	1
F121	540880	5775731	00:51	7/10/2006	2
F121	540870	5775814	12:15	7/10/2006	2
F121	540870	5775814	13:45	7/11/2006	2
F121	540870	5775814	17:59	7/11/2006	2
F121	540870	5775814	01:33	7/12/2006	2
F121	540885	5775839	04:09	7/13/2006	2
F121	540875	5775794	17:51	7/13/2006	2
F121	540878	5775830	17:00	7/14/2006	2
F121	540875	5775740	18:14	7/15/2006	2
M141	540831	5775776	08:30	6/29/2006	1
M141	540899	5775835	19:45	6/30/2006	2
M141	540874	5775823	04:15	7/1/2006	2
M141	540907	5775838	05:30	7/1/2006	4
M141	540829	5775843	20:21	7/1/2006	1
M141	540935	5775850	01:32	7/2/2006	4
M141	540979	5775854	02:57	7/2/2006	2
M141	540958	5775849	01:51	7/2/2006	2
M141	540854	5775803	04:05	7/3/2006	2
M141	540964	5775840	05:28	7/3/2006	2
M141	540958	5775849	12:43	7/4/2006	2
M141	540958	5775849	16:58	7/5/2006	2
M141	540925	5775804	05:27	7/6/2006	2
M141	540920	5775858	06:37	7/6/2006	4
M141	540908	5775801	18:37	7/7/2006	4
M141	540895	5775822	01:48	7/8/2006	2
M141	540953	5775840	03:03	7/8/2006	2
M141	540920	5775858	18:57	7/8/2006	4
M141	540820	5775908	17:19	7/9/2006	1
M141	540830	5775913	01:24	7/10/2006	1
M141	540955	5775850	11:47	7/10/2006	2
M141	540931	5775795	04:57	7/11/2006	2
M141	540920	5775858	17:54	7/11/2006	4
M141	540927	5775798	00:22	7/12/2006	2
M141	540914	5775809	03:53	7/13/2006	4
M141	540940	5775841	17:39	7/13/2006	4
M141	540929	5775805	16:51	7/14/2006	2
M141	540927	5775798	17:51	7/15/2006	2
M141	540913	5775801	01:33	7/16/2006	2
M141	540904	5775812	12:49	7/16/2006	4
F161	540895	5775833	19:45	6/30/2006	2
F161	540964	5775840	13:45	7/2/2006	2
F161	540941	5775880	04:25	7/3/2006	3
F161	540964	5775840	05:41	7/3/2006	2

F161	540985	5775862	12:49	7/4/2006	2
F161	540992	5775858	16:33	7/5/2006	2
F161	540916	5775894	04:41	7/6/2006	3
F161	540951	5775850	06:19	7/6/2006	2
F161	540989	5775874	18:51	7/7/2006	2
F161	540938	5775890	02:10	7/8/2006	3
F161	540937	5775893	03:15	7/8/2006	3
F161	540983	5775854	18:50	7/8/2006	2
F161	540971	5775854	04:49	7/9/2006	2
F161	540971	5775857	17:49	7/9/2006	2
F161	540960	5775846	01:51	7/10/2006	2
F161	540983	5775854	12:01	7/10/2006	2
F161	540953	5775840	04:47	7/11/2006	2
F161	540966	5775863	17:46	7/11/2006	2
F161	540924	5775885	01:48	7/12/2006	3
F161	540953	5775887	03:28	7/13/2006	3
F161	540983	5775854	17:27	7/13/2006	2
F161	540983	5775854	16:35	7/14/2006	2
F161	540950	5775887	00:24	7/15/2006	3
F161	540958	5775849	17:44	7/15/2006	2
F161	540948	5775882	01:56	7/16/2006	3
F161	540971	5775857	12:36	7/16/2006	2
F161	540932	5775882	03:35	7/17/2006	3
F161	540953	5775844	17:52	7/17/2006	4
F161	540967	5775841	16:49	7/22/2006	2
M220	540857	5775849	03:00	7/9/2006	1
M220	540865	5775758	12:40	7/10/2006	2
M220	540801	5775730	04:07	7/11/2006	1
M220	540856	5775825	18:23	7/11/2006	1
M220	540820	5775745	00:49	7/12/2006	1
M220	540794	5775777	04:59	7/13/2006	1
M220	540868	5775827	18:21	7/13/2006	2
M220	540870	5775752	17:36	7/14/2006	2
M220	540853	5775726	18:04	7/15/2006	2
M220	540880	5775860	00:49	7/16/2006	3
M220	540813	5775827	13:24	7/16/2006	1
M220	540831	5775808	04:32	7/17/2006	1
M220	540844	5775835	17:26	7/17/2006	1
M220	540880	5775860	17:49	7/22/2006	3
M220	540857	5775730	00:17	7/23/2006	2
M220	540835	5775891	14:05	7/23/2006	1
M220	540802	5775832	05:28	7/24/2006	1
M220	540813	5775827	17:16	7/24/2006	1
M220	540811	5775884	01:16	7/25/2006	1
M220	540813	5775827	16:35	7/25/2006	1
M220	540798	5775794	03:42	7/26/2006	1
M220	540820	5775745	15:02	7/26/2006	1
M220	540814	5775859	23:17	7/27/2006	1
M220	540806	5775857	16:09	7/28/2006	1
M220	540792	5775776	03:15	7/29/2006	1