ANNUAL VARIATION IN THE DIET OF HOUSE MICE (*MUS MUSCULUS*) ON SOUTHEAST FARALLON ISLAND

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FORWARD

HOUSE MICE (*MUS MUSCULUS)* ON SOUTHEAST FARALLON ISLAND

Megan A. Jones and Richard T. Golightly

Numerous declines and extinctions of native wildlife populations have been caused by the introduction of non-native plants and animals to islands (Huyser et al. 2000, Marinez-Gomez and Jacobsen 2004). Various members of the Order Rodentia have contributed to this world wide phenomenon (Cuthbert and Hilton 2004). Many rodents are omnivores and members of the taxa have been known to feed on bird eggs, birds, insects, ant eggs, meat, bacon, cannibalism, lizards, carrion, slugs, and mammal bones (Landry 1970). Previous studies found house mice (*Mus musculus*) diets to be omnivorous but the diet varied with location of the study (primarily invertebrates in cultivated regions of North America, Whitaker 1966; invertebrates, vegetation, and vertebrate material on sub-Antarctic Islands, Copson 1986; and seasonal change with food availability on South Atlantic Islands, Jones et al. 2003). House mice have also been found to damage eggs (Maxon and Oring 1978) and feed on live chicks of Tristan Albatross (*Diomedea dabbenena)* and Atlantic Petrel (*Pterodroma incerta*) (Cuthbert and Hilton 2004). Egg size probably does not provide protection against mouse predation as Blight and Ryder (1999) found that *Peromyscus* consumed the eggs of Rhinoceros Auklets (*Cerorhinca monocerata*). In addition to direct affects on seabirds through predation, house mice have been found to alter the plant and invertebrate communities on islands and result in greater effects than just through predation (Chown and Smith 1993, Smith et al. 2002). Mice may also indirectly affect seabird populations by supporting winter populations of predators which switch their diet to the seabirds when seabirds become available at nesting colonies in the spring (Drost 1989).

Southeast Farallon Island, in the Farallon Island archipelago, is located 32 km southwest of Point Reyes, California, USA. This important seabird breeding colony in western North America, includes the world's largest populations of breeding Ashy Storm- Petrels (*Oceanodoma homochroa*), Brant's Cormorants (*Phalacrocorax penicillatus*), and Western Gulls (*Larus* *occidentalis*) (DeSante and Ainley 1980). Additionally there are 12 other seabird species with populations on the Farallon Islands (DeSante and Ainley 1980). Many of these seabirds are ground-nesting or burrow-nesting species including the Ashy Storm- Petrel, Cassin's Auklet (*Ptychoramphus aleuticus*), and Rhinoceros Auklet (Ainley and Boekelheide 1990). Sydeman et al. (1998) reported a 28-44% population decline for seabirds from 1972 to 1992. They speculated that this decline was potentially attributed to weather patterns (El Niño), human disturbance, burrowing owl predation on adults, or predation on eggs and chicks by house mice (Sydeman et al. 1998).

House mice were introduced to Southeast Farallon Island by human settlers, likely after the building of a lighthouse in 1855 (Howald et al. 2004, Shorenherr et al. 1999). Few studies have examined the ecology of house mice on the island (McDermott 2002, Schwan 1984). These non-native populations of house mice have the potential to affect survival of Ashy Storm-Petrels and other ground- or burrow-nesting birds by: 1) possibly eating or destroying eggs and reducing breeding success, 2) dispersing seeds of non-native plants species lowering the habitat quality for ground nesting birds, and 3) providing a winter prey source for over-wintering predators which subsequently feed on seabirds when they become available in the spring (Howald et al. 2004).

Eradication of the house mouse on Southeast Farallon Island has been proposed (Howald et al. 2004). Successful eradication of non-native rabbits and cats occurred on the island following the creation of the Farallon National Wildlife Refuge in 1969 (Howald et al. 2004). Eradication of rats or mice has successfully occurred on numerous islands around New Zealand, sub-Antarctic islands, the Aleutian Islands, and on Anacapa Island in southern California (reviewed Donlan et al. 2003). The justification for eradication of mice from Southeast Farallon

Island could have two supporting goals. The first would be to preserve the community in its natural state without human introduced, non-native species. The second, would be the removal of the mice to help the declining populations of seabirds on the island, but this later goal is based on the presumption that mice negatively affect the seabird populations.

The lack of knowledge about seabird population size prior to the introduction of house mice makes studies that demonstrate the impacts of mice on the seabird population and the island community necessary. One part of the assessment of the impact of mice on the island community is to analyze the diet of the mice. Through examination of the material consumed by the mice during the entire year, we could evaluate whether mice have the potential to influence plants, invertebrates, and seabirds on Southeast Farallon Island. This project initially began as a survey of the diet of the mice at the island as part of an undergraduate thesis at Humboldt State University (Chapter 1). The initial survey included the months of February 2002 to March 2003. However, there was no data from April to August 2002 the time period when eggs or chicks could be available for consumption. Subsequent to the first survey, additional mice were acquired from the period April 2003 to August 2004. Which included the time period when eggs or chicks would be available. A second undergraduate thesis (Chapter 2) was under taken that utilized the insight acquired in the first thesis to evaluate the period that seabirds would be vulnerable. We summarize the two theses and provide conclusion in the final section of this report.

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CHAPTER 1

AN EVALUATION OF FALL, WINTER, AND SPRING DIET HOUSE MOUSE (*MUS MUSCULUS*) ON SOUTHEAST FARALLON ISLAND

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ABSTRACT

House mouse (*Mus musculus*) diet on Southeast Farallon Island was examined from February 2002 to March 2003. Plant and animal material was found in 77% of stomachs. Plants consumed by house mice were native (*Lasthenia maritima, Spergularia* spp., and *Claytonia perfoliata*) and non-native (*Hordeum murinum leporinum* and *Urtica urens*). Animal material included Arachnid, Coleopteran beetle, Coleopteran larvae, Diptera, feather, and possible mollusk shell. Some food items were consumed consistently through fall, winter, and spring and other items seasonally.

Key words: Diet, Farallon, house mouse, island, *Mus musculus*, omnivory, seabirds.

Omnivory is well represented in the Order Rodentia (Landry 1970). Omnivorous rodents may impact more than one trophic level and threaten insular communities through diet selection (Hayward and Philipson 1979, Burger and Gochfeld 1990, Begon et al. 1996, Huyser et al. 2000). House mice (*Mus musculus*) were omnivorous on sub-Antarctic islands (Copson 1986, Smith et al. 2002) and at cultivated sites of North America (Whittaker 1966) and Australia (Bomford 1987, Tann et al. 1991). Southeast Farallon Island is a site of major importance to several seabird species along the west coast of the United States; the diversity and number of nesting seabirds is not duplicated within thousands of kilometers (Ainley 1990). House mice were introduced to Southeast Farallon Island in the 1800's (Ainley et al. 1990), yet few studies have examined the ecology of house mice on Southeast Farallon Island (McDermott 2002, Schwan 1984).

Mice are potentially a source of egg loss for some ground nesting birds (Maxson and Oring 1978). House mice may be a source of egg loss for Ashy Storm-Petrels (*Oceanodrama homochroa*, 37g) and other small crevice-burrow nesting seabirds on Southeast Farallon Island. A lack of information on Southeast Farallon Island house mouse food habits and concern over mouse-seabird interactions prompted this study. The goal was to describe the diet of house mice on Southeast Farallon Island.

STUDY AREA

Southeast Farallon Island (37°42'N, 123°00'W) is located 32 km off the coast of Point Reyes, California, USA and is the largest in a group of islands collectively known as the Farallon Archipelago. Southeast Farallon Island is approximately 29 ha with steep topography (0-102m) _(Pyle et al. 1996). Vegetative cover is minimal; *Lasthenia minor* and *Spergularia* spp. are the most abundant plant species (McDermott 2002). Farallon National Wildlife Refuge and PRBO

Conservation Science administer Southeast Farallon Island. There is restricted year round human activity on the island.

METHODS

House mice were collected along the periphery of seabird nesting colonies from February 2002 to March 2003. Covered snap traps (dCon, Reckitt Benckiser, Inc., Wayne, New Jersey, USA) baited with peanut butter were used to trap individual mice. Twenty-eight traps were distributed along four transects, each transect containing seven trap sites within variable habitat types (McDermott 2002). Habitat types included marine terrace, a gently sloping wave-cut bench; and talus slope, a moderate slope of loose granite blocks. Each transect was trapped for three consecutive days at least once per month. Mouse carcasses were frozen within 12 hours of capture for storage and transport to the mainland. Trapping was conducted as part of refuge operations and food habit research (the latter was performed in accordance with Humboldt State University Institutional Animal Care and Use Committee protocol #02/03 W.75.A). Plant and invertebrates were collected opportunistically to compare with stomach contents.

The mice were thawed shortly before dissection. Age (adult/ juvenile), sex, mass (g), reproductive status (reproductively active/ not reproductively active), and anatomical measures (hind leg, ear, snout, tail-length, tail (mm)) were recorded prior to dissection. Mice were categorized as adult if mass was ≥14g and juvenile if less than 14g (Breakey 1963, Pye 1993). Stomachs were opened with scissors, a ligature was tied around the esophagus and the rectum, and complete gastrointestinal tracts removed. The contents of the stomach were washed through serial sieves (106 µm- 1mm) (U.S.A. Standard Testing Sieve #18, #35, #60, #140, W.S. Tyler, Inc., Mentor, Ohio, USA). Sieved material was identified and sorted into visually similar groups using a dissecting microscope (Streozoom 6, Leica Microsystems, Heerbrug, Switzerland).

Stomach contents were compared to plant and terrestrial invertebrate samples and texts (Abrams 1944, 1951,1960, 1961, Hickman 1996) for identification. Mouse prey items were dried, labeled, and stored in glass vials (Type 1 15 x 45mm Glass Vial with plug, Fisher Scientific, Pittsburg, Pennsylvania, USA). Hair was not included in the analysis because of possible ingestion during grooming.

Differences in food digestibility limit description of diet (Swanson and Bartonek 1970). Food types were categorized as present or absent. Temporal variation in food type occurrence was examined using χ^2 Goodness of Fit tests. Food types with less than five stomachs were excluded from statistical tests. Season was categorized to include fall (September and October), winter (November, December, and January), and spring (February and March). Frequency of occurrence was the percentage of stomachs in a season with a food type.

RESULTS

The analysis included 57 house mice (Figure1-1). Of the mice sampled, 82% were adult and 73% were male (Table 1-1). The proportion of stomachs containing both plant and animal material (77%) was greater than for stomachs containing plant or animal material alone (11% and 12% respectively). Plant material found in stomachs included *Claytonia perfoliata*, *Hordeum murinum leporinum, Lasthenia maritima*, *Spergularia* spp., *Urtica urens,* green plant tissue, and unidentified plant tissue. Animal materials include Arachnid, Coleopteran beetle, Coleopteran larvae, Diptera, feather, possible mollusk shell, and unidentified animal tissue. The number of stomachs containing *Hordeum murinum leporinum* (χ^2_2=14.84, P<0.001) and *Lasthenia maritima* (χ^2_2=11.54, P=0.003) differed significantly between seasons (Table 1-2). House mice consumed *Hordeum murinum leporinum* in September and October and *Lasthenia maritima* in February and March more than expected. Frequency of occurrence of coleopteran larvae was less than 50% for fall, winter, and spring. House mice consumed some food items consistently through fall, winter, and spring, however, they consumed other food items seasonally (Table 1-2). *Dipteran* spp. (n=1), mollusk (n=3), *Spergularia* spp. (n=3), unidentified animal tissue (n=4), and *Urtica urens* (n= 4) were present in low frequency.

DISCUSSION

House mice on Southeast Farallon Island were omnivorous. Diet results were consistent with mainland (Whittaker 1966, Bomford 1987, Tann et al. 1991) and other island populations (Copson 1986, Smith et al. 2002).

Native plants (*Lasthenia maritima, Spergularia* spp., and *Claytonia perfoliata*) constitute 60% of plant species found in mouse stomachs, yet 63% of plant species on Southeast Farallon Island are non-native (Coulter and Irwin 2005). *Lasthenia maritima* and *Hordeum murinum leporinum* may be seasonally important in spring and fall, respectively. Invertebrates were consumed from September through March. Coleopteran larvae are a frequent food item in house mouse diet and may be especially important during January, due to low frequency of occurrence of other food items (Figure 1-2).

Interpretation of prey importance was hindered by an inability to quantify digested food. Annual variation in diet could not be described due to the lack of mice from April, May, June, July, and August. The opportunity to locate evidence of house mouse damage to seabird eggs was limited by the lack of samples from late spring and summer, the majority of the seabird breeding season.

Understanding the source and magnitude of ecological disturbance is vital to the management of island communities. House mice that consume native plants may influence plant community dynamics and reduce the efficiency of current invasive plant species management.

Mouse consumption of invertebrates may impact energy flow, nutrient cycling, and pollination at Southeast Farallon Island. House mouse consumption of more than one trophic level may be a concern for Southeast Farallon Island populations of plants, invertebrates, salamander, and birds.

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TABLE 1-1. Age, sex, mass, reproductive status, and anatomical measures ($\bar{x} \pm$ SE) of house mice (*Mus musculus*) on Southeast Farallon Island, USA from February 2002- March 2003.

	Adult	Juvenile
Sample size	47	10
Male	32	10
Female	15	0
Mass (g)	18.5 ± 0.4	11.1 ± 0.8
Active Breeders	27	0
Hind leg (mm)	18.6 ± 0.1	17.5 ± 0.7
Ear (mm)	13.0 ± .01	12.0 ± 0.6
Snout-Tail (mm)	162.1 ± 1.3	137.4 ± 4.8
Tail (mm)	78.2 ± 0.7	66.7 ± 3.0

TABLE 1-2. Frequency of occurrence of house mouse (*Mus musculus*) stomachs with food type present per season from Southeast Farallon Island, California, USA (2002- 2003). Significant differences in frequency of occurrence of stomachs containing the food type between seasons are denoted by *.

	Frequency of occurrence					
Food Type	Fall	Winter	Spring	n	x^2 Statistic	P- value
Arachnid	28.6	0	14.8	9	2.89	0.235
Claytonia perfoliata	7.1	11.1	20.6	9	1.28	0.527
Coleopteran beetle	7.1	11.1	17.6	8	0.84	0.657
Feather	0	33.3	26.5	12	4.07	0.131
Green Plant Tissue	14.3	33.3	44.1	20	1.76	0.415
Hordeum murinum leproinum	71.4	22.2	8.8	15	14.84	<0.001*
Coleoptera larvae	57.1	55.6	50	30	0.11	0.947
Lasthenia maritima	7.1	11.1	70.6	26	11.54	0.003*
Unidentified Plant	50	33.3	26.5	19	1.65	0.438

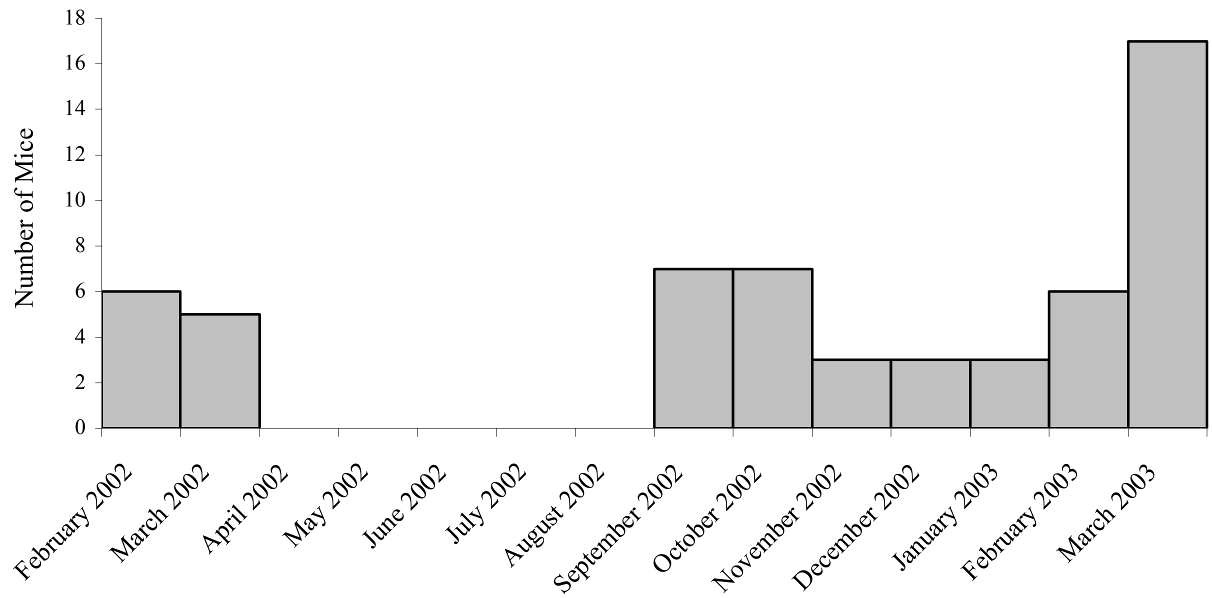

FIGURE 1-1. Sample size of house mice (*Mus musculus*) from Southeast Farallon Island, California, USA included in analysis per month.

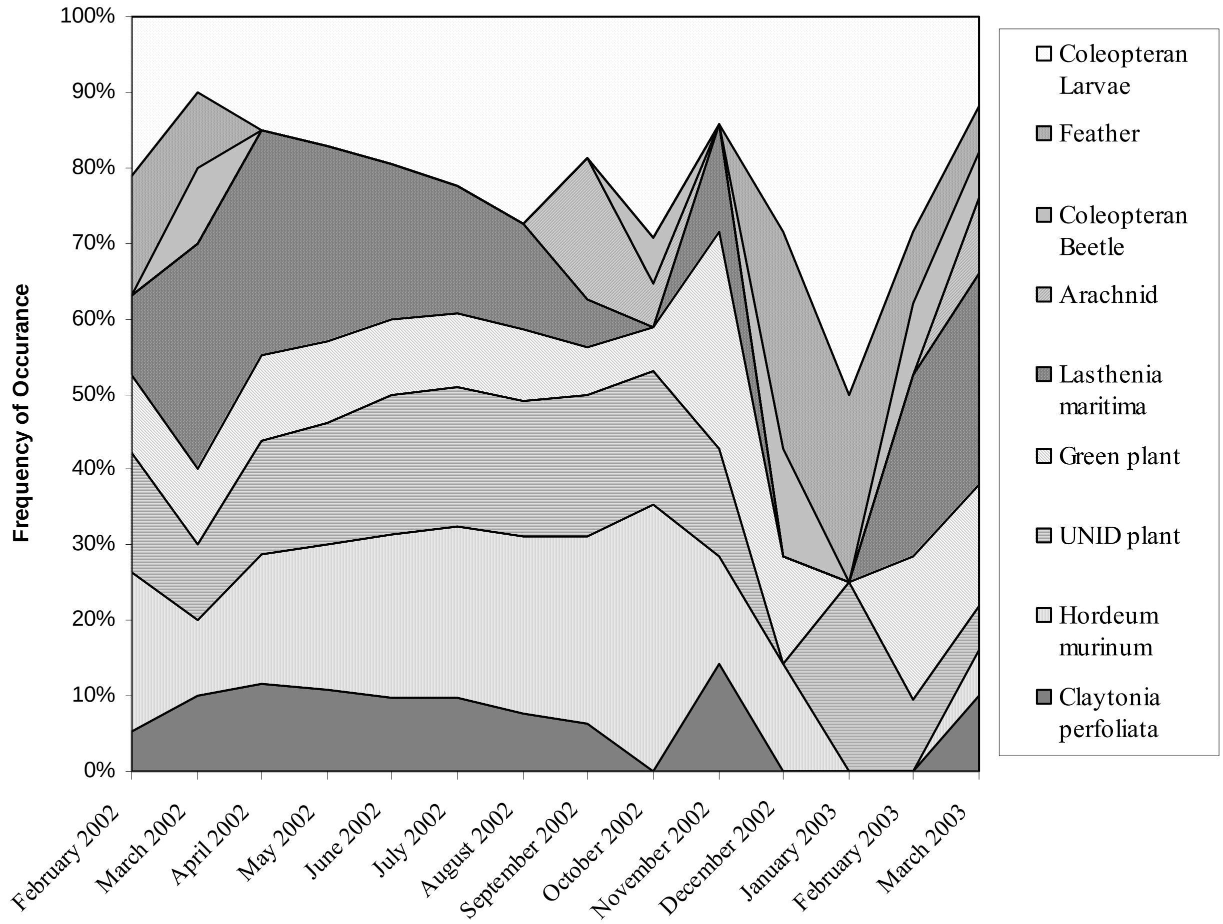

FIGURE 1-2. Frequency of occurrence of house mouse (*Mus musculus*) stomachs with food type present per month on Southeast Farallon Island, USA from February 2002-March 2003. Data from April to August was not available, the numbers shown are extrapolated points between March and September.

CHAPTER 2

SUMMER AND FALL DIET OF HOUSE MICE (*MUS MUSCULUS*) ON SOUTHEAST FARALLON ISLAND

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ABSTRACT

Non-native plant and animal species have contributed to population declines and extinctions on islands worldwide. Introduced rodents in particular have been found to prey on seabird eggs and chicks and to cause a decline in the populations of various ground- and burrow-nesting seabird species. The house mouse (*Mus musculus*) was introduced to Southeast Farallon Island by human settlers and became established on the island. I examined whether mice consumed seabird eggs and whether they were potential vectors for the spread of non-native seeds by examining the gastrointestinal contents of 64 mice trapped on Southeast Farallon Island during the summer and fall of 2003 and 2004. Native plants, non-native plants, insect exoskeletons, eggshells, and feathers were present in the gastrointestinal tracts. There was a no significant difference in the frequency of occurrence of food items in the gastrointestinal tract between plants and insects and between native plants and non-native plants. There was no seasonal trend in the diet from April to December. This study was intended to provide information on the diet of house mice that could be used as a basis for management decisions on the potential eradication of the house mouse from Southeast Farallon Island.

Keywords: Diet, Farallon Islands, house mice, invasive mammal, *Mus musculus,* seabird.

The introduction of non-native plants and animals to islands has been the cause of numerous decreases and extinctions of the native populations (Huyser et al. 2000, Marinez-Gomez and Jacobsen 2004). Introduced rodents are a contributing taxa to this world wide phenomenon (Cuthbert and Hilton 2004). Although rodents are often classified as herbivores they are commonly omnivores and have been known to feed on bird eggs, birds, insects, ant eggs, meat, bacon, cannibalism, lizards, carrion, slugs, and mammal bones (Landry 1970). House mice (*Mus musculus*) diets have consisted primarily of invertebrates with some seeds, plant, and vertebrate material (Copson 1986), plant material (Hagen 2003), or change seasonally with food availability (Jones et al. 2003). House mice have also been found to damage eggs (Maxon and Oring 1978) and feed on live chicks of Tristan Albatross (*Diomedea dabbenena)* and Atlantic Petrel (*Pterodroma incerta*) (Cuthbert and Hilton 2004). In addition to direct affects on seabirds through predation, house mice have been found to alter the plant and invertebrate communities on islands and result in a farther reaching effect than just through predation (Chown and Smith 1993, Smith et al. 2002). Mice may also indirectly affect seabird populations by supporting winter populations of owls which switch to the seabirds when they become available in the spring (Drost 1989).

Southeast Farallon Island, in the Farallon Island archipelago, is located 32 km southwest of Point Reyes, California, USA. A significant seabird breeding colony in western North America, the Farallon Islands have the world's largest populations of breeding Ashy Storm-Petrels (*Oceanodoma homochroa*), Brant's Cormorants (*Phalacrocorax penicillatus*), and Western Gulls (*Larus occidentalis*) (DeSante and Ainley 1980). Additionally, there are 12 other seabird species with populations on the Farallon Islands (DeSante and Ainley 1980). Many of these seabirds are ground-nesting or burrow-nesting species including the Ashy Storm-Petrel, Cassin's Auklet (*Ptychoramphus aleuticus*), and Rhinoceros Auklet (*Cerorhinca monocerata*) (Ainley and Boekelheide 1990).

House mice were introduced to Southeast Farallon Island by human settlers, likely after the lighthouse was built in 1855 (Shorenherr et al. 1999, Howald et al. 2004). These non-native populations of house mice may have affected the survival of Ashy Storm-Petrel and other ground- or burrow-nesting birds by 1) possibly eating or destroying eggs, 2) dispersing seeds of non-native plants species lowering the habitat quality for ground nesting birds, and 3) providing a winter prey source for over-wintering migratory burrowing owls which then feed on seabirds when they become available in the spring (Howald et al. 2004). Hagen (2003) found that house mice on Southeast Farallon Island ate non-native plants (39% of plant material in stomach) and therefore may spread the seeds. However, his samples were only from September to March and he was unable to investigate whether house mice consumed seabirds or seabird eggs due to a lack of samples from the breeding season of Ashy Storm-Petrels and other species (eggs laid from April to October but peak in mid June, chicks fledge late August to December, McIver 2002).

The lack of knowledge about seabird population size prior to the introduction of house mice make studies that demonstrate the direct impacts of mice on the seabird population difficult. I examined the diet of house mice on Southeast Farallon Island from April to November of 2003 and 2004 ,coinciding with the nesting of seabirds living on the island. If mice consume seabirds or seabird eggs then I expected to find eggshell fragments and feathers. Further, if mice can transport seeds of non-native plant species I expect to find them in the gastrointestinal system of the house mice captured on the island. I could not address the third hypothesis concerning the indirect threat of introduced mice on the seabird colony through the mouse population's support of winter burrowing owls. Finally, the overall diet of the house mice was examined to document the relative proportions of food items consumed by the introduced house mice in order to determine what food resources support the mouse population year round. The results of this work will provide useful information in the potential determination of an eradication program of the house mice on Southeast Farallon Island.

STUDY AREA

Southeast Farallon Island (37° 42'N, 123° 00'W) is located 32 km southwest of Point Reyes, California, USA. The entire Farallon Archipelago is managed as the Farallon National Wildlife Refuge by US Fish and Wildlife Service and PRBO Conservation Science. The island is approximately 29 ha of steep rocky topography (0-105 m.). Two wave gut terraces (8 m and 15 m) give the island a step-like appearance and provide the flat terraces where human habitation occurs (Schoenherr et al. 1999). The native flora includes primarily grasses and forbs, although most of the island is relatively bare and rocky (Coulter and Irwin 2005).

METHODS

Mice for this study were collected between April 2003 and August 2004 on Southeast Farallon Island. Four transects of seven traps were used. Snap traps (dCon, Reckett Benskiser, Inc., Wayne, New Jersey, USA) baited with peanut butter were used to capture all mice (McDermott 2002, McDermott and Buffa 2003). From December 2001 to August 2004 trap lines were in operation for three consecutive days twice per month (McDermott 2002). Mouse collection after August 2003 was done under Humboldt State University Institutional Animal Care and Use Committee Protocol (HSU IACUC) #02/03 W.75.A (Hagen 2003). Mice were frozen within 24 hours of capture and prepared for transport to the mainland and then Humboldt State University (McDermott and Buffa 2001). The collection of the mice was done for a study involving mouse density (McDermott 2002). My study only used the frozen carcasses killed in the density study and no additional mice were trapped for this study (exempt under HSU IACUC No. 05/06.W.42.E.).

Mice were thawed within two days of dissection and dissected at Humboldt State University. Prior to dissection, the sex, reproductive status (pregnant and number of fetuses), and approximate age (adult or juvenile) were estimated. The complete gastrointestinal system (from now on referred to as stomach) had a ligature tied around each end to prevent the loss of any material and was then removed. All contents were washed through a set of sieves and sorted under a dissecting microscope. Any identifiable or potentially identifiable material was removed. Hair was not included as one of the categories due to the possibility of ingestion during grooming (Copson 1986, Hagen 2003). All food items were dried, labeled, and stored for further review. Plant material was identified by comparing specimens from the Humboldt State University Herbarium of the species on the Southeast Farallon Island plant species list by Coulter and Irwin (2005) with the specimens found in the stomachs. Species unavailable in the herbarium were identified by examination of closely related species in the herbarium and by using the Jepson identification key (Hickman 1993). The diet was quantified as the frequency of occurrence of a particular food item in the mouse stomachs.

Presence of eggshell or feathers in mice stomachs was used to determine if house mice ate seabird eggs or chicks (Copson 1986, Hagen 2003, McKay and Russell 2005). The presence of eggshell or feathers could be the result of either predation or scavenging and the possibility that mice may scavenge broken eggs or dead seabirds cannot be ruled out by this study.

Chi-squared Goodness of Fit tests were used to test the difference in the frequency of occurrence of native and non-native plants found in all stomachs. Chi-squared Goodness of Fit tests were also used to test whether the presence of insect or vegetation changed seasonally in the diet (Zar 1999).

RESULTS

I dissected and analyzed the stomach content of 64 mice (30 male, 21 female, and 13 unsexed). Mice were trapped in April (n=5), June (n=16), July (n=21), August (n=10), September (n=3), October (n=3), and November (n=6) of 2003 and 2004. From these 64 mouse stomachs, 229 potentially identifiable specimens were found including plant material, insect exoskeleton, eggshells, and feathers (Table 2-1). From these specimens, 7 plant species were positively identified based on seed characteristics, representing 70% of all plant samples (Table 2-1). Three of these plants were native to the island (*Claytonia perfoliata, Lasthenia maritima, Spergularia macrotheca*) and four of these were non-native species (*Coronopus didymus, Sononchus* spp., *Stellaria media,* and *Urtica urens*). I was able to identify all but four types of seeds. Failing to identify these four types of seeds can be attributed to the lack of seeds preserved with herbarium specimens and the partial digestion of seeds rendering the seeds unrecognizable.

Plant material was found in 92% and insects in 59% of the stomachs (Table 2-2). There was one positive identification of an eggshell and one that appeared to be eggshell; both were treated as eggshell for analysis. Likewise, three feathers were positively identified and one appeared to be a feather; all four were treated as feather for analysis. The eggshells were found in June and September, while the feathers were found in June, July, and August. The most common plant in the mouse stomachs was *Lasthenia maritima* (Table 2-3). Native plants were present in more stomachs than non-native plants although it was not significant (χ^2_6=6.18, P=0.33) (Table 2-2). More seeds were eaten in June, July, and August than in other months

(Figure 2-1). However, the frequency of occurrence of vegetation or insect material in mouse stomachs did not change significantly with season (χ^2_6=0.72, P=0.99, χ^2_6=2.12, P=0.90 respectively) (Figure2- 2).

DISCUSSION

House mice on Southeast Farallon Island eat vegetation, insects, and birds. The presence of eggshells and feathers in the stomachs of mice support the first hypothesis that mice may contribute to seabird population dynamics by preying on seabirds or their eggs. However, caution should be used in the application to this finding since the ingestion of eggshell or feathers may be due to scavenging of broken eggs or dead birds and not predation. At the same time predation cannot be ruled out because other studies have found house mice to feed on eggs and seabird chicks (Maxson and Oring 1978, Cuthbert and Hilton 2004) and house mice have killed and eaten at least one Leach's Storm-Petrel (*Oceanodroma leucorhoa*) chick on Southeast Farallon Island (Ainley et al. 1990). Direct monitoring of the nesting sites of burrow- and ground-nesting species would be necessary in order to determine if house mice do damage eggs or chicks.

Although the frequency of occurrence of eggshell and feathers in the mouse stomachs was not prevalent, consumption occurred regularly during the entire nesting season of the seabirds are on the island. The regular consumption of birds and eggs could have a significant impact on the seabird population if the actual consumption is greater than the apparent consumption (presence of feather or egg in stomach). Golightly (pers. comm.) found that red foxes (*Vulpes vulpes*) ingested more eggs than the number of eggshells found in the stomach. If consumption of eggshell only occurs accidentally as the individual is trying to open the egg, then the actual number of eggs eaten could be considerably more than reflected by the presence of eggshell. The impact on the seabird community could also be greater than reflected by the number of samples of feathers and eggshell found if the egg consumption is concentrated in only one area or on only one species of seabird. The result of egg consumption by only a few individual mice in any of these scenarios could have detrimental affects on the seabird population.

The presence of both native and non-native plants in the diet of the house mice on Southeast Farallon Island support the hypothesis that house mice may potentially affect seabird populations by degrading nesting habitat through the dispersal of non-native plants. The consumption of any non-native seeds may lead to an increase in the range of a species and the encroachment of these species onto nesting grounds could be detrimental to seabirds (Howald et al. 2004). None of the plant species identified as species of concern for spreading on the island by Coulter and Irwin (2005) were found in the diet of house mice in this study and had the mice been eating the seeds they would have occurred in the stomachs. If eradication of the house mice is based on the spread of non-native seeds by the house mice, then consideration of which plant species are actually spreading on the island and which plant species house mice consume would be necessary. Coulter and Irwin (2005) attributed the containment of non-native plants to the southeast end of the island to the predominant northwest winds. Wind likely plays a dominant role in the distribution of plant communities across the island.

There was no seasonal variation in the diet of house mice from April to December. The presence of eggshell and feather in the diet in June, July, August, and September reflect the presence of nesting and fledging of seabirds, although the lack of any specimens from April may be due to small sample size (n=5) (Figure 2-2). The small size of the eggshell and feather fragments prevented the identification of the affected seabirds species. The absence of data in late winter prevented examination of the diet of house mice during the winter, although Hagen (2003) found that an increased proportion of insects made up the diet. Insects could be an important source of protein for the mice during the winter. In the spring and summer when seabird chicks and eggs are available the mice may switch their feeding to these sources of protein, leading to a decrease in insect consumption.

The eradication of non-native rabbits and cats occurred on Southeast Farallon Island following the creation of the Farallon National Wildlife Refuge and the eradication of the house mouse has been proposed (Howald et al. 2004). Successful eradication of rats or mice has occurred on numerous islands around New Zealand, sub-Antarctic islands, the Aleutian Islands, and on Anacapa Island in southern California (reviewed Donlan et al. 2003). The eradication of mice from Southeast Farallon Island could be conducted following two conservation ideas. The first, to return the community to its natural state without non-native species requires the removal of the mice. The second, that the removal of the mice may help the declining populations of seabirds on the island, needs to be scientifically examined and determined how mice harm the seabird populations. Based on my study, I cannot distinguish whether mice actually prey on seabird eggs and nestlings or scavenge remains. However, mice may in fact have an impact on the island community through the distribution of seeds and direct impact on seabirds. How mice affect seabird populations through the maintenance of winter burrowing owl populations was not addressed in this study.

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TABLE 2-1: The number and type of specimens removed from 64 house mice (*Mus musculus*) stomachs. Mice were collected on Southeast Farallon Island in 2003 and 2004. * indicates proportion of total vegetation, not proportion of total specimens.

Specimen Type	n	Proportion of Total Specimens
Vegetation	175	0.764
Identified Vegetation	123	0.703*
Unidentified Vegetation	52	0.297*
Insect	44	0.192
Eggshell	2	0.009
Feather	4	0.017
Other	4	0.017
Total	229	

TABLE 2-2: The number and frequency of occurrence of with stomachs containing plant matter, insect exoskeleton, eggshell, or feathers in house mice (*Mus musculus*) (n=64). Mice were collected on Southeast Farallon Island between 2003 and 2004.

Food Matter	n	Frequency of Occurrence
Plane	49	0.922
Insect	32	0.594
Plant and Insect	29	0.547
Plant Only	20	0.359
Insect Only	3	0.047
Eggshell	2 (1 probable)	0.031
Feather	4 (1 probable)	0.063

TABLE 2-3: The frequency of occurrence of each plant species found in stomachs of house mice (*Mus musculus*) and the total proportion of the diet made up of non-native or native plant species. Mice were collected on Southeast Farallon Island between 2003 and 2004.

Plant Species	n	Frequency of Occurrence
Non-native		
Stellari media	27	0.422
Coromopus didymus	3	0.047
Urtica urens	2	0.031
Sonochus spp.	1	0.016
Total Non-native	33	0.438
Native		
Lasthenia maritima	53	0.703
Claytonia perfoliata	28	0.438
Spergularia macrotheca	9	0.141
Total Native	90	0.859

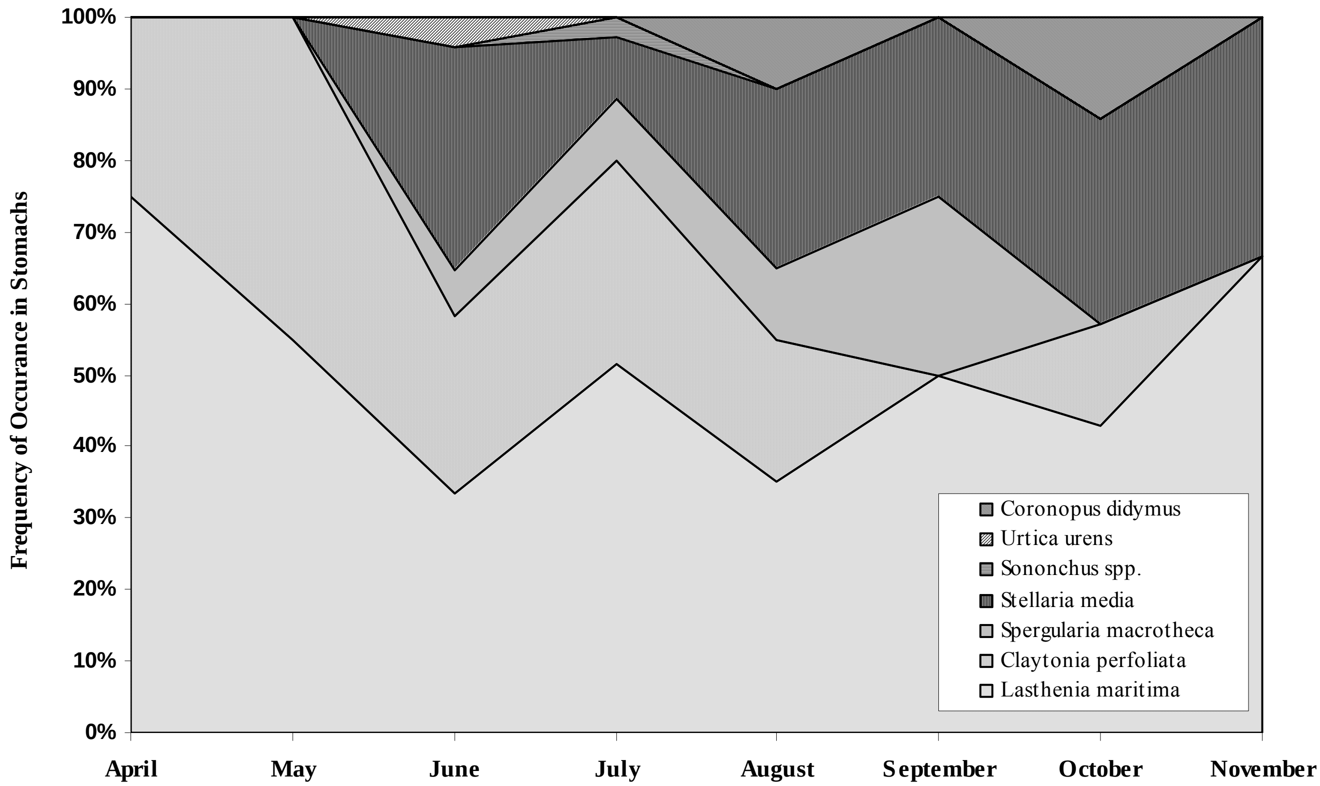

FIGURE 2-1: The number of house mouse (*Mus musculus*) stomachs (n=64) that native (gray shaded) and non-native (striped) plant species occurred, during each month. Mice were collected on Southeast Farallon Island between 2003 and 2004. No mice were collected in May and the data shown was interpolated from the April and June data.

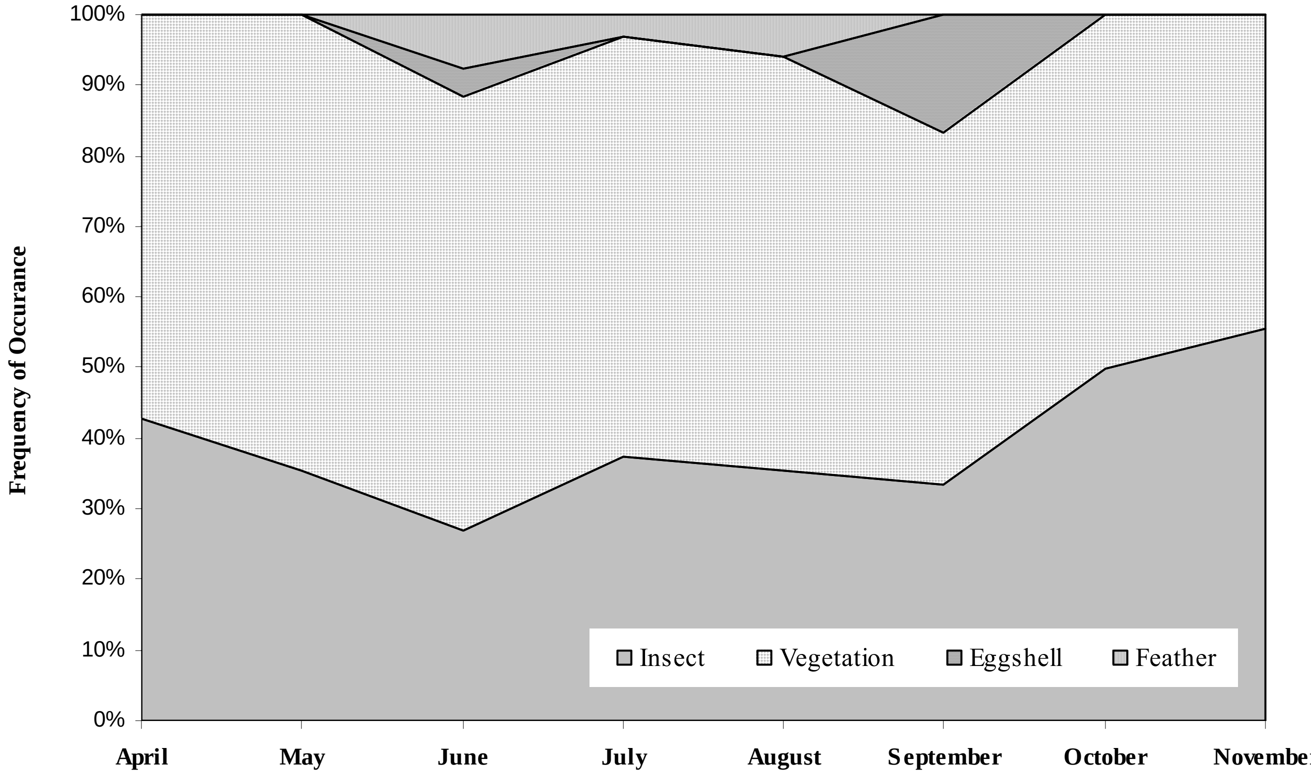

FIGURE 2-2: The diet of house mice (*Mus musculus*) does not differ significantly from April to November. The presence of eggshell and feather during June, July, and August coincides with the nesting of seabirds. Mice (n=64) were collected on Southeast Farallon Island between 2003 and 2004. No mice were collected in May and the data shown was interpolated from the April and June data.

CONCLUSION

DIET OF HOUSE MICE (*MUS MUSCULUS*) THROUGHOUT THE YEAR AND MANAGEMENT IMPLICATIONS FOR SOUTHEAST FARALLON ISLAND.

Megan A. Jones and Richard T. Golightly

The diet of the house mice (*Mus musculus*) on Southeast Farallon Island was examined to determine the potential impacts of the mice on the island community. Analysis of fall, winter, and spring diet was presented in Chapter 1. While summer and fall diets were presented in Chapter 2. Both studies found remains of invertebrates, vegetation, and bird feathers in the gastrointestinal tract of the mice. Small amounts of eggshell remains were found coinciding with the seabird nesting season.

Mice used in the study were collected from February 2002 to August 2004. In combination of both studies a total of 121 mice were trapped, dissected, and diet analyzed. Mice were collected in all months except May (Figure C-1). Differences in data and slightly different methods used for identification limited the number of food items that could be compared between the studies. We compared use of the plants *Claytonia perfoliata, Lasthenia maritima, Urtica urens,* and *Spergularia macrotheca* across the entire year. Additionally, insect, feather, and eggshell diet data were compared across all seasons.

A minimum estimate was that 79% of stomachs contained vegetation. Insect material was the second most frequent food material and found in 70% of the stomachs (Table C-1). Feathers were found in all months except April, September, October, and November (Figure C-2). Eggshell was only found in June and September (Figure C-2).

Only *Lasthenia maritima* and insect data were adequate to meet assumptions of Chi-squared tests. There was a significant difference in the frequency of occurrence of *Lasthenia maritima* in the house mouse diet between pre-breeding (January, February, and March), breeding (April, May, June, July, and August), and post-breeding (September, October, November, and December) seasons (χ^2_4=15.4, P=0.004). Mice consumed less *Lasthenia maritima* than expected during the post-breeding season and more than expected in the breeding season. There was no significant difference in the frequency of occurrence of insect remains in the diet between pre-breeding, breeding, and post-breeding seasons (χ^2_4=6.39, P=0.172).

We were unable to compare the frequency of occurrence in the diet of native and non-native plants across all seasons due to inconsistent sample sizes. However, in Chapter Two comparison was possible for a stratified subsample of native and non-native plants.

House mice on Southeast Farallon Island eat vegetation, insects, and possibly birds throughout the year. The presence of eggshells and feathers in the stomachs of mice confirm that house mice do consume seabirds and eggs. However, we caution that ingestion of eggshell or feathers may be due to scavenging of broken eggs or dead birds and not predation. At the same time predation cannot be ruled out and other studies have found house mice to feed on eggs and seabird chicks (Maxson and Oring 1978, Cuthbert and Hilton 2004). Additionally predation of a Leach's Storm-Petrel (*Oceanodroma leucorhoa*) chick has been documented on Southeast Farallon Island (Ainley et al. 1990). The presence of feather in the diet outside of the breeding season probably indicates that the house mice ingest at least some of the avian material through scavenging dead birds or coincidental intake of feathers with other food items. The large size and flight capacity of the adult birds makes predation on adults unlikely. Direct monitoring of the nesting sites of burrow- and ground-nesting species would be necessary in order to determine if house mice do damage eggs or chicks.

Although the frequency of occurrence of eggshell in the mouse stomachs was not prevalent (one presence in June, one in September), consumption occurred during the nesting season of the seabirds. The simple act of consumption of eggs by itself does not demonstrate impact on seabird populations. However, the regular consumption of birds and eggs could have a significant impact on the seabird population if the actual consumption was greater than the apparent consumption (presence of feather or egg in stomach). Red foxes (*Vulpes vulpes*) consumed few shells while they ingested many eggs, and the number of eggshell fragments that were found in the diet was not representative of the eggs consumed (RTG, unpublished data). If consumption of eggshell only occurs accidentally as the individual is trying to open the egg, then the actual number of eggs eaten could be considerably more than reflected by the presence of eggshell. Consumption of feather occurred regularly throughout the entire year (January, February, March, June, July, August, and December). The impact on the seabird community could also be greater than reflected by the number of samples of feathers and eggshell found if the consumption is concentrated in only one area or on only one species of seabird. The result of concentrated consumption by only a few individual mice in any of these scenarios could have severe detrimental affects on the seabird population. However, the details of how mice consume egg is unknown, and thus judgment of impact is only speculation. The small size of the eggshell and feather fragments prevented the identification of the affected seabird species.

There was some seasonal variation in the diet of house mice during the entire year. *Lasthenia maritima* varied throughout the year likely reflecting the variation in seed availability, although no food availability data from the island was available for evaluations. Insect consumption did not vary over seasons when compared on an annual basis, which is contrary to the early findings (Chapter 2).

We cannot distinguish whether mice actually prey on seabird eggs or nestlings or scavenge remains. Alternatively, mice may have an impact on the island community through the distribution of grass seeds and direct impact on seabirds. Although we demonstrate the potential for house mice to consume seabirds, these results do not demonstrate impact on seabird populations, which will require further investigation.

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TABLE C-1: The frequency of occurrence of food matter found in the stomachs of house mice (*Mus musculus*) collected on Southeast Farallon Island from February 2002 to August 2004. n represents the number of mouse stomachs containing the food item.

Food Matter	n	Frequency of Occurrence
Claytonia perfoliata	37	0.306
Lasthenia maritima	79	0.653
Urtica urens	6	0.050
Spergularia macrotheca	12	0.099
Insect	85	0.702
Feather	16	0.132
Eggshell	2	0.017
Total Vegetation (minimum est.)	96	0.793

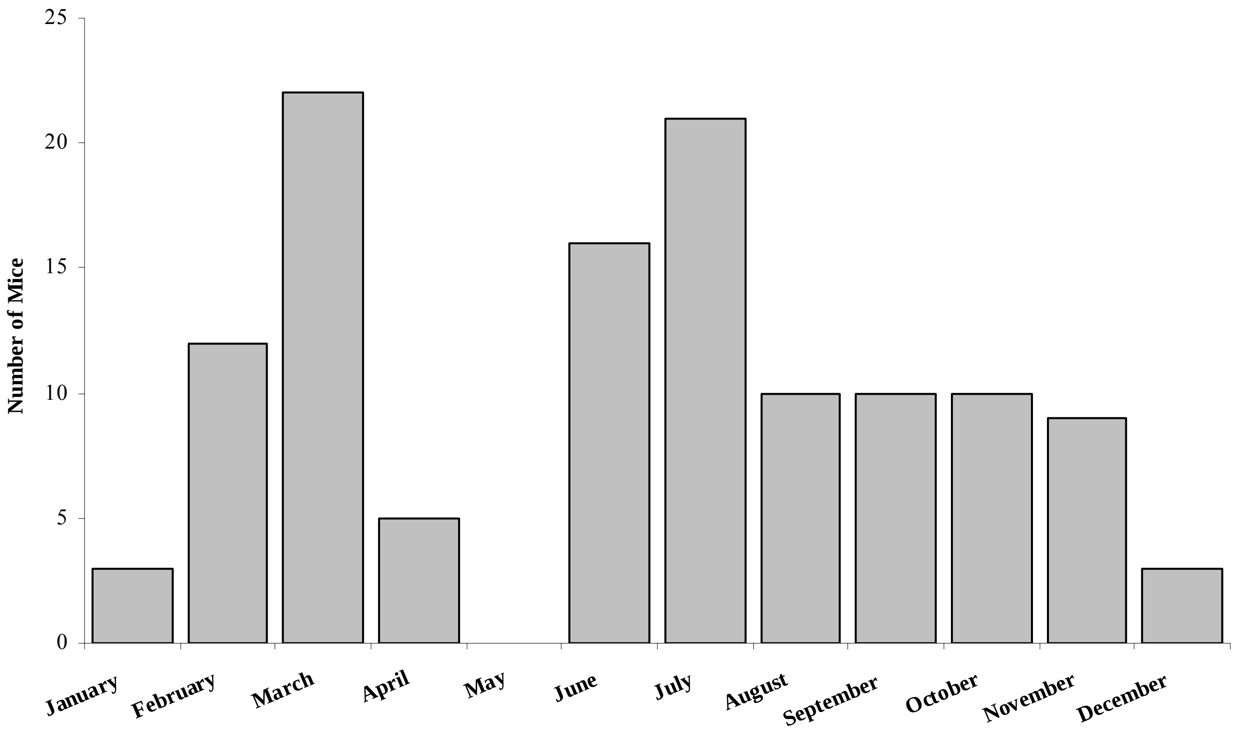

FIGURE C-1: The total number of house mice (*Mus musculus*) (n=121) by month included in analysis. Mice were collected from February 2002 to August 2004 on Southeast Farallon Island, California, USA.

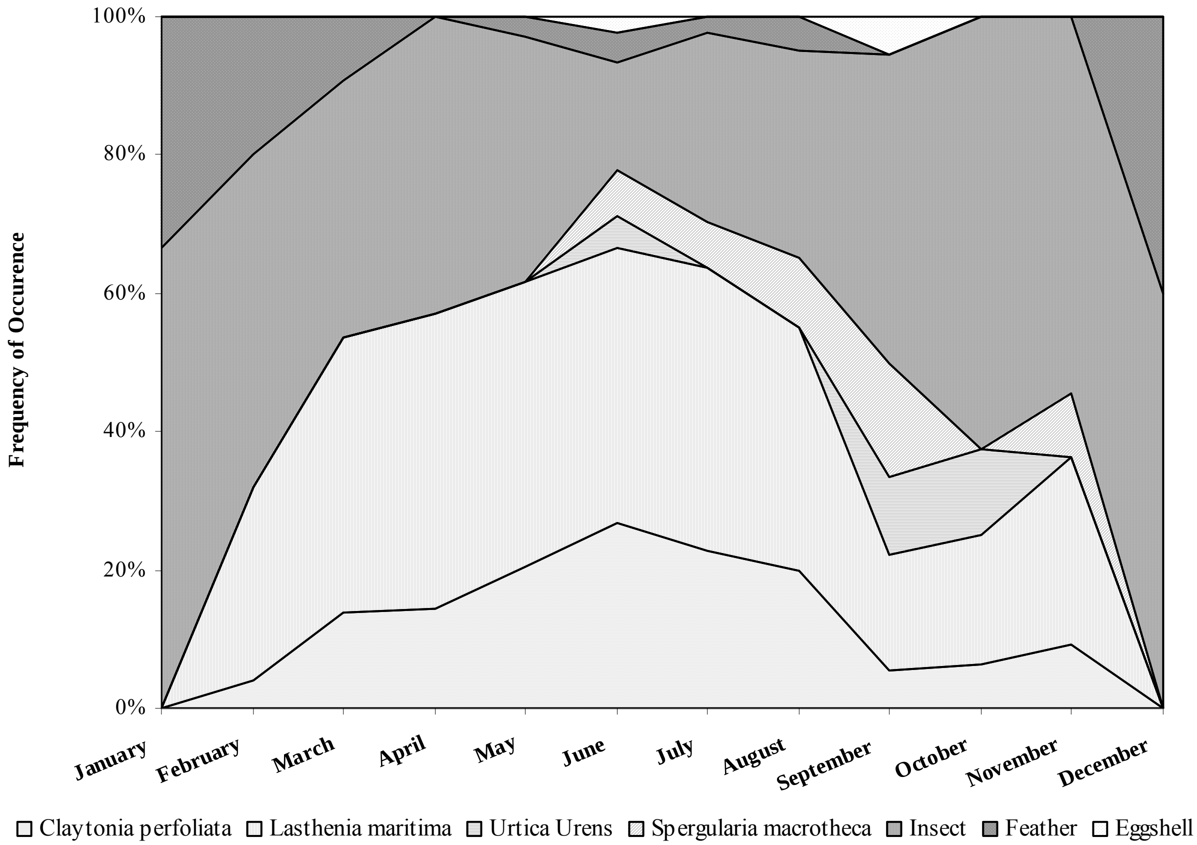

FIGURE C-2: Proportional frequency of occurrence of food items in the diet of house mice (*Mus musculus*) by month. Mice were collected on Southeast Farallon Island from February 2002 to August 2004. No mice were collected in May and the data shown was interpolated from the April and June data.