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Ecology of the American Mink & the Potential Impact on Species of Concern in Cape Romain National Wildlife Refuge, South Carolina

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ECOLOGY OF THE AMERICAN MINK & THE POTENTIAL IMPACT ON SPECIES OF CONCERN IN CAPE ROMAIN NATIONAL WILDLIFE REFUGE, SOUTH CAROLINA

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ABSTRACT

Species reintroduction projects are becoming more common as a conservation tool to reestablish populations following extirpation. The implementation of these projects can be controversial due to the potential impact the reintroduced animal could have on endangered, threatened, or at risk prey species. In 1999, South Carolina's Department of Natural Resources (SCDNR) reintroduced the American mink (*Neovison vison*), a SCDNR designated species of high conservation priority, to the northern coastal marshes of the state, including Cape Romain National Wildlife Refuge (CRNWR). In order to estimate the impact of this opportunistic predator on other species, especially those of special concern to the US Fish and Wildlife Service (USFWS) at CRNWR, a literature-based bioenergetics model was constructed using diet analysis data from 45 mink stomach/gastrointestinal tracts collected from CRNWR. Diet was predominately crustacean (51.9% of prey occurrences) and fish (40.7%) with occasional avian occurrence (7.4%). The bioenergetics model estimated, on average, that a single mink could consume 158 crustacean, 38 fish, and 8.5 avian prey items per month.

Additionally, 7 female mink were captured, implanted with an intraperitoneal transmitter, and monitored from March through August (2010 and 2011) to determine home range size and activity pattern. Average lactating female mink home range and core area measured 2.12 ha and 0.26 ha, respectively, and average linear home range (i.e., marsh edge utilization within home range) measured 1.0 km. Lactating female mink activity was negatively related to tide height. Although activity was not significantly influenced by temperature and light, lactating female mink appeared to be less active

during the day, especially at mid-day when temperatures were high. Based on the findings of this study and others that have monitored avian species of concern in CRNWR, predation (e.g., mink, raccoon, great horned owl, black vulture, rat, and ghost crab) has been demonstrated to contribute to lost shorebird and seabird productivity (i.e., nest loss or chick loss). Since American mink, American oystercatcher (*Haematopus palliates*), black skimmer (*Rynchops niger*), and least tern (*Sternula antillarum*) have high conservation value in South Carolina, further monitoring and research of the interaction of these species is necessary to restore the historical ecological integrity of the system. A joint mink culling-relocation program between SCDNR and USFWS at CRNWR could benefit both mink and beach-nesting bird conservation.

DEDICATION

I dedicate this thesis to my loving family. To my parents, Carolyn and Joe, for their guidance and support. To my brother, Matthew, for his encouragement every step of the way. Thank you for always believing in me. I could not have reached this goal without you.

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CHAPTER ONE

GENERAL INTRODUCTION

Species reintroduction projects are becoming more common as a conservation tool to reestablish populations following extirpation (Seddon et al. 2007). Reintroduction efforts require careful planning, which typically includes population modeling, pre-release health-risk assessment, and post-release monitoring (Beck 2001, Seddon et al. 2007). Reintroduction efforts often lack an ecosystem perspective beyond that of restoring the ecological integrity of a system (Armstrong and Seddon 2007). Armstrong and Seddon (2007) proposed a series of *a priori* questions at the population, metapopulation, and ecosystem levels to provide a more strategic approach to reintroduction projects, and one of these questions addressed the potential effect of a reintroduced animal on an ecosystem. Predator reintroductions, in particular, are controversial due to this potential impact, especially when a reintroduction area contains endangered, threatened, or at risk prey species.

In the 1980s, South Carolina's Department of Natural Resources (SCDNR) reported the American mink (*Neovison vison*) population to be in decline statewide. The mink, an opportunistic predator, was found to be nearly absent within the coastal marshes north of Charleston, South Carolina, where the species had previously been abundant. The specific cause for decline is unknown, but habitat degradation and the presence of environmental contaminates (such as mercury or polychlorinated biphenyls) are the primary hypotheses (Baker 1999). In 1998, SCDNR assessed the feasibility of reintroducing the mink to the northern coastal marshes of the state (Peeples 2001).

Following the identification of areas with suitable mink habitat, 62 mink from stable populations along the southern coast of South Carolina (south of the city of Charleston) were captured and released in Cape Romain National Wildlife Refuge (CRNWR). A post-release study reported the restoration project to be a success, documenting an 89% survival rate of 19 monitored mink for 125 days post-release (Peeples 2001). In 2005, SCDNR listed mink as a species of high conservation priority in the South Carolina Comprehensive Wildlife Conservation Strategy (Kohlsaat et al. 2005).

Recently, mink-specific predation on nesting shorebird and colonial beach nesting birds as well as loggerhead sea turtles (*Caretta caretta*) has been observed by US Fish and Wildlife Service (USFWS) officials at CRNWR. Mink predation on waterfowl, shorebirds, and seabirds has been documented both in North America and abroad (Craik 1997, Ferreras and MacDonald 1999, Nordström et al. 2002, Hall and Kress 2004, Sabine et al. 2006, Shüttler et al. 2009). Several areas have reported colony-wide breeding failures of various colonial nesting avian species due to mink presence (Craik 1997, Hall and Kress 2004, Brooks 2011), while other areas have found mink predation to negatively impact nest survival of solitary nesting species (Shüttler et al. 2009). The majority of the documentation regarding mink impact on avian species, however, has occurred outside of North America where the mink is an invasive species.

Mammalian predation (and predation in general) is not a new occurrence in CRNWR. Raccoons (*Procyon lotor*) have been frequent predators of avian and turtle nests at CRNWR. Rat (species unknown), black vulture (*Coragyps atratus*), great horned owl (*Bubo virginianus*), laughing gull (*Larus atricilla*), and ghost crab (*Ocepode* *quadrata*) have recently been documented depredating nests of American oystercatchers (*Haematopus palliates*), black skimmer (*Rynchops niger*), and least terns (*Sternula antillarum*) (Brooks 2011; S. Collins, personal communication, September 9, 2011; S. Dawsey, personal communication, February 11, 2010).

In order to estimate the potential impact of this opportunistic predator on other species, especially those of special concern to USFWS at CRNWR (i.e., American oystercatcher, black skimmer, least tern, and loggerhead sea turtles), a literature-based bioenergetics model was constructed using diet analysis data collected from mink stomachs and gastrointestinal tracts in CRNWR. Additionally, mink were captured and implanted with an intraperitoneal VHF-transmitter, and monitored from March through August of 2010 and 2011 to determine activity pattern and home range size.

STUDY AREA

Cape Romain National Wildlife Refuge (Figure 1.1) is a 26,817 ha migratory bird refuge located along 35 km of South Carolina's coastline just north of Charleston. The refuge is a combination of barrier islands, salt marshes, tidal creeks, coastal waterways, beaches, fresh and brackish water impoundments, maritime forest, and open water (Godsea et al. 2010). CRNWR is a Western Hemisphere Shorebird Reserve Network Site of International Importance, hosting approximately 277 species of waterfowl, wading birds, shorebirds, and raptors (Godsea et al. 2010). Avian species at CRNWR such as the brown pelican (*Pelecanus occidentalis*), American oystercatcher, piping plover (*Charadrius melodus*), least tern, and black skimmer are of high conservation priority to the USFWS. The refuge also provides habitat to the largest nesting population of loggerhead sea turtles north of Cape Canaveral, Florida (approximately 1,000 nests per year), as well as raccoon, mink, white-tailed deer (*Odocoileus virginianus*), river otter (*Lutra canadensis*), American alligator (*Alligator mississippiensis*), and other species (Godsea et al. 2010).

My research focused on the ecology of mink that inhabited the salt marsh and barrier island complex in the northern region of the refuge near McClellanville, South Carolina. This area is important to the refuge due to the high number of nesting shorebird and colonial beach nesting birds (mainly black skimmers, least terns, and American oystercatchers) and loggerhead sea turtles that utilize the barrier islands. Vegetation of the CRNWR salt marsh system is dominated by smooth cordgrass (*Spartina alterniflora*), while the barrier islands are primarily beaches, sand dunes, and salt marsh (Godsea et al. 2010).

BIOLOGY OF THE AMERICAN MINK

The American mink is a member of the weasel family Mustelidae and has the long cylindrical body, short legs, and short ears characteristic of mustelids (Larivière 2003). Adults weigh between 500 and 1500g with females weighing approximately 50% less than males (Hall 1981). Average overall body length ranges from 470 mm to 700 mm, with the tail accounting for one third of the length (Jackson 1961). The pelage is typically a uniform dark brown with the exception of the tip of the tail, which tends to be nearly black. White markings are often found on the chin but also on the throat, chest, and belly (Jackson 1961).

Historically, this semi-aquatic species has inhabited aquatic areas, such as swamps, rivers, streams, lakes and fresh and saltwater marshes, throughout the United States and Canada with varying densities in South Carolina (Larivière 2003, Butfiloski and Baker 2005). American mink were taken to Europe in the 1920s for the fur industry, and, either due to accidental or intentional release, populations have become established throughout the region (Larivière 2003). As a result, mink are negatively impacting prey species like the water vole (*Arvicola amphibius*) and various avian species (Aars et al. 2001, Nordström et al. 2003). Interspecies competition with the European polecat appears unlikely due to resource partitioning (Lodé 1993). Bonesi and MacDonald (2004) reported a reduction in mink density following Eurasian otter (*Lutra lutra*) reintroduction, suggesting interference competition as the cause, and proposed Eurasian otter reintroductions in Europe could be used to control invasive mink.

Mink are a denning species that rarely excavate their own dens, using cavities within tree roots and rock piles or burrows of other species like the muskrat (Butfiloski and Baker 2005). Gerell (1970) reported mink utilizing 2 to 5 dens that were 70-2060 m apart. Populations inhabiting tidal systems rarely utilize permanent dens due to fluctuating water levels (Peeples 2001). In CRNWR, mink use tide racks, or dead smooth cordgrass (*Spartina alterniflora*) accumulation, along creek edges to escape high tides (Peeples 2001).

Immediately following the reintroduction of mink into CRNWR, Peeples (2001) monitored 19 mink and documented the largest recorded home range for the species in a marsh environment (males: 6.91 km^2, females: 2.28 km^2). The home range was also found to be two-dimensional, unlike the linear home ranges reported for mink along rivers in Europe (Peeples 2001). Mink are considered to be territorial, and Peeples (2001) documented intersexual but not intrasexual home range overlap for adult mink in CRNWR.

Mink are strict carnivores with a diet that reflects prey availability and abundance (Ben-David et al. 1997). Depending on the season and the system, mink diet can include fish, crustacean (crabs and crayfish), amphibians, small mammals, birds and their eggs, reptiles, lagomorphs, and arthropods (Arnold and Fritzell 1987, Birks and Dunstone 1985, Larivière 2003, Previtali et al. 1998, Shüttler et al. 2008). Relative frequency of avian prey in mink diet, for instance, tends to increase during the spring and summer months when this prey is more readily available (Arnold and Fritzell 1987, Bartoszewicz and Zalewski 2003, Shüttler et al. 2008).

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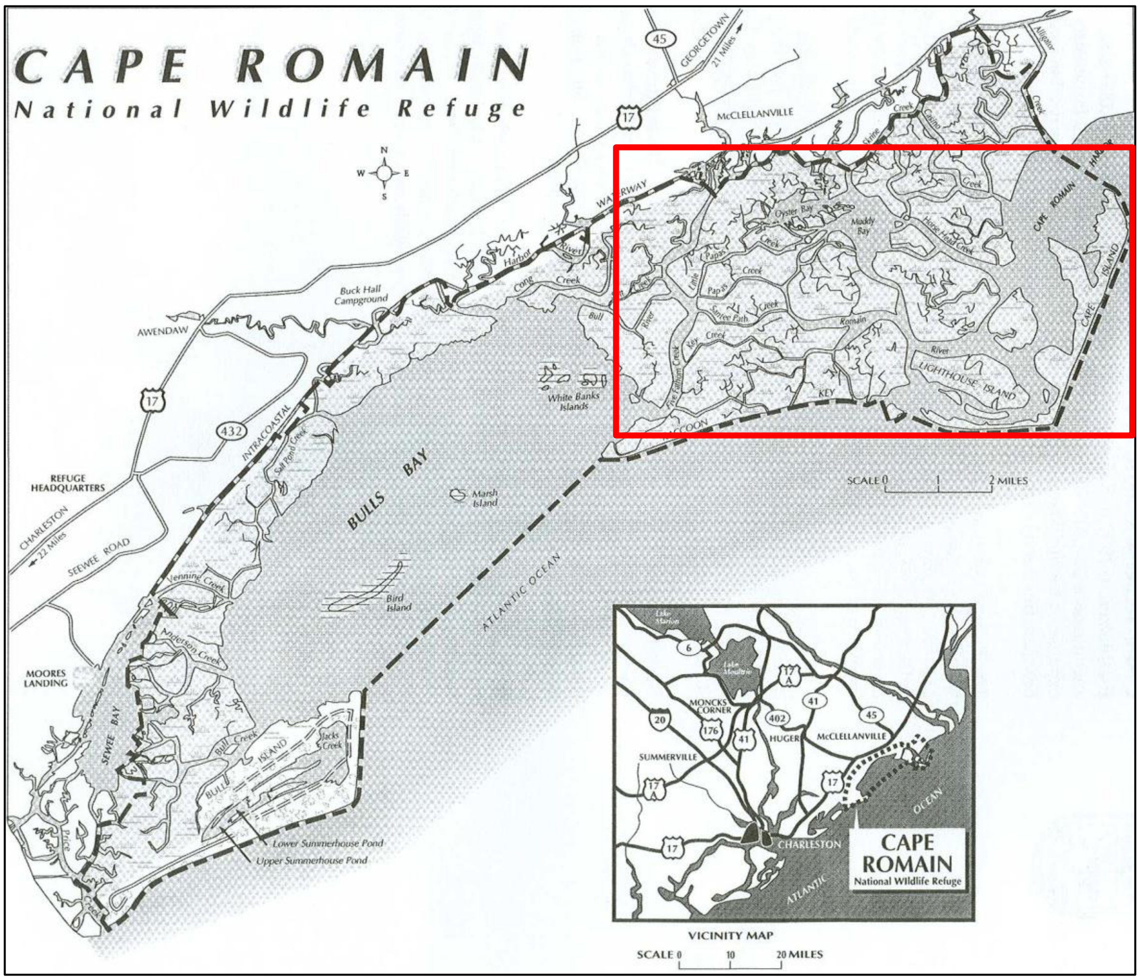

Figure 1.1: Cape Romain National Wildlife Refuge, Charleston County, South Carolina. Research was concentrated in the northern marshes (see inset), adjacent to Cape Island, Lighthouse Island, and Raccoon Key.

CHAPTER TWO

DIET ANALYSIS OF THE AMERICAN MINK & ESTIMATING POTENTIAL IMPACT ON PREY SPECIES USING A BIOENERGETICS MODEL

INTRODUCTION

The American mink is an opportunistic and generalist predator with a diet that typically includes fish, crustacean, small mammals, and amphibians while opportunistically includes avian and reptiles eggs, adult birds, lagomorphs, and arthropods (Ben-David et al. 1997, Birks and Dunstone 1985, Arnold and Fritzwell 1987, Previtali et al. 1998, Larivière 2003, Shüttler et al. 2008). The impact of mink predation on seabirds and shorebirds, in particular, has either determined the level of productivity lost to predation (Hall and Kress 2004, Shüttler et al. 2009) or quantified mink diet to determine the importance of avian prey (Arnold and Fritzell 1987, Ibarra et al. 2009). In this study the goal was to quantify food habits of mink in a system where avian prey was common.

Local prey availability and abundance influences the proportion of prey species found in the mink diet, which can differ between ecosystems (Delibes et al. 2004, Hammersh et al. 2004, Shüttler et al. 2008), seasons (Arnold and Fritzwell 1987, Bartoszewicz and Zalewski 2003, Hatler 1976), sex (Birks and Dunstone 1985), and individuals (Sidorovich et al. 2001). Frequency of avian prey, for instance, tends to increase in mink diet during months while birds are nesting and rearing chicks, which is a time when birds are more vulnerable to predation (Arnold and Fritzwell 1987, Bartoszewicz and Zalewski 2003, Shüttler et al. 2008).

Mink predation on avian species, in particular, can result in colony-wide breeding failure for colonial nesting seabirds as well as significantly reduce productivity of solitary nesting birds (Craik 1997, Ferreras and MacDonald 1999, Schüttler et al. 2009). For example, in CRNWR, Brooks (2011) suggested mink to be the cause of colony failures of least tern (*Sternula antillarum*) on Lighthouse Island (2009) and Raccoon Key (2010). Evidence has shown that mink, along with other predators like raccoon (*Procyon lotor*), rat (species unknown), black vulture (*Coragyps atratus*), great horned owl (*Bubo virginianus*), laughing gull (*Larus atricilla*), and ghost crab (*Ocepode quadrata*) are negatively impacting (i.e. disturb and/or depredate) shorebirds and seabirds (Brooks 2011; S. Collins, personal communication, September 9, 2011).

Loggerhead sea turtle (*Caretta caretta*) nest depredation in CRNWR has primarily been caused by raccoons, which were the main mammalian egg predator present in CRNWR prior to the reintroduction of mink in 1999. Mink depredation of sea turtle nests was not observed until 2007 when a lactating female raided 3 nests (Dawsey 2007). Since the 2007 incident, sea turtle nest depredation by mink has not been observed. Although no official study documenting mink predation on sea turtles has occurred, it is hypothesized that mink are more likely to target emerging hatchlings than nests (S. Dawsey, personal communication, February 11, 2010).

In 2010, CRNWR released the Comprehensive Conservation Plan and Environmental Assessment, describing the management goals, objectives, and strategies for the refuge over the next 15 years. To achieve the goals of (a) conserving, protecting, and enhancing populations of endangered, threatened, and rare species on the refuge; and,

(b) sustaining healthy and viable migratory bird populations, implementation of mammalian predator (i.e., raccoon and mink) management was included in numerous objectives and strategies (Godsea et al. 2010:42,47). Within the goal of conserving South Carolina's native wildlife and fish populations, however, the game animal objective states, "keep raccoon population density at low levels to [prevent] predation of sea turtle and ground nesting birds. Remove mink from the refuge" (Godsea et al. 2010:52). Prior to implementing large-scale predator management such as removing a native species from an area, it is important to quantify loss to predation as well as the impact of that loss on prey population dynamics.

Breeding failure in coastal nesting birds in CRNWR has been attributed to predation and environmental factors, e.g., overwash caused by high tides or boat wakes and erosion of barrier islands (Thibault 2008, Brooks 2011). Loggerhead sea turtle nests are also in danger of overwash and beach erosion; therefore, the Cape Romain Nest Relocation Program relocates nests in danger of inundation or erosion to self-releasing hatcheries built by the program or more appropriate nesting sites on the beach (Dawsey 2009). Due to the inability to protect nests of coastal breeding birds from overwash, reducing predation-caused nest loss is CRNWR's most practicable management option if increasing nesting productivity of shorebirds, seabirds, and loggerhead sea turtles is a goal.

Bioenergetics models are often used to quantify the impact of predators on prey by mathematically modeling energy flow between the populations (Dekar et al. 2010, Glahn and Brugger 1995, Matias and Catry 2008, Roby et al. 2003). Such models can be created from data collected in the field from focal populations, or can be built from data in the literature and basic energetic equations. While the former typically results in a more accurate model, the latter can be useful for creating a more broadly focused model that can highlight critical data needs without an investment in labor-intensive and expensive field studies. In either case, energy estimates can vary depending on how the input parameters are calculated, and validation of the estimates can be difficult.

My goal was to develop a literature-based bioenergetics model to determine monthly estimates of the amount of aquatic and avian prey consumed by American mink during spring and summer in CRNWR. Although mink are generalist predators, mink predation on CRNWR's avian species of concern will be the primary focus of this study. Stomach and gastrointestinal tracts from mink in CRNWR were collected and the relative frequency of occurrence of prey items (i.e., fish, crustacean, avian species) in these samples was determined. This data was then used to create the bioenergetics model, and data not available directly from the focal population in CRNWR was found in the literature. This model will allow managers to quantify the potential negative impact of mink on other species, particularly nesting shorebirds and seabirds (i.e. American oystercatcher, least tern, and black skimmer; referred to as "species of concern").

MATERIALS & METHODS

Mink Diet Analysis

Mink diet composition was estimated through gross stomach and gastrointestinal tract (digestive tract) content analysis. Determining diet through scat analysis (as reported by Arnold and Fritzell 1987, Delibes et al. 2004, Salo et al. 2010) would have been a challenge due to the difficulty of collecting scat in a system with fluctuating water levels. Digestive tracts were obtained from mink carcasses that were removed by USFWS personnel during routine predator management activities on the refuge in 2010 and 2011. Cape Island, one of the barrier islands at CRWNR, was the primary location for predator management since both shorebirds and loggerhead sea turtles nest on this island. Bull's Bay was also included in mink removal efforts following reports of predation on American oystercatcher (*Haematopus palliatus*). Date of capture, location of trap (GPS location, UTM coordinates), sex, age, and weight were recorded for each carcass by USFWS personnel. Carcasses were immediately frozen to halt decomposition and preserve contents of the digestive tract for later analysis. Digestive tracts were removed at CRNWR, re-frozen, and later analyzed at Clemson University.

Contents were removed from each stomach and intestinal tract, washed with distilled water, and examined under a dissecting scope. Undigested prey remains were documented using the frequency of occurrence method (Hyslop 1980) and sorted into one of four categories: crustacean (exoskeleton fragments), fish (scales, bone, vertebrae), bird (chick remains, egg shell, feathers), and other (i.e., vegetation, sand, etc.) (Fasola et al. 2009). Due to the small sample size, digestive tract data from different locations and collection years was pooled for analysis. Relative frequency of occurrence (RFO), or the total number of items in a category in relation to the sum of all prey occurrences across all categories, was calculated. Digestive tracts containing only sand and/or vegetation were excluded from the analysis.

Diet Composition by Relative Energetic Contribution

Bioenergetics studies use diet composition analyses to determine the percent of each prey type by biomass, which is then converted to the relative energetic contribution of the prey item to the daily energy requirement of the predator. Energetic contribution of a prey category (i.e., crustacean) is used instead of the RFO to account for the discrepancy between the relative frequency of an item in the diet and the energetic contribution of an item to the diet (i.e., common items may not always contribute the majority of the energy). Due to the small sample of digestive tracts obtained from CRNWR, percent biomass (and therefore percent energy) could not be determined. Literature reporting mink diet composition (primarily from scat analyses) was compiled to supplement my data in the bioenergetics model.

Prey Mass & Energy Content

Prey mass (wet weight in grams) was estimated for all three prey categories based on field observations and supplemented with the literature. Diet analysis and observations in the field indicated that crustaceans consumed by mink in CRNWR were fiddler crabs (Atlantic marsh fiddler crab, *Uca pugnax* and/or sand fiddler crab, *Uca pugilator*) and Atlantic blue crab (*Callinectes sapidus*). The range for mass of crustaceans as a prey category was estimated to be 5 - 85 g based on values obtained in the field and from the literature. For example, the minimum weight was based on direct observations of fiddler crabs, while the maximum weight was based on Atlantic blue crab meat content. It was estimated that, on average, a blue crab contained between 57 and 85 g of non-exoskeleton content (i.e., meat, internal organs) (Table 2.1).

The range for the mass of fish as a prey category was estimated to be 30-125 g based on direct observations of fish carcasses, primarily channel catfish (*Ictalurus puncta*), found on floating tide racks occupied by mink (Table 2.1). The minimum weight (30 g) was based on the average length and weight of commercial channel catfish purchased for a double-crested cormorant (*Phalacrocorax auritus*) digestibility study (Brugger 1993). The maximum weight (125 g) was based on the length of the larger fish found on mink tide racks (approximately 22-23 cm) that was converted to weight using the equation given by Keenan et al. (2011):

$$W(L) = aL^b \tag{1}$$

where W is the weight (kg), L is the length (cm), and a and b are constants (0.00522, 3.2293) specific to channel catfish.

Data on mass of avian eggs was compiled for the species of special concern to the refuge (Table 2.1), and the range (8 to 50 g) was determined. Adult birds were not included in the analysis since mink do not appear to predate on adult black skimmers, least terns, and American oystercatchers in CRNWR. This bioenergetics model focused on avian egg predation, but it can be adapted to include chicks and/or adult birds like clapper rail (*Rallus longirostris*), which was found in the tide rack nest of a lactating female mink in 2011.

Energy density, or the energy per unit mass of a food item, is a measure of the heat released from the burning of a unit of a substance (Barboza et al. 2009). Crustacean, fish, and avian egg energy density estimates were taken from the literature (Table 2.1). Using the estimated energy density (kJ/g wet weight) and mass (wet weight in grams) of each prey category, energy content (kJ, total heat released/prey item, or gross energy, i.e., kJ/g * mass of the item) was calculated. The gross energy content of a food item, however, is not completely available to the consumer (Robbins 1993, Barboza et al. 2009). The metabolizable energy (ME, %) is the portion of the gross energy content of a particular food item that is available to the consumer (Robbins 1993). Evans (1967b, 1976, 1977, unpublished data) reported metabolizable energy values of various mink diets falling between 72 and 85% with an average of 77% (as cited in National Research Council 1982). Since bioenergetics studies on other mustelids (Dekar 2010, Bodey et al. 2011) and strict carnivores (Matias and Catry 2008) used similar ME estimates, the range reported by Evans (1967b, 1976, 1977) was selected for this model.

Mink Daily Energy Expenditure

Daily energy expenditure (DEE), or the field metabolic rate (FMR), is the total amount of energy required by a free-ranging individual per day, and it is computed by summing the basal metabolic rate (BMR), thermoregulation, activity (e.g., locomotion, feeding, grooming, etc.), and reproduction (Powell and Leonard 1983, Robbins 1993, Barboza et al. 2009). Using the available literature, methods estimating the energy requirements of American mink were compiled (Table 2.2) and compared. Since the American mink is a valuable furbearing species, the majority of the literature reports BMR or food energy required for maintenance of farm-raised mink. These values do not take into account the higher energy demands of free-ranging individuals (Powell 1979). Robbins (1993) reported DEE in captive terrestrial eutherians to be approximately 15% lower than that of free-ranging eutherians (neither breeding nor lactating). To estimate the DEE of mink in CRNWR, this study used the following allometric equation for the FMR of carnivores provided by Nagy et al. (1999, Eq. 12):

$$kJ/day = 2.23(g\ bodymass)^{0.85} \tag{2}$$

This allometric equation compiled direct measurements of FMRs from several mammalian carnivore species, primarily cannids and pinnipeds, in order to provide an estimate of energy requirements for similar species that have yet to be directly measured (Nagy et al 1999). This equation accounts for the energy demands of mink beyond that of general maintenance, and it utilizes the available mink mass (g) data specific to the study site.

Powell (1979) and Powell and Leonard (1983) used both field and laboratory data to build energy expenditure models for the free-ranging fisher (*Martes pennanti*), which is also in the Mustelidae family. Powell's (1979) DEE model for the forest-dwelling fisher could not be adapted to the semi-aquatic mink in CRNWR primarily because the equation variables (e.g., daily swimming energy, activity budgets, etc.) could not be directly measured nor found in the literature. However, Powell and Leonard (1983) took the model built by Powell (1979) a step further by incorporating reproduction energy (i.e., copulation energy and lactation energy). Due to the high demands of lactation (Tauson et al. 1998), the model for female mink that were lactating used the allometric equation and added a daily lactation energy demand (L, Equation 2 in Moors 1974, Powell and Leonard 1979) to the allometric equation given by Nagy et al. (1999).

$$L = \frac{(litter\ size)(kit\ growth\ energy + kit\ maintenance\ energy)}{(efficiency\ of\ lactation)(efficiency\ of\ milk\ assimilation)} \tag{3}$$

Based on capture data for activity and home range analyses in my study, mean litter size was set at 5 kits. Powell and Leonard (1979) defined kit growth energy as kit daily weight gain multiplied by the energy per unit weight. For weasels Moors (1974) found this to be 6.88 kJ/g (as cited in Wamberg and Tauson 1998). Wamberg and Tauson (1998) reported kit daily weight gain weekly during the first four weeks following parturition, and the average daily weight gain (4.675 g/day) was used in Equation 2. The kit maintenance energy, or the kit BMR, was estimated from Wamberg and Tauson's (1998) mink kit data to be 87.1 kJ/day. Brody (1945) estimated the efficiency of lactation, or milk production, to be 0.90, and Tauson et al. (2004) estimated 0.85 for milk assimilation efficiency in mink. The daily lactation energy for female mink in CRNWR was estimated as 780 kJ/day.

Bioenergetics Model

Three separate bioenergetics models (male, female, and lactating female mink) were constructed in SAS version 9.3 (SAS Institute, Cary, North Carolina) in order to estimate prey consumption of mink in CRNWR. Input parameters and the structure of the model were based on energetics models found in the literature (Beja 1996, Roby et al. 2003, Matias and Catry 2008, Bodey et al. 2011). The number of prey items within a category, *i*, consumed per month (N_i) was estimated using the following equation:

$$N_i = \frac{(EE)(\%C_i)}{m_i d_i (\%ME)} \quad (4)$$

where *EE* is the monthly energy expenditure of an individual male, female, or lactating female mink (kJ/month); $\%C_i$ is the energetic contribution of the prey category, *i* (based on diet analysis results); m_i is the mass of the prey item (g); d_i is the energy density of the prey item (kJ/g); and *%ME* is the metabolizable energy of mink.

The input variables, mink mass, mink metabolizable energy, and prey mass were assumed to follow a triangular distribution. The triangular distribution is applied to data when the minimum, maximum, and likely mode are available but the actual distribution is unknown (Kotz and van Dorp 2004). Using the RANTRI function in SAS, a likely modal value for mink mass, assimilation efficiency, and prey mass was randomly generated from a triangular distribution. The analysis included 300,000 iterations of each model (male, female, lactating female) with each run utilizing a different combination of randomly generated input values. Mean, standard deviation, and range were calculated using the PROC UNIVARIATE statement in SAS. The SAS program code for the male bioenergetics model appears in Appendix A.

RESULTS

Mink Diet

In total, 44 mink carcasses (31 male, 13 female) were obtained from USFWS personnel between March and August of 2010 and 2011 (Table 2.3, Table 2.4, Figure 2.1). Thirty of the digestive tracts were removed from individuals captured on Cape Island. In an early attempt to compare the diets of marsh-dwelling mink to island-dwelling mink, 4 mink were captured in the northern marshes on CRNWR adjacent to the barrier islands. The remaining 9 individuals were trapped on shell rakes within Bulls Bay, which is an area within CRNWR just south of the study area (not depicted in Figure 2.1).

Approximately half of the digestive tracts contained undigested material (n = 23, male: 16, female: 7). Typically one prey type was found per digestive tract, but 4 tracts (2 adult males, 1 juvenile male, and 1 adult female) contained two. Three males (D1, D18, D24) contained crustacean and fish, while one female (D9) contained adult avian feathers and crustacean exoskeleton.

Due to the small number of digestive tracts containing prey items, a comparison of the relative frequency of occurrence of dietary items between years, locations, and sex was not conducted, and the data was subsequently pooled. Diet items found in trapped mink in CRNWR were almost exclusively crustacean (RFO 51.9%; primarily crab) and fish (RFO 40.7%) (Table 2.5, Figure 2.2). Avian prey was found in two digestive tracts (RFO 7.4%).

The digestive tract of D9, an adult female, and D16, a lactating female, were the only two tracts containing avian prey. Female D9 contained avian feathers and was trapped on Cape Island in March 2010. Although the feathers were not identifiable, the small size of the feathers (<25 mm) and the time of year (i.e., pre- or very early breeding season) suggest it likely was not a black skimmer (*Rynchops niger*), least tern (*Sternula antillarum*), or American oystercatcher adult or chick. Other possibilities include passerines, such as marsh wrens (*Cistothorus palustris*), or a species migrating through the area. Female D16 was captured on Cape Island in July 2010 due to reports of predation events in one of the least tern colonies, and partially digested feathers were found in the stomach.

Diet Composition by Relative Energetic Contribution

Relative frequency of occurrence (RFO) reported in the literature for crustacean, fish, and avian prey was compared to that found for mink in CRNWR (Table 2.6). Mink populations described in the literature with high occurrences of mammalian prey (Birks and Dunstone 1985, Dunstone and Birks 1987, Hammersh et al. 2004, Wilson 1954) were not used in this study due to the lack of small mammal occurring in the digestive tracts of mink collected in CRNWR. Other studies reporting RFO values for avian prey ≥ 30% (Bartoszewicz and Zalewski 2003, Salo et al. 2010) were also not used due to the large discrepancy with the CRNWR avian RFO value of 7.4%. Hatler (1976) and Delibes et al. (2004), however, reported RFO values for coastal-dwelling mink comparable to those found by this study. Unfortunately, appropriate estimates for prey energy contributions that coincided with this study's RFO results were not found in the literature. Consequently, RFO values from CRNWR were used in place of percent energy contributions in the model.

Bioenergetics Model Output

Average estimates of the daily energy requirements for male, female, and lactating female mink in CRNWR were translated to monthly estimates and assumed to be constant across an entire month: 25004 kJ, 15697 kJ, and 39097 kJ (*EE* in Equation 4, Table 2.7). Energetic contribution ($\%C_i$), which was approximated using RFO values from this study's diet analysis results, suggested that avian eggs could contribute, on average, 1850.3 kJ/month, 1161.6 kJ/month, or 2893.2 kJ/month to male, female, and lactating female mink (7.4%; RFO of avian prey). Average metabolizable energy

($m_i d_i \%ME$) of a typical avian egg was estimated to be 182.12 kJ/egg, suggesting that male, female, and lactating female mink in CRNWR could consume, on average, 10.2, 6.4, and 15.9 avian eggs per month, respectively. The analysis in SAS comprised of 300,000 runs of each bioenergetics model (Equation 4 with triangular distributions of each input parameter) in order to obtain standard deviation, median, range, and percentile estimates for the 3 prey categories (Table 2.8, Table 2.9, Appendix B). Potential avian consumption per month was 7.95±4.76, 4.99±2.98, and 12.43±7.37 eggs for male, female, and lactating female mink.

DISCUSSION

Part I: Mink Diet

The majority of mink removed from CRNWR in 2010 and 2011 were male. Mink breeding season occurs between January and March, so males are highly active and traveling extensively, often beyond home range boundaries (Mitchell 1961, Gerell 1969, Garin et al. 2002, Butfiloski and Baker 2005), and hence may be more susceptible to trapping. In contrast, female mink do not move as extensively as males, especially during the early kit-rearing months from April through June/July (Ireland 1990). It is possible that the males captured on Cape Island were not all residents, but traveled there to find mates. Based on female movements found in this study, females captured on Cape Island were most likely resident mink. Although less time was spent trapping on Cape Island in 2011, a similar number of males were captured in both years (2010 n = 14; 2011 n = 17), while far fewer females were captured in 2011 (2010 n = 10; 2011 n = 3).

Trapping methods used at CRNWR are likely the reason nearly 50% of the captured minks' digestive tracts were completely empty. USFWS personnel captured mink with snares set in mink runs, which typically stretched along the edges of marshes or dunes. It is likely that these mink were exiting a sheltered area in order to forage along a waterline and were caught prior to consuming prey items. It is also possible that, due to the mink's mean prey retention time (the average time between ingestion and excretion of a prey item) of approximately 4 hours (Warner 1981 as cited in Blaxter 1989), a meal was fully digested and excreted prior to the mink being euthanized. The data suggest that, in order for diet analysis using digestive tracts to be effective, either more trapping throughout a larger area is necessary or the trapping method needs to be modified. Alternatively, a longer-term assessment of diet may be undertaken using different techniques (e.g., stable isotope analysis, fatty acids). If the goal of CRNWR is to continue removing mink to reduce predation on species of concern, then data in this study suggests that trapping should be conducted during the mink breeding season to capitalize on high male and female activity. A late winter/early spring trapping period would remove predators prior to the nesting season for coastal birds and sea turtles and reduce late-summer trapping activity (April-August), which typically occurs as a response to predation events.

The RFO in CRNWR was similar to that found for mink in other coastal systems. The diet of a mink population along a rocky shoreline in Spain was nearly identical to the findings in this study (Delibes et al. 2004: RFO: crab 51.6%, fish 46.3%, bird 1.2%). Hatler (1976) also found fish, crab and bird items to occur most frequently in the diet of coastal-dwelling mink (approximately, crab: 80%, fish: 40-60%, bird < 20%). Similarly, CRNWR mink consumed more crustacean than fish. Due to the small sample of digestive tracts, which were spatio-temporally restricted, it is likely the relative occurrence of avian prey in mink diet at CRNWR was underestimated. For example, the majority of digestive tracts came from a single location – Cape Island (68%). Of the samples that contained prey items, 52% were collected prior to 1 April when American oystercatcher nesting in CRNWR tends to begin (Thibault 2008), 17% were collected in April when avian eggs were available on the refuge, and 30% were collected from mid-July through late August when few eggs of any bird species are available and when chicks of American oystercatchers, black skimmers, and least terns are close to fledging or fledged (Thibault 2008, Brooks 2011). The RFO method showed crustacean and fish were most often found in the digestive tracts of mink at CRNWR, but this method cannot infer true proportions (as determined by feeding trials), preference for particular prey items, or the impact on demography of the prey (Carss and Parkinson 1996).

Although species identification of prey items was not possible in this study, the size of chelae found in digestive tracts suggested fiddler crabs (Atlantic marsh fiddler crab, *Uca pugnax*, sand fiddler crab, *Uca pugilator*) as the main prey type in the crustacean category. Mink were observed at high tides consuming primarily the body meat of Atlantic blue crabs (*Callinectes sapidus*) while on floating tide racks. In terms of fish, channel catfish (*Ictalurus puncta*) were the primary species found on floating tide racks used by mink. In 2011, the tide rack nest of a lactating female mink included one channel catfish and an adult clapper rail (*Rallus longirostris*).

The concurrent study at CRNWR monitoring reproductive success of least tern and black skimmer colonies documented mink, raccoon, black vulture, ghost crab, great horned owl, and laughing gull presence in the colonies in 2009 and 2010 (Brooks 2011). Brooks (2011) monitored colonies, on average, every 3 days, reporting cause of nest loss, or the failure of eggs to hatch, based on visual cues in proximity to the nest. Based on observations of mink or mink sign in or near the colonies, Brooks (2011) suggested mink predation to be the reason two least tern colonies failed. Due to the difficulty of classifying avian nests as depredated and identifying the species of the nest predator (Staller et al. 2005, Brooks 2011), it is possible that nest failure due to predation in CRNWR was underestimated (Brooks 2011). In terms of this study's findings, it is possible that mink in CRNWR consume avian prey more frequently than the overall RFO suggested, especially due to the spatio-temporal restrictions of the digestive tract sampling method. A further, more detailed diet analysis using a greater sample size of digestive tracts as well as scat or other techniques (e.g., stable isotopes, fatty acids) is necessary before any inferences regarding the importance of any specific prey item to mink diet in CRNWR can be made.

Part II: Bioenergetics Model

Evidence has shown large imprecision in estimates of energy requirements using allometric equations (Furness 1978, Williams et al. 1993). Equations that predict FMR from body weight are not necessarily species-specific, and they do not take into account FMR oscillation due to season, reproductive status, gender, etc. Nagy et al. (1999) advised researchers to select the equation that would most specifically apply to the study animal. The energy expenditure measurements for various mammalian carnivores compiled by Nagy (1999) formed the equation used in this model, but many of the species were pinnipeds or canids. Due to the variability in output when allometric equations are used in bioenergetics models, caution should be taken in terms of applying results to management purposes.

Since it was not feasible for this study to measure mink FMR, Equation 2 was likely the most accurate estimate of mink FMR available. Direct measurements to build the equation used the doubly labeled water method, DLW (Nagy et al. 1999). The DLW technique measures the elimination rates of hydrogen and oxygen isotopes introduced into an animal in the form of water, and the difference in rate is used to approximate energy expenditure (Speakman 1997). This method has been administered to a wide variety of species in both the laboratory and in the field successfully, but the considerable cost of the isotopes and sample analysis limits its application (Speakman 1997). As more species are directly measured using this technique and incorporated into the appropriate equations, accuracy and precision of estimates for unstudied species will increase.

Mink lactation energy was calculated and added to the allometric equation in order to provide a more accurate estimation of mink energy expenditure during kit-rearing season, which coincides with the nesting activities of CRNWR's species of concern. Lactation energy (equation 3) was likely overestimated in this model because it, like FMR, is not a constant value during the 6 weeks prior to weaning. During the first 4 weeks following parturition, mink kits are completely dependent on milk and grow rapidly at approximately 12% per 24-hour period. Female daily milk production during this time increased 100g between week 1 and week 4 of lactation (Tauson et al. 1998). Energy deficiencies during the final weeks of lactation suggest that female mink are unable to meet the high energy demands by food consumption (Tauson et al. 1998 as cited in Tauson and Elnif 1994). It is possible, therefore, that the most significant mink predation on prey populations would occur later in the summer (July – September) while females are attempting to sustain energy needs and kits are weaned, learning to hunt, and beginning to disperse.

Using RFO values in place of energetic contribution in the model may have resulted in overestimates of crustacean (51.9% and 3 kJ/g) and underestimates of avian consumption (7.4% and 8 kJ/g). It is also possible, however, that due to the tendency of occurrence analyses to be biased by overestimating rare and underestimating abundant diet items (Carss and Parkinson 1996), the RFO values accounted for the energetic contribution discrepancy. Accurate average prey size estimates are also necessary, especially if mink consume large prey items that provide multiple meals. A more comprehensive mink diet analysis, preferentially using other techniques such as scat or stable isotope analysis, measuring the RFO, percent biomass, number of individuals (prey) per scat, and energetic contribution of prey is necessary before this model can provide more reliable estimates of mink impact on demography of avian prey populations in CRNWR.

Bioenergetics model studies, especially for avian species, tend to report estimates of population consumption. This study constructed three separate models (male, female, lactating female) to predict consumption per individual since mink do not forage together in one area but individually within separate home ranges. Therefore, the entire mink population in CRNWR is not foraging on the barrier islands and not, in its entirety, impacting species of concern. Model estimates could be reported for mink utilizing Cape Island, which could be estimated using trapping data (Tables 2.3, 2.4), to quantify prey consumption if predator management activities ceased.

In order for bioenergetics models to be effective at quantifying prey loss to predators, prey density should also be known. Monthly consumption estimates for crustaceans are high. Fiddler crab density, for instance, has been estimated at 27 crabs/m^2, in southeastern salt marshes (Teal 1958), and home range of female mink in CRNWR ranged from 2,936.86 m^2 to 171,378.17 m^2. Estimates of standing fish stock biomass and total predation (include all avian and mammalian predators) in CRNWR is necessary in order to provide context for mink consumption estimates. It can be assumed, however, that, due to the high productivity of salt marsh systems, mink are not significantly impacting population dynamics of fish species (Stevens 2002).

Avian species of concern to the refuge (least tern, black skimmer, and American oystercatcher) are annually monitored at CRNWR, and during the 2009-2010 breeding seasons, nest counts and predation events were recorded on least tern and black skimmer colonies. Using nest counts from Brooks (2011), approximately 190 least tern nests (typically 2 egg clutches) and 720 black skimmer nests (3 to 4 egg clutches) were recorded in CRNWR between 2009 and 2010. Sanders et al. (2008) reported approximately 230 breeding pairs of American oystercatchers, which typically lay 2 to 3 egg clutches, to nest in CRNWR annually. Using nest and breeding pair counts, an estimation of egg availability throughout the refuge is approximately 3,475 eggs/breeding season for American oystercatcher, least tern, and black skimmer combined. Based on nest counts for least tern and black skimmer on Cape Island in 2009 and 2010, approximately 1,330 eggs/breeding season are available on Cape Island alone.

The goal of this study was to determine the potential impact of mink on other species in CRNWR, particularly those of special concern to the refuge. A bioenergetic modeling approach was applied to assess this impact since determining the cause of avian nest failure in CRNWR has proven to be a challenge. The model provided estimates of fish, crustacean, and avian (egg) consumption for individual mink in CRNWR during the spring and summer. Further research, however, is necessary to increase the accuracy of model estimates. Research should focus on mink diet composition in CRNWR, especially in terms of the energetic contribution of different prey items to mink diet and the estimated mass range of those prey items. Although primarily built from the literature, the model is a starting point in terms of assessing the potential impacts of American mink on other species.

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Table 2.1: Bioenergetics model input parameters - Estimated prey mass range, g wet weight, and prey energy density, kJ/g wet weight, found in the literature.

Prey Category	Mass Range, g wet weight	Source	Energy Density, kJ/g wet weight	Source
Crustacean	5 to 85	Based on observations in the field	3	Ferreras and MacDonald 1999
Fish	30 to 125	Based on observations in the field, Brugger 1993, Keenan et al. 2011	5.02 ± 1.00	U.S. EPA 1993
Avian (Egg)	8 to 50	Egg weight range of species of concern within CRNWR (i.e., Least tern[a], Black skimmer[b], American oystercatcher[c])	8 ± 0.3	Carey et al. 1980

Notes: [a]Massey 1974, [b]Sotherland and Rahn 1987, [c] Nol et al. 1984

Table 2.2: Bioenergetics model input parameter – Methods compiled from the literature to estimate daily energy expenditure, kJ/day, of an American mink.

	Method	Source	Notes
A.	$BMR = 84.6(kgWeight)^{.78} \pm 0.15$ kcal/day	Iverson 1972	Mink Body Weight, kg > 1kg
B.	$ME_M = 147.8 \pm 6.06$ kcal/$(kgWeight)^{0.734}$/day	Harper et al. 1978	Male Mink, n=31 Metabolic Body Size $=kgWeight^{0.734}$
C.	Daily Intake, Maintenance: 140 kcal ME/kgBodyWeight	National Research Council 1982	Recommended daily intake for farm-raised adult mink, non-breeding
D.	Energy Expenditure @ 18°C = 768 kJ/day/kgBW Energy Expenditure @ 24°C = 501 kJ/day/kgBW	Wamberg 1994	Female Mink, 24-hr Direct Calorimetry
E.	Metabolizable Energy = 573 kJ/day: non-mated ♀ ME = 612 kJ/day: 3rd trimester ♀ ME = 762 kJ/day: lactation week 1 ME = 986 kJ/day: lactation week 2 ME = 1074 kJ/day: lactation week 3 ME = 1294 kJ/day: lactation week 4	Tauson et al. 1998	Lactating, Non-lactating Female Mink •Weights of females almost double the weights of females in CRNWR
F.	$FMR = 4.82(gBodyMass)^{0.734}$	Nagy 2005	Allometric Equations - All Mammals
G.	Carnivora: FMR, kJ/day $= 1.67(gBodyMass)^{0.869}$ Carnivores: FMR, kJ/day $= 2.23(gBodyMass)^{0.85}$	Nagy et al. 1999	Allometric Equation 5 Allometric Equation 12*

Notes: * Referred to as "Equation 2"

Table 2.3: Trapping data (capture date, sex, age class, weight, and general location) collected by USFWS personnel as well as stomach and gastrointestinal (GI) tract contents of mink captured in CRNWR in 2010 (March through August).

Mink ID	Trap Date	Sex	Age	Weight (g)	Stomach & GI Tract Contents	Trap Site
D1	13-Mar	M	Adult	1162.3	Fish, Crustacean	Cape Island
D2	15-Mar	M	Adult	1247.4	Crustacean	
D3	16-Mar	M	Adult	992.2	○	
D4	16-Mar	M	Adult	1275.7	Crustacean	
D5	17-Mar	M	Juvenile	652.0	Fish, (Sand)	
D6	18-Mar	F	Adult	652.0	(Sand, Vegetation)	
D7	18-Mar	M	Adult	1219.0	○	
D8	18-Mar	M	Adult	822.1	(Vegetation)	
D9	18-Mar	F	Adult	538.6	Crustacean, Feathers	
D10	19-Mar	M	Adult	1304.1	○	
D11	20-Mar	F	Adult	680.4	Fish (Sand)	
D12	20-Mar	M	Adult	907.2	Fish	
D13	21-Mar	F	Adult	595.3	(Sand, Vegetation)	
D14	22-Mar	M	Juvenile	680.4	Fish	
D15	26-Mar	M	Adult	[Unknown]	Crustacean	Bulls Bay
D16	10-Jul	F	Lactating	453.6	Avian (Vegetation)	Cape Island
D17	11-Jul	F	Juvenile	425.2	Crustacean	Northern Marsh
D18	11-Jul	M	Juvenile	538.6	Fish, Crustacean	
D19	11-Jul	F	Juvenile	425.2	Crustacean	
D20	14-Jul	F	Adult	652.0	Fish	
D21	27-Jul	F	Juvenile	283.5	(Vegetation)	Cape Island
D22	26-Aug	F	Adult	510.3	○	
D23	26-Aug	M	Juvenile	623.7	Fish	
D24	26-Aug	M	Adult	964.9	Fish, Crustacean	

Notes: "○" - Stomach and GI tract was empty; Contents enclosed in "()" were not included in the analysis

Table 2.4: Trapping data (capture date, sex, age class, weight, and general location) collected by USFWS personnel as well as stomach and gastrointestinal (GI) tract contents of mink captured in CRNWR in 2011 (March through April).

Mink ID	Trap Date	Sex	Age	Weight (g)	Stomach & GI Tract Contents	Trap Site
D25	24-Mar	M	Juvenile	517.1	Crustacean	Cape Island
D26	25-Mar	M	Adult	1088.6	O	
D27	25-Mar	M	Adult	907.2	Crustacean	
D28	25-Mar	F	Adult	635.0	(Sand, Vegetation)	
D29	27-Mar	M	Juvenile	521.6	(Sand)	
D30	28-Mar	M	Adult	907.2	O	
D31	29-Mar	M	Juvenile	517.1	Crustacean	
D32	7-Apr	M	Adult	1088.6	O	Bulls Bay
D33	7-Apr	F	Adult	503.5	Fish	
D34	8-Apr	M	Adult	975.2	O	
D35	8-Apr	M	Adult	1088.6	O	
D36	8-Apr	M	Adult	1270.1	O	
D37	10-Apr	M	Juvenile	503.5	Fish	
D38	10-Apr	M	Juvenile	517.1	Crustacean	
D39	12-Apr	F	Adult	726.0	O	
D40	12-Apr	M	Adult	966.2	(Sand)	
D41	17-Apr	M	Adult	861.8	Crustacean	Cape Island
D42	17-Apr	M	Juvenile	503.5	O	
D43	20-Apr	M	Adult	997.9	(Sand)	
D44	21-Apr	M	Adult	979.8	O	

Notes: "O" - Stomach and GI tract were empty; Contents enclosed in "()" were not included in the analysis

Table 2.5: Diets of CRNWR mink (male, female, and both sexes combined, “total”) during spring/ summer 2010 and 2011 using the relative frequency of occurrence method of analysis.

	Prey Occurrences, N			Relative Frequency of Occurrence, %
Prey Category	Male	Female	Total	Total, N=27
Crustacean	11	3	14	51.9
Fish	8	3	11	40.7
Avian	0	2	2	7.4
Total	19[a]	8[b]	27	

Notes: 44 Digestive Tracts; Excluded from analysis: 21 Empty (11 with Sand/Vegetation); # of Tracts w/ Contents: Male 16, Female 7; [a] Three Digestive Tracts contained 2 items; [b] One Digestive Tract contained 2 items

Table 2.6: Bioenergetics model input parameter – Diet composition of the American mink in terms of relative frequency of occurrence (RFO) compiled from the literature.

	Source	Relative Frequency of Occurrence, %			
		Crustacean	Fish	Avian	Mammal
Mammalian Consumption	Wilson 1954	10.1	34.4	12.2	25%
	[a]Birks and Dunstone 1985	♂: 18.8 ♀: 29.2	♂: 20.4 ♀: 37.5	♂: 7.1 ♀: 11.1	♂: 53.9 ♀: 21.9
	Dunstone and Birks 1987	18.7	29.1	11.2	40.9
	Hammersh et al. 2004	n/a	13.1	15.4	24.0
High Avian Consumption	Bartoszewicz and Zalewski 2003	n/a	22[b]	65-74[b]	27-38[b]
	Salo et al. 2010	n/a	32.8	28.4	15.2
Coastal-Dwelling Mink	Delibes et al. 2004	51.6	46.3	1.2	n/a
	Hatler 1976	80.0	40-60	< 20	n/a

Notes: [a] Gender differences in mink diet, [b] Estimates given as % biomass

Table 2.7: Bioenergetics model input parameters – Weight range, g, of mink trapped in CRNWR, South Carolina and the estimated daily, kJ/g/day, and monthly, kJ/g/month, energy expenditure of the mink using Equation 2 (Nagy et al.1999).

	Weight Range, g	Average Daily Energy Expenditure (kJ/g/day)	Average Monthly Energy Expenditure (kJ/g/month)
Male	822.1 to 1304.1	833.47	25004
Female	503.5 to 726.0	523.24	15697
Lactating Female	503.5 to 726.0	1303.24	39097

Table 2.8: Bioenergetics model simulation output – Estimated mean monthly consumption (± standard deviation) of each prey category by male, female, and lactating female mink during the spring/summer in CRNWR, South Carolina.

	Mean Monthly Consumption ± Standard Deviation		
Prey Category	Male	Female	Lactating Female
Crustacean	148.7±89.1	93.3±55.7	232.51±137.9
Fish	35.8±11.0	22.5±6.8	56.0±16.6
Avian	8.0±4.8	5.0±3.0	12.4±7.4

Table 2.9: Bioenergetics model simulation output – Median, range, 3rd Quartile (75th percentile), and 95th Percentile obtained from 300,000 iterations of each bioenergetics model (male, female, and lactating female mink).

		Bioenergetics Model Output, # prey consumed/month/category			
Prey Category		Median	Range	3rd Quartile	95th Percentile
Crustacean	Male	122.7	52.12-1229.9	166.5	315.4
	Female	77.1	34.2-758.5	104.4	197.7
	Lactating Female	192.0	93.0-1809.2	259.5	490.7
Fish	Male	33.3	16.6-102.8	40.9	58.0
	Female	20.9	10.8-63.0	25.6	36.3
	Lactating Female	52.1	29.3-148.0	63.6	90.0
Avian	Male	6.6	2.7-64.6	8.9	16.9
	Female	4.1	1.79-39.9	5.6	10.6
	Lactating Female	10.3	4.9-95.1	13.9	26.2

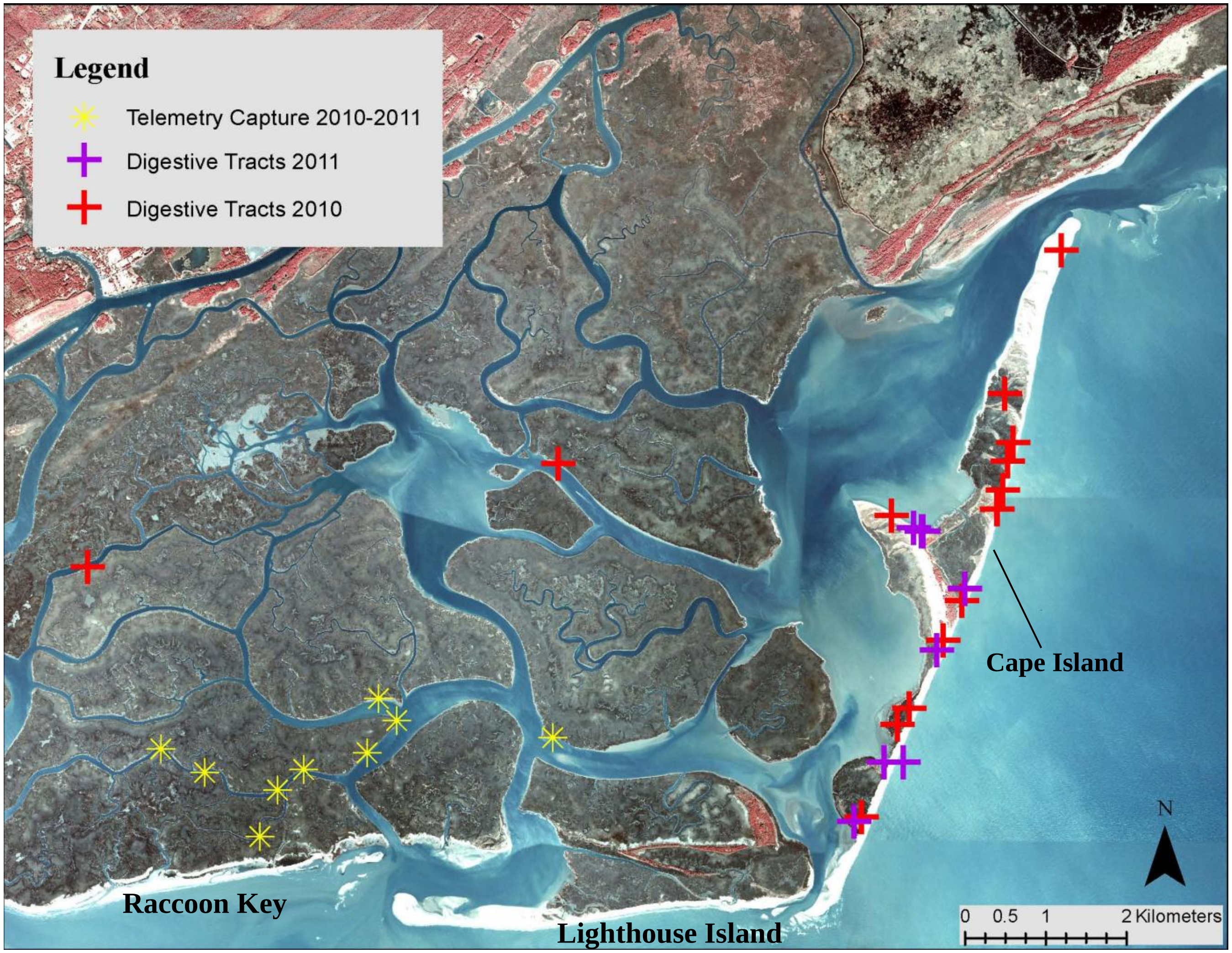

Figure 2.1: Locations of predator management activities within the northern marsh (inset represents 3 juvenile mink culled in the same location) and on Cape Island in relation to capture sites of 9 radio-monitored mink in CRNWR, 2010-2011.

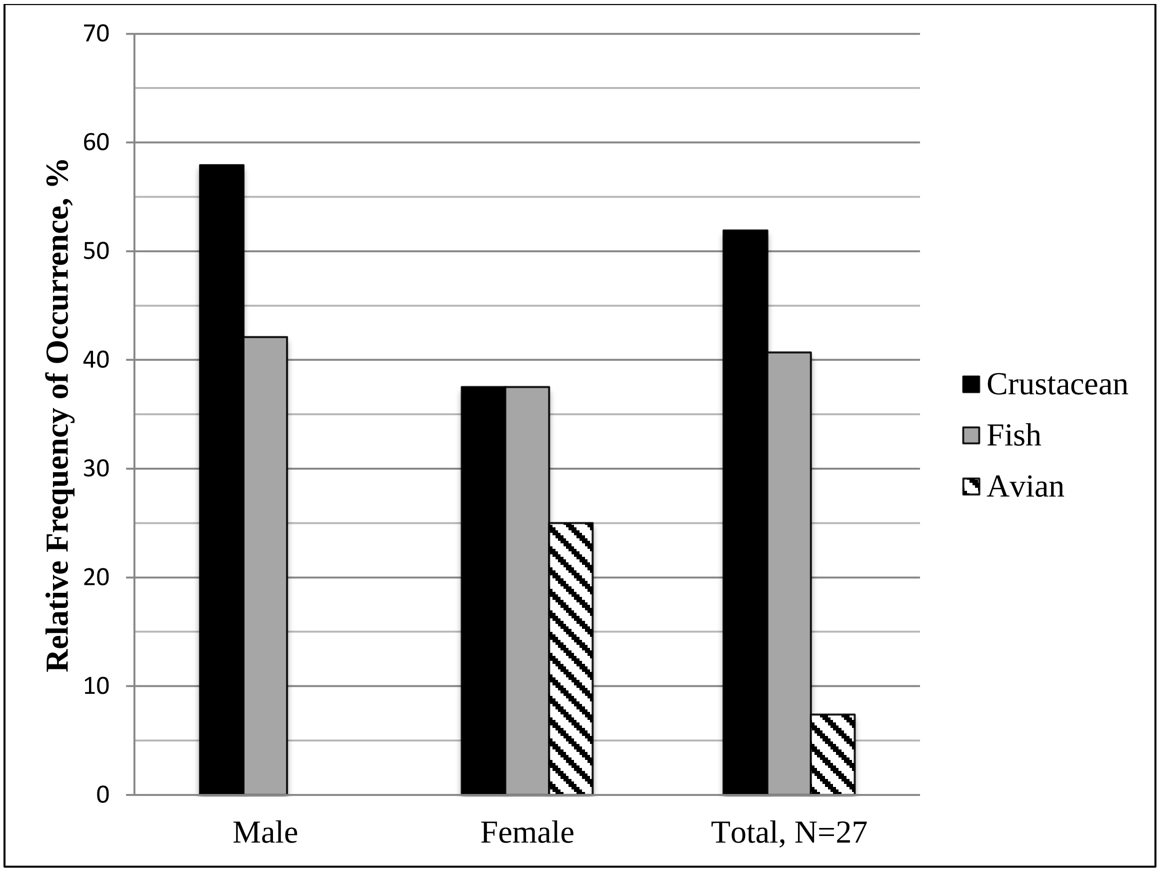

Figure 2.2: Relative frequency of occurrence analysis of mink diet (male, female, and both sexes combined, “total”) in CRNWR, South Carolina during spring and summer 2010 and 2011.

CHAPTER THREE

ACTIVITY PATTERN & HOME RANGE OF THE AMERICAN MINK IN A TIDAL MARSH SYSTEM, CAPE ROMAIN NATIONAL WILDLIFE REFUGE, SOUTH CAROLINA

INTRODUCTION

The literature documenting American mink ecology in salt marsh ecosystems is limited. Most coastal studies focus on the ecology of mink utilizing rivers, lakeshores, freshwater marshes, or beaches (Marshall 1936, Hatler 1976, Gerell 1969, Ireland 1990, Niemimaa 1995, Zschille et al. 2010). In 1998, the South Carolina Department of Natural Resources (SCDNR) and Clemson University successfully reintroduced 62 mink to Cape Romain National Wildlife Refuge (CRNWR). Peeples (2001) monitored 13 of the released individuals for a 15-month period (September 1999-November 2000) and his data indicated that the mink in this system had home range sizes larger than those reported elsewhere in marsh systems (male, n = 4: 6.91 km^2; female, n = 9: 2.28 km^2). Based on observations in the field, Peeples (2001) hypothesized that tidal fluctuations likely influenced the daily activity pattern of this population. The goal of this study was to examine home range size 10 years following reintroduction as well as assess whether tide influences mink activity in CRNWR.

Burt (1943) defined an animal's home range as "that area traversed by the individual in its normal activities of food gathering, mating, and caring for young," excluding exploratory trips. Generally, the space within the home range is used disproportionally, and so smaller areas, or core areas, are selected by the individual and used more than can be expected by random use (Burt 1943, Powell 2000, Plowman et al.

2006). For mink, core areas include suitable denning sites and access to foraging areas (Gerell 1970). Two home range shapes have been reported for mink in the literature and are based on the type of aquatic system inhabited: 1) 2-dimensional in marsh habitats (Arnold and Fritzell 1987, Niemimaa 1995); and 2) linear, or 1-dimensional, in riparian and reservoir systems (Birks and Linn 1982, Dunstone and Birks 1983, Yamaguchi and MacDonald 2003, Gerell 1970, Stevens et al. 1997, Melero et al. 2008). Mink home ranges observed in CRNWR are considered to be 2-dimensional (Peeples 2001).

Mink are influenced by the daylight-dark cycle and are considered a nocturnal species (Gerell 1969, Garin et al. 2002). Research has found, however, that females are less active while pregnant and often diurnal during kit-rearing season (Gerell 1969, Ireland 1990), while males are predominately nocturnal or crepuscular year-round (Gerell 1969, Hatler 1976, Birks and Linn 1982, Ireland 1990, Niemimaa 1995, Zschille et al. 2010). Both sexes reduce activity in the cold months to conserve energy (Marshall 1936, Birks and Linn 1982, Ireland 1990, Zschille et al. 2010) and increase activity during the breeding season (i.e., January-March) (Garin et al. 2002, Zschille et al. 2010).

Prey availability and habitat features have been shown to influence both the daily and seasonal activity pattern of mink and other mustelids (Marshall 1936, Gerell 1969, Zielinski et al. 1983, Gelatt et al. 2002, Zuberogoitia et al. 2006, Wellman and Haynes 2009). Wellman and Haynes (2009) found mink more active at night in upland stream systems than in wetland systems potentially because of the higher presence of nocturnal terrestrial prey in the upland area. In wetland systems with a high presence of aquatic prey, Wellman and Haynes (2009) observed higher diurnal activity, suggesting that due to the mink's poor visibility underwater, foraging for aquatic prey is most successful during the day than at night (Sinclair et al. 1974).

In CRNWR, the mink population primarily inhabits the tidal marsh system and is therefore subject to a fluctuating environment in terms of both habitat structure (i.e., flooding events) and weather conditions. It has been suggested that coastal-dwelling mink (i.e., utilization of beaches or rocky coastlines) are less active than those populations inhabiting freshwater systems due to the greater food availability found in tidal marsh systems (Hatler 1976, Gerell 1969, Whitman 1981, Ireland 1990). This species' opportunistic foraging strategy, paired with observations of high prey availability, low risk of predation, and little competition with other species in the CRNWR suggests that tidal fluctuations could influence activity more so than other factors (Hatler 1976, Ireland 1990, Peeples 2001).

MATERIALS AND METHODS

Capture of American Mink

Trapping efforts for this study focused on mink inhabiting the northern tidal salt marshes adjacent to the barrier islands of CRNWR. South Carolina experiences extreme high tides between April and December with water levels rising 0.3-0.6 m above the mean high water level (1.6 m), or the high-water norm. During high tides, mink utilize tide racks (i.e. accumulations of floating dead smooth cordgrass, *Spartina alterniflora*) along creek edges as areas to rest and consume prey until the water recedes (Peeples 2001). Between April and July, lactating females build nests on top of tide racks to conceal kits during high tides. These flooding events provide the opportunity to easily locate this otherwise elusive species.

Trapping occurred at night during extreme high tides in April and May 2010 and 2011. Individual mink (i.e., males or non-lactating females) were spotlighted from a boat and captured using dip nets and then transferred to a plastic-coated wire mesh cage (75 cm x 75 cm x 25 cm) containing a PVC hide tube (12 cm x 30 cm) (Peeples 2001).

Females with kits were caught using Tomahawk, double-door live traps (14 cm x 14 cm x 48 cm, Tomahawk Trap Company, Tomahawk, WI) rather than dip nets. Due to a female mink's strong affinity toward her kits, she would only depart from the nest briefly upon the boat's arrival. This departure allowed for the altricial kits to be collected and relocated to a closed live trap. An open live trap was then zip-tied to the closed trap containing the kits, and both were placed on a piece of foam insulation and returned to the tide rack. The trap was checked every 15 minutes until the female, in her attempts to remove the kits from the adjacent trap, was captured (Peeples 2001). The family group was then transferred to the above-mentioned holding cage.

Mink were transported from the marsh to a holding area prior to being taken to an approved veterinary clinic (Daniel Island Animal Hospital, 291 Seven Farms Dr. Suite 103, Daniel Island, SC 29492) where a radio-transmitter was surgically implanted into the abdominal cavity of each adult mink (Hernandez-Divers et al. 2001, Peeples 2001, Zschille et al. 2008, Zschille et al. 2010). As shown by Zschille et al. (2008), internal radio-transmitters are more suitable for mink and other species with similar neck and head circumferences than radio collars. Following surgery, mink were transported back to the capture-site and released < 12 hours following capture (Animal Use Protocol 2010-002, Clemson University).

Surgery

A qualified veterinarian, Dr. Lynne Flood, D.V.M, performed a general health examination prior to implanting (Zschille et al. 2008) each mink with an intra-peritoneal, mortality sensing radio-transmitter weighing 22g (ATS Model 1230, Advanced Telemetry Systems, Isanti, Minnesota). To ensure that the mobility of the animal was not significantly impacted, transmitters weighed no more than 5% of the expected mink body mass (Cochran 1980, Yamaguchi et al. 2002). Only male and female mink weighing more than 500g received a transmitter in this study (Cochran 1980, Zschille et al. 2008, Animal Use Protocol 2010-002 Clemson University). Mink were anesthetized with isoflurane gas while in the PVC hide tube and then transferred to an anesthesia mask (Yamaguchi et al. 2002). Mink were sexed and weighed while anesthetized. Kits were separated from the female prior to the delivery of the anesthetic, weighed, and then transferred to a heating pad until the female recovered.

The abdominal region was shaved and cleansed for surgery using standard aseptic techniques, and the transmitter was immersed in absolute isopropanol and rinsed with sterile water. Using sterile surgical techniques, a 2 to 2.25cm incision was made along the avascular midline through the skin, muscle, and peritoneum, allowing for the transmitter to be placed freely within the abdominal cavity (Zschille et al. 2008). Using a simple uninterrupted suture technique, the peritoneum and muscles were closed together in one layer (Zschille et al. 2008, Animal Use Protocol 2010-002 Clemson University).

Above this, a simple interrupted suture pattern was used subcutaneously to close the skin (Zschille et al. 2008). The incision was then sealed with surgical glue. To reduce risk of infection, a long-acting antibiotic (cefovecin sodium, Convenia®, at 8 mg/Kg body weight - a cephalosporin with 7 – 14 days duration) was administered. The surgery took no longer than 30 minutes. Following recovery, mink were transported back to the capture site (Animal Use Protocol 2010-002, Clemson University).

Telemetry

Tracking of radio-implanted mink began ≤ 36 hours following release, but collection of activity and home range data began between 48-72 hours following release to allow individuals time recover from surgery and handling. Each mink was monitored daily until the individual died, the transmitter ceased to function, the signal was lost, or the study period ended (Peeples, 2001). Activity was defined as a change in signal strength for at least 15 seconds, or the signal alternating between audible and inaudible for the same duration of time (Gerell 1969, Zielinski et al. 1983, Niemimaa 1995, Zschille et al. 2010). To be classified as "inactive," the signal strength remained constant and audible for at least 60 seconds (Zschille et al. 2010).

Mink activity was monitored and locations were triangulated from a boat using a portable TR-5 model receiver connected to a H-antenna (Telonics Inc., Mesa, Arizona). The environment (primarily thick smooth cordgrass, wind, and rising and falling water levels) and the internal placement of the transmitter limited detection to approximately 50-100m. Between the limited range of the transmitter signal and the constraints of the environment (shallow and narrow creeks, flooded marsh, strong winds, etc.), collecting three or more bearings ≥ 60 degrees apart for home range analysis was not always feasible (UTM positions, using a Lowrance® HDS-5 GPS Unit, Tulsa, Oklahoma, USA). As a result, two bearings were recorded with the angle of intersection between 60 and 120 degrees.

From June through August 2010, locations for home range analysis were recorded (activity was not recorded in 2010). Mink were monitored randomly during the night and daylight hours at randomly chosen tide heights. Locations were separated by at least 9 hours to reduce the impact of temporal correlation. In order to determine whether tide cycle impacted horizontal movement across the landscape, tracking periods occurred during rising, falling, and high tides. It was proposed that a mink would utilize different areas within its home range during different tide levels, so at high tide a mink would move to an elevated site until the water subsided (taken from observations by Peeples 2001). This initial hypothesis was not formally tested, however, following observations throughout the 2010 field season when lactating females were observed moving vertically by using the same tide rack as cover during low tide and as a floating raft during high tide.

From March through August 2011, both activity and locations were recorded. Due to limited manpower and variable weather conditions, continuous monitoring (as seen in Gerell 1969, Birks and Linn 1982, Niemimaa 1995, Yamaguchi and MacDonald, 2003) was not feasible, so a 24-hour cycle, consisting of 24 time blocks, was divided into five possible tracking shifts: Day_A (08:00-13:00), Day_B (13:00-18:00), Twilight_2 (18:00-

23:00), Night (23:00-03:00), Twilight_1 (03:00-08:00) (Zschille et al. 2010). No more than two tracking shifts would occur in the same 24-hour cycle.

During a 4-5 hour tracking shift, the location of each mink was triangulated once, while activity data was recorded hourly for each mink with (1) indicating “active” and (0) indicating “inactive” (Drew and Bissonette 1997). Occasionally, a mink could not be relocated during the following time block or located during an entire shift, hence “not found” was recorded when a signal was not detected within a time block. Locations were separated by at least 9 hours and activity was separated by at least one hour to minimize auto-correlation (Rooney et al. 1998, Zschille et al. 2010). Activity between the hour of sunrise (typically 06:00) and sunset (typically 20:00) was considered to occur during daylight hours. Tide height and weather conditions (i.e., temperature, cloud cover, wind) were recorded with each activity reading. In the field, tide heights were estimated using the Southeastern Edition of the 2010 TIDELOG (Pacific Publishers, Box 480, Bolinas, CA 94924). The estimates were later replaced with verified tide heights (mean low water datum) from station 8665530 in Charleston, SC found on the National Oceanic and Atmospheric Administration (NOAA) database. Verified tides were then adjusted for the study site using the tide corrections provided in the 2010 TIDELOG.

Prior to radio-tracking, triangulation error was evaluated by locating a transmitter placed on the edge of the marsh (Location A) and then 10 meters off the marsh edge (Location B). The exact position of the transmitter was recorded using a handheld GPS device (Lowrance® GlobalMap 100, Tulsa, Oklahoma, USA). Three triangulated locations per transmitter site were recorded and compared to the exact location, and the mean distance (arithmetic mean) between relocation estimates and the actual transmitter location was the mean location error (Kauhala and Tiilikainen 2002). Mean linear error was 20.3 m for marsh edge relocations, 12 m for interior marsh relocations, and 16.2 m overall.

Data Analysis

Locations of transmittered mink were determined using the maximum likelihood estimator with default settings in Location of a Signal v.4.0.3.7 (LOAS™, Ecological Software Solutions LLC™, Hegymagas, Hungary) and then projected into ArcGIS 10 (ESRI 2011, Environmental Systems Research Institute, Redlands, California, USA). Biotas™ v.2.0a (Ecological Software Solutions LLC™, Hegymagas, Hungary) was used to calculate home range (95% of an individual's locations) and core areas (50%) using the fixed kernel density estimator and least squares cross validation (LSCV*h*) to select a smoothing parameter, *h*. This method is currently recommended for home-range estimation (Powell 2000, Horne and Garton 2006). Linear home range was then estimated in GIS by measuring the linear distance of utilized marsh edge within the 95% kernel (Melero et al. 2008).

Using the Glimmix procedure (PROC GLIMMIX, $P<0.05$) provided by SAS/STAT® software version 9.3 (SAS Institute, Cary, North Carolina), the degree of influence of various environmental factors on mink activity was analyzed. This generalized linear mixed model was used due to its ability to account for the individual random effects of each mink on the response variables, allowing for the activity data of all mink captured to be pooled. The data were tested to determine whether the tide height, time of day (data combined within each of the 24 time blocks), presence or absence of light (light phase), temperature, and/or presence or absence of kits significantly impacted the dichotomized activity variable. All five explanatory variables were considered fixed effects, while the identity of the mink was a random effect. Due to the potential for correlation between explanatory variables, the analysis was run without time block and then again with time block but without light phase and temperature.

A quadratic spline was then applied to smooth the data using 11 equally spaced, randomly chosen, time block knots: 0, 3, 5, 7, 9, 11, 13, 15, 17, 19, and 21 (Pedan 2003, Jo et al. 2007). These time block knots were input as a random effect with SAS determining each knot's degree of influence (i.e., automatic knot selection). Using observed combinations of tide height, light phase, and temperature, the predicted values of activity were averaged within each time block to produce the "expected activity" for that hour (i.e., the likely or average predicted level of activity for females in CRNWR during that time period).

RESULTS

Captured Mink

Nine mink and twenty-eight kits were captured during this study (Table 3.1, Figure 3.1). Implanted transmitters weighed 2.5 and 3.5% of the average body mass of males (911.5 g; range=880-943 g, n=2) and females (634 g; range=535-720 g, n =7) captured in this study. Mink F1, F2, and F3 (all lactating females) were captured in late May 2010 and radio-located between June and August of that year. In 2011, F1 was not relocated, while F2 and F3 were monitored briefly in March and April before both transmitters ceased to function. Mink F6, F7, and F9 all had kits and were captured in May 2011. Mink F8 was pregnant when captured in May 2011, and parturition occurred 2 weeks following surgery. All four females were monitored from May through August of that year. Unlike the other family groups, F7 was not relocated for over a week after surgery and was located infrequently throughout the summer compared to other females.

Mink M4 and M5 were juvenile males captured in April 2011. Mink M4 was captured in open water, fleeing from a larger male mink in what was assumed to be a territorial dispute. Both juvenile males were monitored only briefly before mortality signals were detected. The carcass of M5 was recovered approximately 5 km inland from the capture site and taken to Daniel Island Animal Hospital to determine cause of death. Multiple, small puncture wounds found on M5's hindquarter appeared to have resulted in a severe infection, which likely led to reduced ambulation and eventually death due to starvation.

Home Range

Between May and August 2010 and 2011, 324 relocations of 7 radio-implanted female mink were obtained (Table 3.2). Total home ranges were estimated for 3 lactating females in 2010, 3 lactating females in 2011, and one female (F7) without kits in 2011. Captured males did not survive long enough to gather sufficient data for home range size and activity pattern analyses. Females F2 and F3 were briefly relocated between March and April 2011, so home ranges were estimated using 2010 data as well as locations from both years. While additional locations on F3 refined her core area (0.235 ha to 0.171 ha), the core area for F2 remained the same (Table 3.2).

Estimates of 95% kernel home range size for all females ranged from 0.3 to 17.1 ha. When F7 was excluded, however (i.e., a female without kits for all locations), the maximum home range size decreased to 4.23 ha (Table 3.2). Core areas ranged from 0.03 to 2.26 ha for all females, but when F7 was excluded, the maximum core area declined to < 1.00 ha (Table 3.2). Maps of fixed kernel home ranges for all individuals appear in Appendix C. Approximate linear distance ranged from 0.44 km to 1.81 km (Table 3.2, mean = 1.00 km).

Family groups were often located in close proximity to drainage creeks (< 5 m wide) along the larger, navigable creeks (Figure 3.2 specifically, also Appendix C). Un-tagged mink were observed crossing these larger creeks (approximately 60-80 m wide), but in terms of the tagged mink, only F7 was located on either side of a larger creek (Appendix C-5). Mink F6 and F9 were captured 0.43 km apart and utilized adjoining areas throughout the summer (Figure 3.3). At no point was either F6 or F9 located within the other individual's home range (i.e., there was 0% overlap in home ranges).

Activity Pattern

In total, 941 activity measurements were made on 6 female mink between March and August 2011. Of the 941 measurements, 38% (n = 359) were "active" readings and 58% were gathered during daylight hours (time block 06:00-09:00) (Table 3.3). On 47 occasions, a female (typically F7) was not located within a time block. During daylight hours (time block 06:00-19:00), mink were found active 34% of the time, while 44% of the recordings taken at night (time block 20:00-05:00) were active (Table 3.4). Lactating females were found to spend approximately 36% of the cycle active, while non-lactating females spent 43% active (Table 3.5).

The first test of fixed effects in Glimmix used the explanatory variables (tide height, time of day, light phase, temperature, and/or presence or absence of kits) as fixed effects, while making the identity of the animal (due to grouping of all activity data) a random effect. Tide height (p=0.0002, Figure 3.4) and time of day (p=0.02) significantly impacted activity. A negative relationship was observed between tide height and activity. Light phase (p=0.2436), temperature (p=0.4843), and kit presence/absence (p=0.1898) did not significantly influence activity level.

In order to further explain how time of day impacted mink activity, time block was set as a random effect and a quadratic smoothing spline was applied to the data. Activity of all individuals was shown to be at a minimum at midday (between 11:00 and 13:00), at a maximum near midnight, and then gradually decreasing through the early morning hours (Figure 3.5). Using observed combinations of tide height, light phase, and temperature, the predicted values of activity of all individuals were averaged within each time block (Figure 3.6), showing activity sharply declining three hours following sunrise and reaching its minimum at midday. Female mink activity then sharply increased three hours prior to sunset, reaching its maximum at 23:00.

The potential correlation between time block, light phase, and temperature was considered further due to the pattern observed in Figure 3.5. When time block was excluded from the analysis, ambient temperature was then significantly and negatively related to activity (p=0.03), while light phase was marginally significant (p=0.06). The inclusion of time block with the removal of temperature and light from the analysis resulted in a highly significant relationship between time block and activity (p=0.0004). Both analyses suggest that temperature, light, and time of day jointly impact activity.

DISCUSSION

Captured Mink

All nine captured mink underwent successful surgeries and, based on direct observations and radio-tracking, eight of the nine mink did not appear to be negatively impacted by the surgery or implanted transmitter. The behavior of F7 following surgery was unusual, compared to that of the other 5 lactating females. Typically the female would regain awareness and immediately return to protecting her kits in the PVC hide tube (also observed by Zschille et al. 2008). Mink F7, however, took a considerably longer period of time (approximately 45 minutes) to re-accept the kits. Although age was not recorded in this study, a dental health check suggested that F7 was younger than the other females and potentially in her first kit-rearing season. It is possible the stress of the situation, coupled with her age and inexperience, interfered with her maternal instinct.

Juvenile males did not survive the length of the study period. Based on carcass condition, M5 appeared to have died during a territorial dispute with an adult male. Multiple puncture wounds on the hindquarter of M5 appeared to match mink dentition patterns. Mink M4 was captured during a territorial dispute, and following release at the capture site, was observed successfully foraging at low tide in the same general area (0.4

km from capture site). The mortality signal was detected 4 days following the foraging observation in an area approximately 0.3 km from the capture site and 0.5 km from the foraging area. The carcass could not be retrieved to determine cause of death. It is possible the territorial dispute resumed and M4, like M5, suffered significant enough injuries to cause death.

The carcass of M5 was located wedged underneath what appeared to be a scent mound, or a mound of dirt used to elevate an animal's scent in order to increase scent dispersal for territorial purposes. The use of scent mound communication is heavily documented for both the Eurasian and North American beaver (*Castor fiber*, *Castor canadensis*) but not for mink. Mink mark an area by depositing feces in prominent, elevated places (Gerell 1968 as cited in Brinck 1978), and a small amount of scat was found on the mound. Elevated areas are not common within the tidal marsh system, and therefore the CRNWR population may use scent mound structures to aid in marking territory. Further research, however, regarding mink territorial behavior in CRNWR is necessary to support this observation.

Home Range

Birks and Linn (1982) estimated that 80% of a mink's total home range could be determined if locations were taken at least twice a day for 5 or more days, while the entire home range required at least two locations per day for a minimum of 10 days. Zabala et al. (2007) found that 15 fixes taken on different days could reveal at least 30% of the home range. Due to the limited movement typical of pregnant and lactating females (Ireland 1990), however, the majority of an individual's home range was likely not ascertained in this study (i.e., wintering home ranges may have been larger than those recorded during the breeding season).

Peeples (2001) monitored mink in CRNWR and reported an average female home range of 228 ha, and linear range between 1.40 km and 3.63 km. Both home range (95% kernel) and linear range approximations from my study appeared to be smaller than that reported by Peeples (2001). It is likely that this difference was primarily because Peeples (2001) reported home range size using the minimum convex polygon method (MCP). Due to the tendency of mink to utilize areas along shorelines (Larivière 2003), the MCP most likely overestimated home range of mink in CRNWR. Female mink on islands off the coast of Finland (mean: 10 ha Niemimaa 1995; mean: 9.41 ha, Salo et al. 2010) had larger ranges than this study's lactating females. Also, my study collected data during a shorter time period, which occurred while females were lactating (i.e., May-August), than Peeples (2001) whose larger home ranges were reported from year-round data from both sexes.

Linear home ranges along rivers and streams are most commonly reported for American mink, since the majority of foraging activity typically occurs within 2 meters of the shoreline (Larivière 2003). Home ranges in this study were reported two-dimensionally due to mink utilizing areas within the marsh as well as along the main creeks; however, linear estimates were also calculated because locations within the marsh were typically found along small drainage creeks. Linear ranges of female mink in England (0.9-4.3 km, Yamaguchi and MacDonald 2003), Sweden (2.8 km, Gerell 1970), and Spain (0.42-0.77 km, Melero et al. 2008) were similar to this my estimations (range:

0.44-1.81 km). Further monitoring may show linear representations of mink home range in CRNWR to be more accurate than two-dimensional estimates.

Although sample sizes were limited (1 pair of females), intrasexual overlap in home ranges was not observed. Peeples (2001) also did not observe any intrasexual overlap in home ranges for females or males. Gerell (1970) and Peeples (2001) both found that males often overlapped or subsumed at least one female home range, while evidence of juvenile males within adult male territories was not found. Yamaguchi and MacDonald (2003), however, found both intrasexual and intersexual home range overlap. Consequently, it is possible that mink exhibit territorial behavior within a spatio-temporal framework (Gerell 1970, Ireland 1990). Mink in Sweden, for instance, restricted activity to a portion of the home range for several days before moving to a new area for a similar length of time (Gerell 1970). Therefore, intermittent sampling or short study duration could be causing difficulty in documenting range overlap between mink.

Lactating females were often located in the same area throughout the study, especially during the beginning of the summer when the kits were most vulnerable. Ireland (1990) reported that as the kits grew, a female's home range increased. During my study, it appeared from the frequent day-to-day location changes and the increased home range size that Female 7 was no longer rearing kits for the entire study period. Compared to the other family groups, Female 7 regularly shifted to new areas between days and during telemetry shifts (unlike the other family groups). Her home range was approximately 10 ha larger than the largest home range reported for lactating females. Unpredictable movements and the abnormal behavior observed during the recovery period following surgery suggested that F7 abandoned her kits during the week she was not detected.

A previous study in CRNWR reported that mink were most often found along creeks less than 200 meters wide (Waller 2010). It is likely the narrower creeks provided protection from wind and wave exposure typical of a coastal environment (Hatler 1976, Gerell 1969, Ben-David et al. 1995). Family groups, in particular, appeared to have an affinity for areas adjacent to smaller drainage creeks (< 5 m wide) along the larger, navigable creeks (approximately 60-100 m wide). These areas are characterized by numerous tide racks, a habitat feature often used for nesting and loafing, and substantial areas of shallow water, a habitat feature often used for foraging. Dunstone (1983) reported that shallow water and low flow rates contributed to a mink's foraging success, especially since this species exhibits poor visibility underwater (Sinclair et al. 1974).

Activity Pattern

In CRNWR, activity level of female mink within a 24-hour cycle (non-lactating: 43.3%, lactating: 36.3%, all females: 38.4%) was slightly higher than those found in other studies. Males and lactating females in British Columbia were active on average, for 32.2% of a 24-hour period (Hatler 1976), and a lactating female in Sweden significantly increased her activity from 13.5% during pregnancy to 30.5% during kit-rearing (Gerell 1969). When active fixes within the den were excluded, female mink in Scotland were active for 12.1% of a 24-hour period, but when den activity was included, the estimate increased to approximately 33.3% (Ireland 1990). Mink activity in CRNWR could be higher than the reports in the literature because, unlike beach-dwelling mink, the CRNWR population inhabits an area that is flood twice a day.

Although no significant difference was found in activity level between lactating (F6, F8, and F9) and non-lactating females (F2, F3, and F7), the percentage of activity within a 24-hour cycle was higher for non-lactating females. Two of these individuals (F2 and F3) were captured in 2010 and relocated and monitored in 2011 from the last week in March through the last week in April. Both females may have been pregnant, but the transmitters ceased to function before kits could be detected. Gerell (1969) reported low activity in April and May for a pregnant female just prior to parturition and a 100g increase in weight during that time. Figure 3.5 shows high levels of activity for both females from late March (end of the breeding season) through late April. It is possible that a decrease in activity for pregnant females in CRNWR occurs closer to parturition in April and May as observed by Gerell (1969).

In terms of time spent foraging, the limited observational data from this study agrees with the literature, which found coastal-dwelling male and female mink in Scotland to forage for a 3-hour period per day (Ireland 1990). Mink M4 was observed foraging successfully on a mudflat for a similar 3-hour period (08:00-11:00, 25-April) before retreating into the marsh grass, where he remained inactive for the last two hours of the morning telemetry shift. It is reasonable that daily energy requirements can be met during this 3-hour period due to the high foraging success rate reported for mink in highly productive ecosystems (Hatler 1976).

The activity pattern described in this study (i.e., minimum at midday, maximum near midnight, a gradual decrease in the early morning with a brief peak in activity between 05:00 and 08:00) is similar to that found for other coastal-dwelling mink (Hatler 1976, Ireland 1990, Niemimaa 1995). Gerell (1969) and García et al. (2009) also observed a spike in activity between 05:00 and 08:00. Gerell (1969) attributed this spike in activity to the favorable weather conditions at dawn. It is likely that the females in CRNWR sharply increased their activity during the cooler morning hours before temperature and relative humidity surged upward between 08:00 and 17:00. Extreme heat could force females to display a crepuscular/nocturnal pattern during kit-rearing, instead of the diurnal pattern typically reported for lactating females in the literature (Gerell 1969, Hatler, 1976, Zschille 2010).

Although light phase was not found to have a significant influence on activity, it appears as if monitored females increased activity between dusk and dawn due to the sharp increase in activity through the evening until midnight, followed by a sudden spike in activity during early morning hours. Longer summer days (approximately 14 hours of daylight) could have resulted in the absence of light appearing to be a less influencing factor on mink activity. Further monitoring in CRNWR, specifically during the winter and fall months, is necessary to accurately determine how light phase and temperature influence mink activity pattern.

The combined activity data of 6 monitored female mink indicated that as tide height increased, female activity level decreased in CRNWR. Ireland (1990) found that on a rocky coastline in Scotland mink activity was not significantly related to tide cycle, but in terms of shore-based foraging activity, female mink were present during low tide. Hatler (1976) also suggested that coastal mink foraging activity would increase during low tide to optimize foraging success. Although this study's findings cannot link activity with specific behaviors (i.e., foraging, travel, etc.), it is possible that mink in this study were foraging at low tides along mudflats and within drainage creeks (Peeples 2001). Prey availability is often high along mudflats, which often swarm with sand and mud fiddler crabs (*Uca pugilator* and *Uca pugnax*) at low tide, and drainage creeks can contain prey items stranded by rapidly falling tides. Since the majority of mink observed in CRNWR appeared to not have access to permanent denning sites or alternate foraging areas unaffected by tidal fluctuations, mink inhabiting salt marshes are more influenced by tide than those living along coastal shorelines.

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Table 3.1: Sex, age class, weight (g), capture date, and transmitter frequency, and kit measurements (when applicable) of 9 mink captured for this study in CRNWR, South Carolina, in May 2010 and April-May 2011.

Mink ID	Sex	Age Class	Weight, g	Capture Date	Transmitter (173.xyz)	Kits	
						Sex	Weight, g
F1	F	Adult	535	26-May-10	732	F	60
						F	55
						M	50
F2	F	Adult	540	28-May-10	808	F	60
						M	70
						M	70
F3	F	Adult	650	28-May-10		F	45
						F	60
						F	60
						M	70
						M	60
						M	60
						M	65
M4[a]	M	Juvenile	943	18-Apr-11	752	N/A	
M5[a]	M	Juvenile	880	20-Apr-11	819	N/A	
F6	F	Adult	675	18-May-11	712	F	17
						F	17
						M	17
						M	17
F7	F	Adult	685	20-May-11	772	F	10
						F	10
						F	10
						M	15
						M	15
						M	15
F8	F	Adult	720	20-May-11	831	Pregnant, evidence of kits ~ 03-June	
F9	F	Adult	720	20-May-11	861	F	17
						F	17
						M	17
						M	23
						M	23

[a] Mortality Signals Detected: Mink 4 on 29-April; Mink 5 on 09-May

Table 3.2: Home range (95% Fixed Kernel, ha), core area (50% Fixed Kernel, ha), and linear range (km) of 7 radio-monitored mink in CRNWR, South Carolina, June- August 2010 and March-August 2011.

Mink ID	Monitored (years)	Number of Relocations	Kernel Home Range, 95%, hectares (2010 & 2011 combined)	Core Area, hectares (2010 & 2011 combined)	Linear Range, km
F1	June '10 - August '10	51	1.26	0.068	0.61
F2	June '10 - August '10 March '11 - April '11	53 11	0.29 (0.39)	0.045 (0.045)	0.95
F3	June '10 - August '10 March '11 - April '11	51 10	2.77 (3.96)	0.235 (0.171)	1.54
F6	May '11 - August '11	42	4.96	0.961	0.83
F7[a]	May '11 - August '11	40	17.14	2.259	1.81
F8	May '11 - August '11	43	0.71	0.034	0.44
F9	May '11 - August '11	44	2.75	0.245	0.75

Notes: [a]Female F7 assumed to have lost kits during the week following surgery

Table 3.3: Dates monitored for activity pattern analysis, total number of fixes (active + inactive), and number of active fixes per monitored female in CRNWR, South Carolina. The number of “not found” occurrences in which a female was not located (i.e., not detected) during a time block.

Mink ID	Monitored	Total Fixes (Active, Inactive)	Active	Not Found
F2	25-March to 25-April	48	16	8
F3	25-March to 25-April	48	28	7
F6	23-May to 10-August	224	83	1
F7	29-May to 10-August	177	72	25
F8	23-May to 10-August	225	76	0
F9	23-May to 10-August	219	84	6
Total		941	359	47

Table 3.4: Total number of active and inactive fixes recorded during the day (0600 to 20:00) and at night (20:00 to 06:00) for all 6 females monitored in CRNWR, South Carolina, from March through August 2011.

	Duration	Active	Inactive
Light	06:00 to 20:00	185	364
Dark	20:00 to 06:00	174	218

Table 3.5: Percentage of time within a 24-hour cycle in which lactating & non-lactating females are expected to be active in CRNWR, South Carolina, March-August 2011. Data were combined to estimate an average percentage of active time for all monitored females.

Time Block	Lactating Female		Non-Lactating Female		All Female Activity		
	Active	Inactive	Active	Inactive	Active	Inactive	% Active
0	13	16	7	3	20	19	51.3
1	10	19	7	3	17	22	43.6
2	9	21	4	4	13	25	34.2
3	9	20	6	6	15	26	36.6
4	13	17	6	5	19	22	46.3
5	6	24	7	5	13	29	31.0
6	13	16	5	8	18	24	42.9
7	17	13	10	5	27	18	60.0
8	10	17	2	11	12	28	30.0
9	13	14	4	9	17	23	42.5
10	9	17	2	10	11	27	28.9
11	8	18	2	12	10	30	25.0
12	4	23	3	11	7	34	17.1
13	9	18	3	8	12	26	31.6
14	5	22	5	6	10	28	26.3
15	6	21	2	9	8	30	21.1
16	5	22	2	9	7	31	18.4
17	11	16	6	5	17	21	44.7
18	13	14	5	6	18	20	47.4
19	9	18	6	4	15	22	40.5
20	9	18	5	4	14	22	38.9
21	13	14	6	5	19	19	50.0
22	16	11	8	4	24	15	61.5
23	13	16	3	5	16	21	43.2
Avg % Active per 24 hr	36.3		43.3				38.4

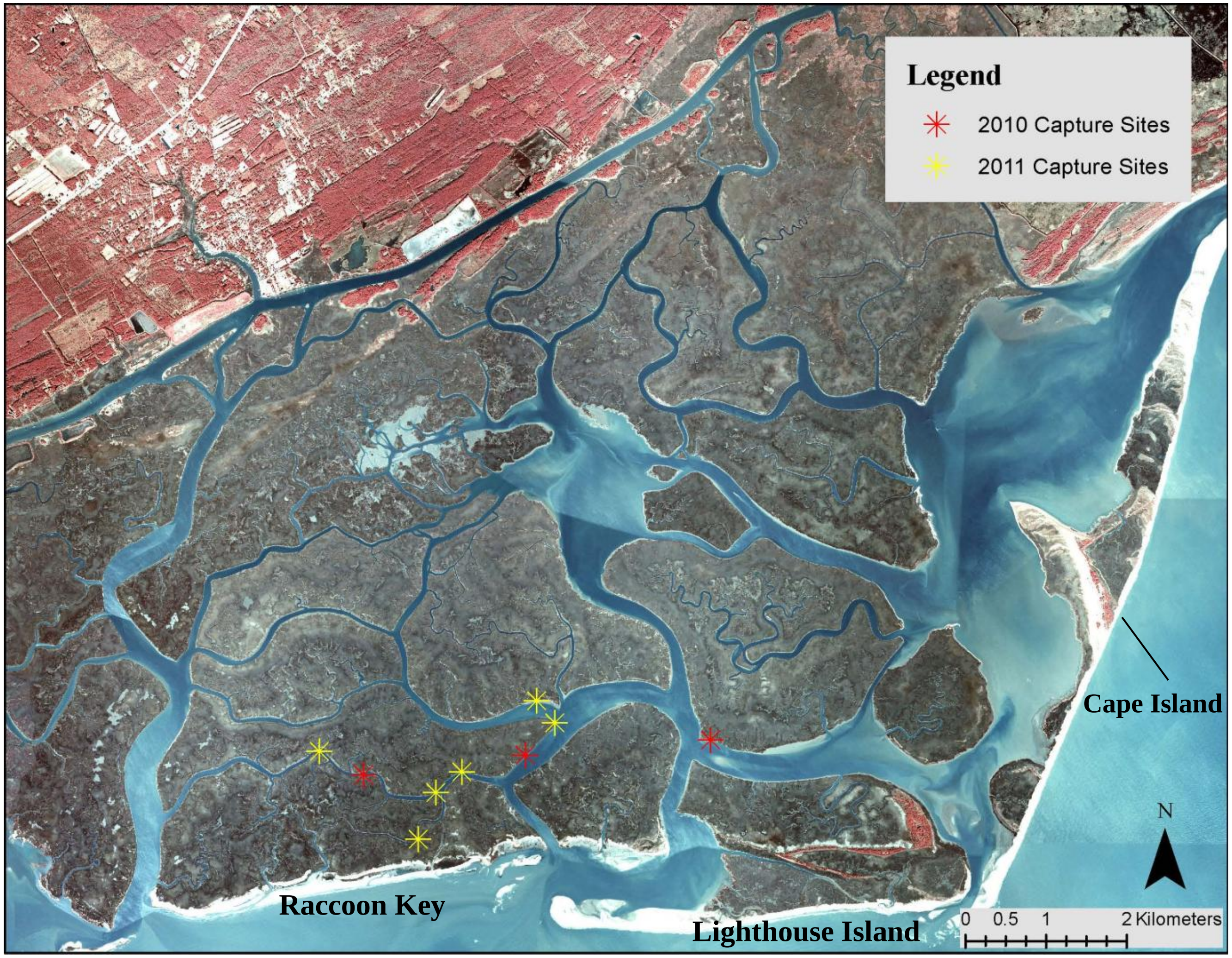

Figure 3.1: Capture locations of 9 mink (2 juvenile males, 7 adult females) in the northern marshes of CRNWR, South Carolina, in May 2010 and from April to May, 2011.

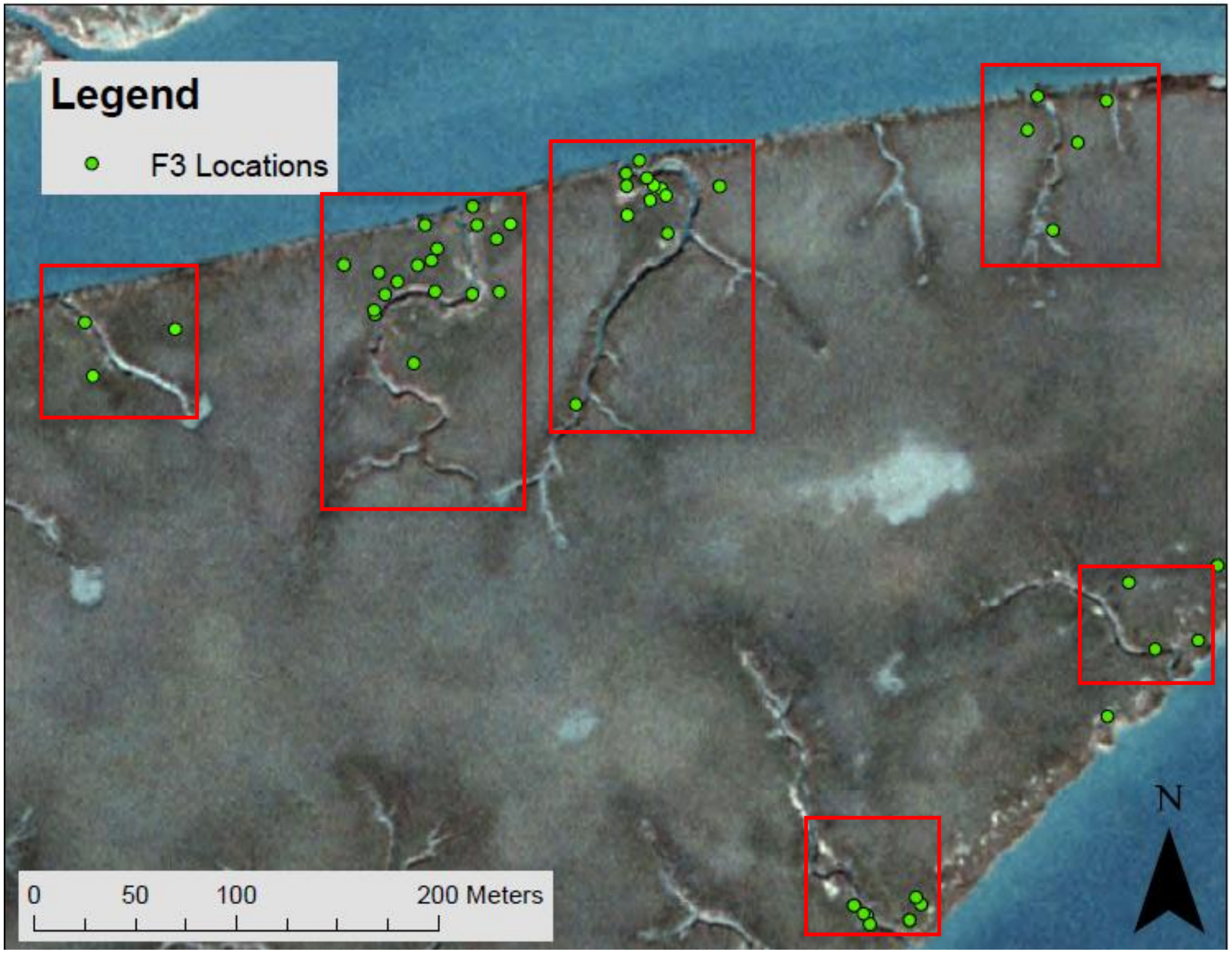

Figure 3.2: Use of small drainage creeks (enclosed in red boxes) by lactating female mink, F3, in CRNWR, South Carolina, June-August 2010 locations.

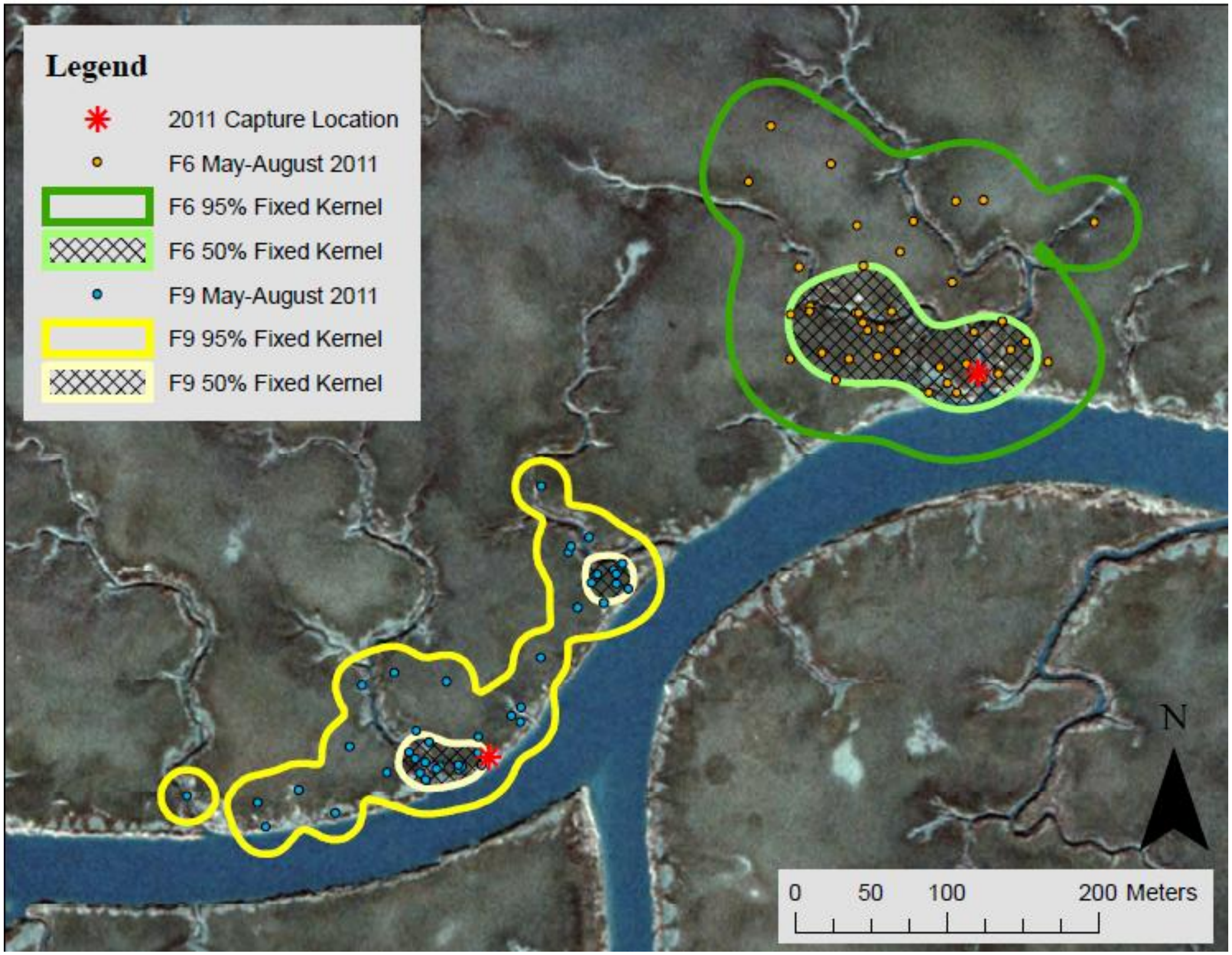

Figure 3.3: Home range, core area, and estimated monthly locations of mink F6 and F9 in CRNWR, South Carolina, May-August 2011. Note the total lack of home range overlap.

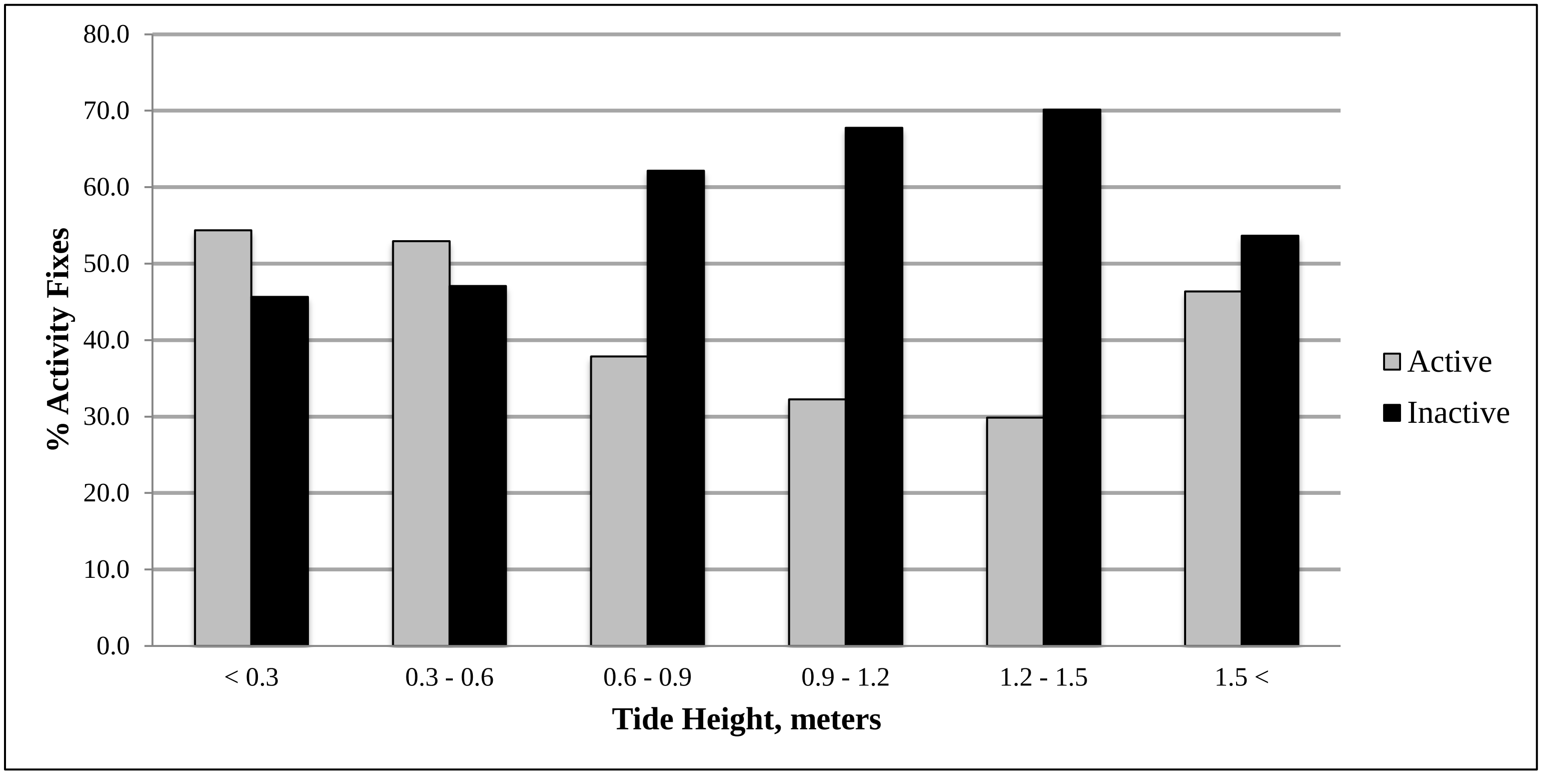

Figure 3.4: Percentage of all active and inactive fixes on 6 female mink at various tide heights (m) in CRNWR, South Carolina, March to August, 2011.

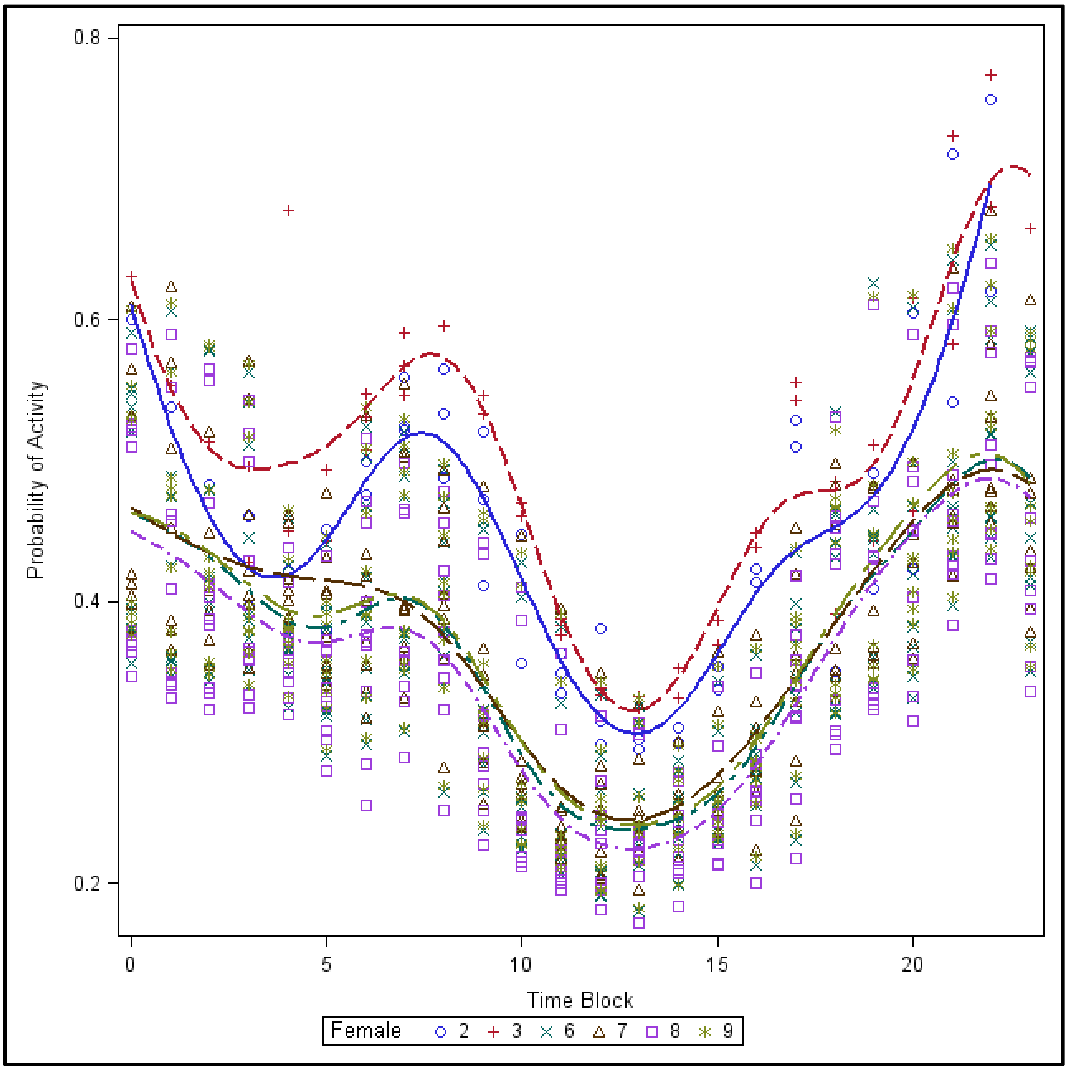

Figure 3.5: Range of activity within a time block for each monitored female mink in CRNWR, South Carolina, March-August 2011. Mink F2 and F3 (royal blue and red) were monitored between March and April 2011 during the end of the mink breeding season.

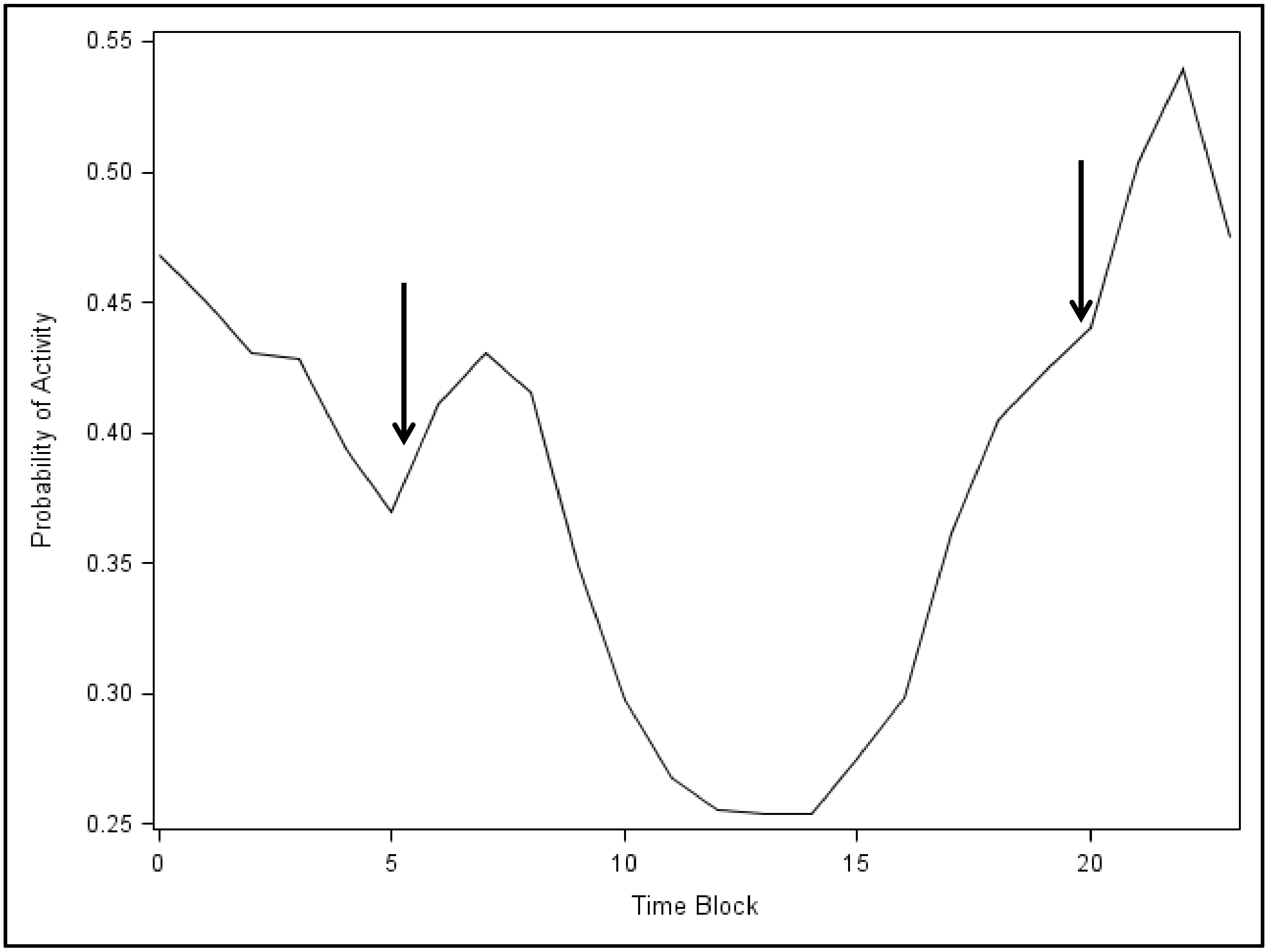

Figure 3.6: Average predicted activity within each time block for female mink during spring and summer in Cape Romain National Wildlife Refuge, South Carolina, March-August, 2011. Arrows indicate approximate sunrise and sunset throughout the study.

CHAPTER FOUR

SUMMARY & CONCLUSIONS

Ecology and management techniques of the American mink are well documented in the literature (Dunstone 1993, Harrington et al. 2009, Larivière 2003). Most of this research, however, has occurred in Europe and South America where mink are an invasive species, and the management and research goals revolve around mink impact on native species and/or mink removal from the system (Bartoszewicz and Zalewski 2003, Ferreras and MacDonald 1999, Salo et al. 2008). In South Carolina, mink are considered to be in decline statewide and have been designated a species of high conservation priority by South Carolina's Department of Natural Resources (SCDNR) (Kohlsaat et al. 2005). Unlike populations studied abroad, South Carolina's coastal mink populations inhabit tidal saltwater marshes. Since reestablishing a successful mink population in Cape Romain National Wildlife Refuge (CRNWR), research regarding effective trapping techniques, surveying methods, and basic ecology have occurred (Butfilsoki and Baker 2005, Osowski et al. 1995, Peeples 2001). This study measured home range and activity pattern of lactating females in the refuge. It was found that mink activity was negatively related to tide height. A diet analysis of mink stomach and gastrointestinal tracts showed mink diet to be predominately fish and crustacean in CRNWR.

As the mink population established itself in the refuge, reports of mink-specific predation on species of concern (i.e., black skimmer, least tern, American oystercatcher, and loggerhead sea turtle) to U.S. Fish and Wildlife Service (USFWS) at CRNWR have increased. Consequently, USFWS has proposed the removal of all mink from the refuge.

Predation by mink and other species (e.g., ghost crab, black vulture, raccoon, and great horned owl) as well as overwash and beach erosion have been observed to contribute to lost avian productivity (i.e., American oystercatcher, least tern, black skimmer) either through nest loss or chick loss in CRNWR (Thibault 2008, Brooks 2011, Godsea et al. 2010); however, it is unclear to what extent any of these factors contribute individually or collectively to beach nesting bird or loggerhead sea turtle losses. Further research is necessary to document and understand causes of specific and significant losses to help guide sound management decisions.

If the goal of the refuge is to reduce avian nest and chick loss, particularly for species of special concern, USFWS trapping data (this study; Dawsey 2007, 2009) and the estimates of the bioenergetics model suggest culling of mammalian predators within and adjacent to avian nesting sites on Cape Island, Lighthouse Island, and Raccoon Key may be important. Based on mink movements reported in this study and in the literature, it is suggested that mink removal from barrier islands should take place between January and March (i.e., mink breeding season) when mink are most active. The bioenergetics model presented in this study provides preliminary estimates of monthly consumption rates of mink in CRNWR. However, further research, especially regarding diets of mink in the refuge, is highly recommended to refine estimates of mink prey consumption and provide a more accurate description of potential mink impact on other species.

Since mink, American oystercatcher, least tern, and black skimmer have high conservation value in South Carolina, further monitoring and research of the interaction of these species is necessary to restore the historical ecological integrity of the system. If the goal of SCDNR's Furbearer Project is to continue mink reintroduction efforts in other areas along the northern coast of the state, then it is recommended that the CRNWR population be used as the source population for such efforts. This would reduce the number of mink within the refuge (i.e., reduce predation on species of concern in CRNWR), as well as provide for further research opportunities on mink ecology in South Carolina's coastal marshes (i.e., a goal of SCDNR's Furbearer Project). A joint mink culling-relocation program between SCDNR and USFWS at CRNWR could benefit both mink and beach-nesting bird conservation.

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APPENDICES

Appendix A

Bioenergetics model SAS program code for the estimation of fish, crustacean, and avian consumption of a male mink in Cape Romain National Wildlife Refuge, South Carolina

```
data male;
fishpc=.407;
crupc=.519;
avipc=.074;
do rep=1 to 300000;

   wt = ((1304-822)*rantri(234,.5) + 822);
   fmr = (2.23*(wt)**.85)*30;

   fishwt = (125-30)*rantri(345,.5) +30;
   fishcv = fishwt*5.02;
   fishae = ((85-72)*rantri(567,.5) + 72)/100;
   fishen = fishcv*fishae;

   cruwt = (85-5)*rantri(345,.5) +5;
   crucv = cruwt*3.0;
   cruae = ((85-72)*rantri(567,.5) + 72)/100;
   cruen = crucv*cruae;

   aviwt = (50-8)*rantri(345,.5) +8;
   avicv = cruwt*8.0;
   aviae = ((85-72)*rantri(567,.5) + 72)/100;
   avien = avicv*aviae;

   fmrfish=fmr*fishpc;
   fmrcru=fmr*crupc;
   fmravi=fmr*avipc;

   fish=fmrfish/fishen;
   cru=fmrcru/cruen;
   avi=fmravi/avien;

output;
end;

proc univariate plot;
var fish cru avi;
run;
quit;
```

Appendix B

Histograms generated from 300,000 iterations of each bioenergetics model showing the distribution of the outcomes using the male model (crustacean, fish, and avian), female model (avian only), and lactating female (avian only).

Figure B-1: Male Bioenergetics Model Output for Crustacean Consumption

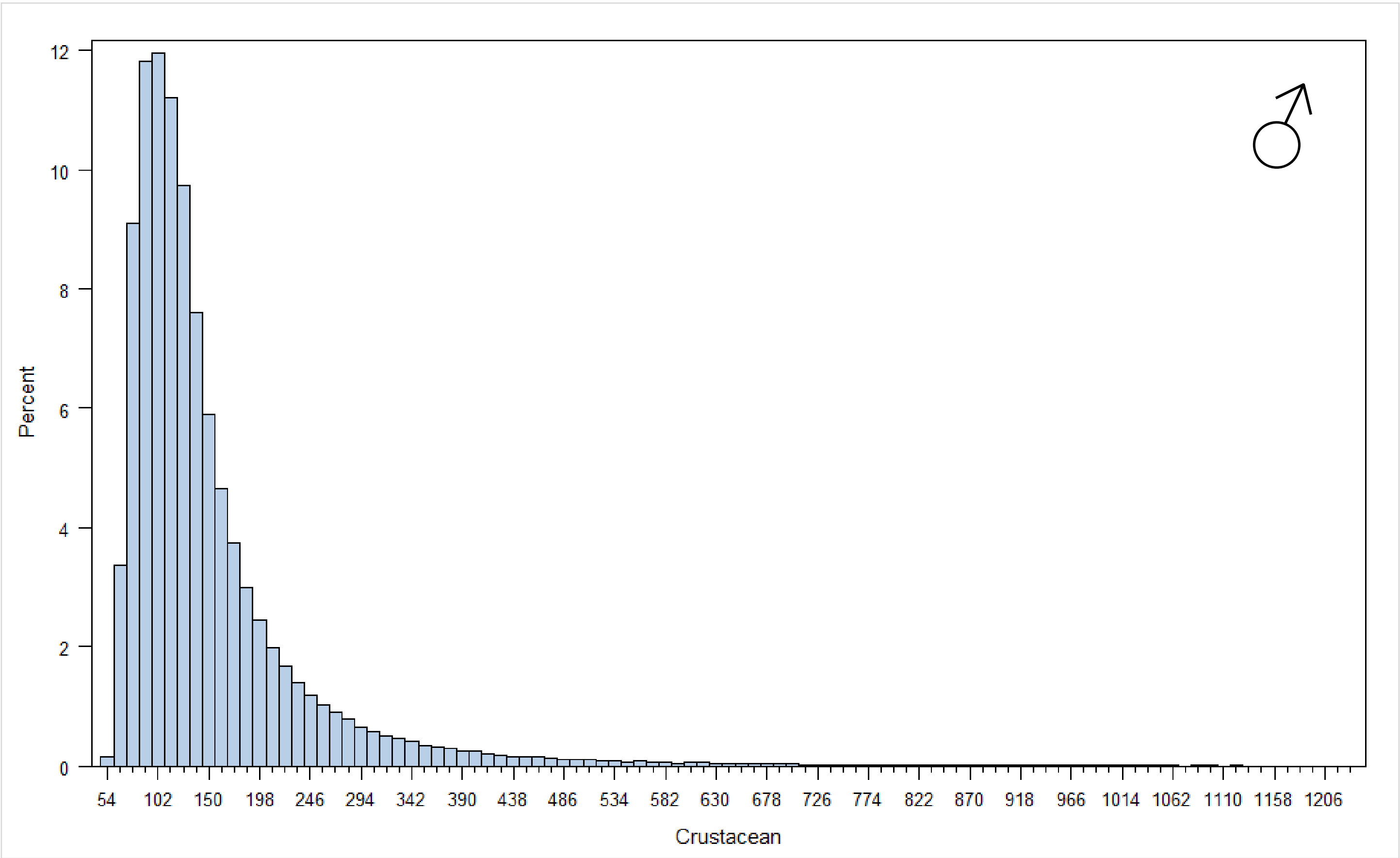


Figure B-2: Male Bioenergetics Model Output for Fish Consumption

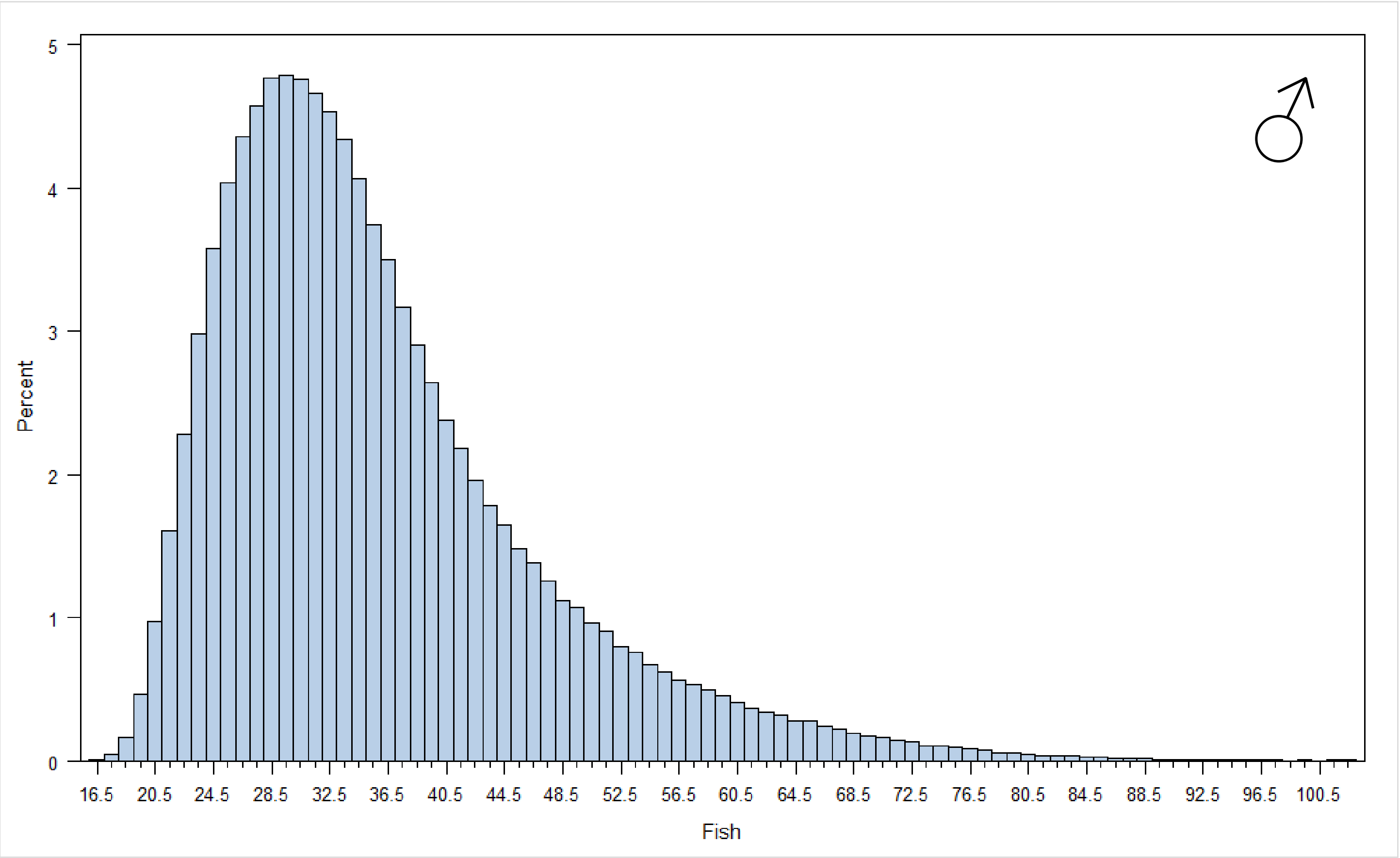


Figure B-3: Male Bioenergetics Model Output for Avian Consumption

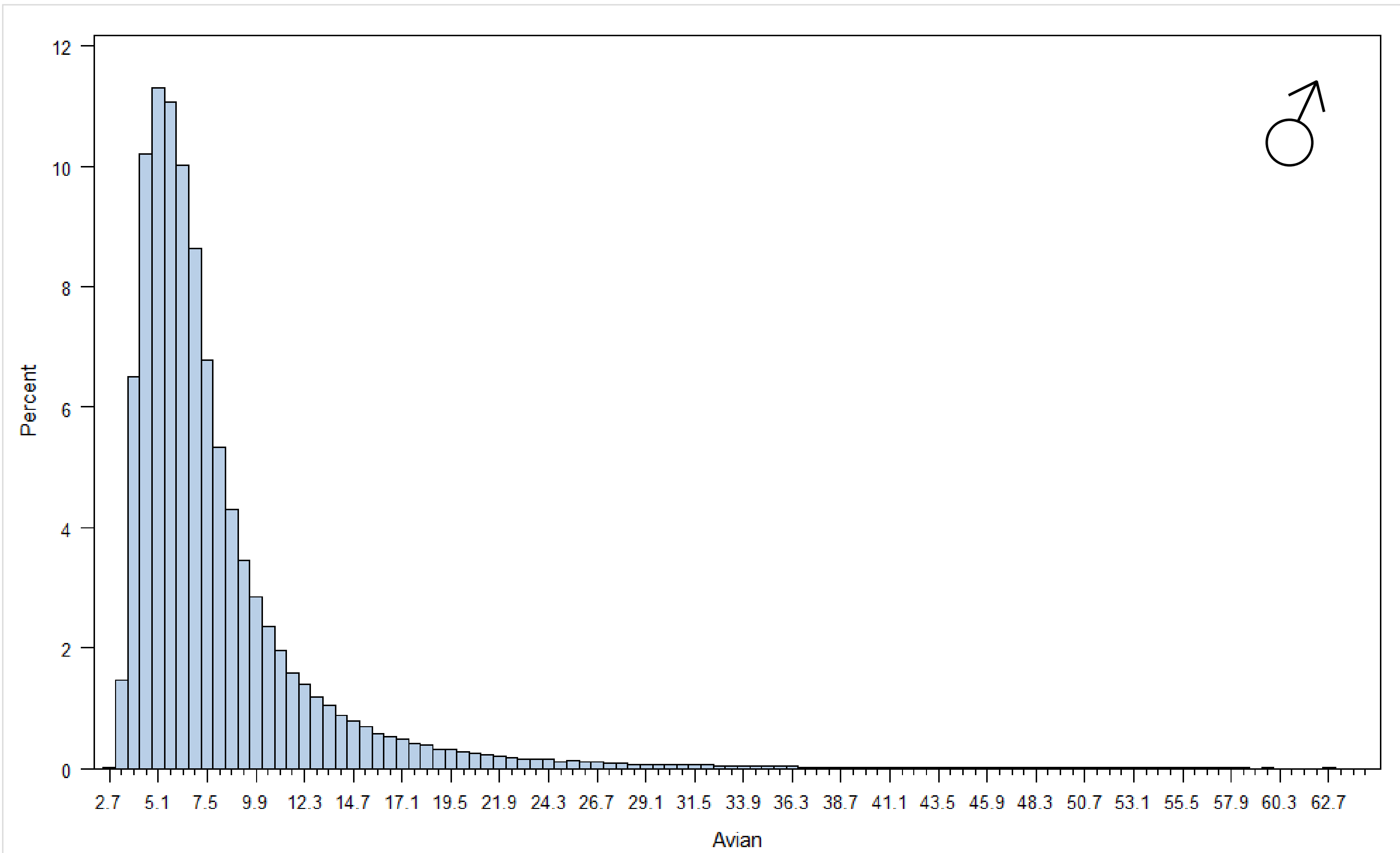


Figure B-4: Female Bioenergetics Model Output for Avian Consumption

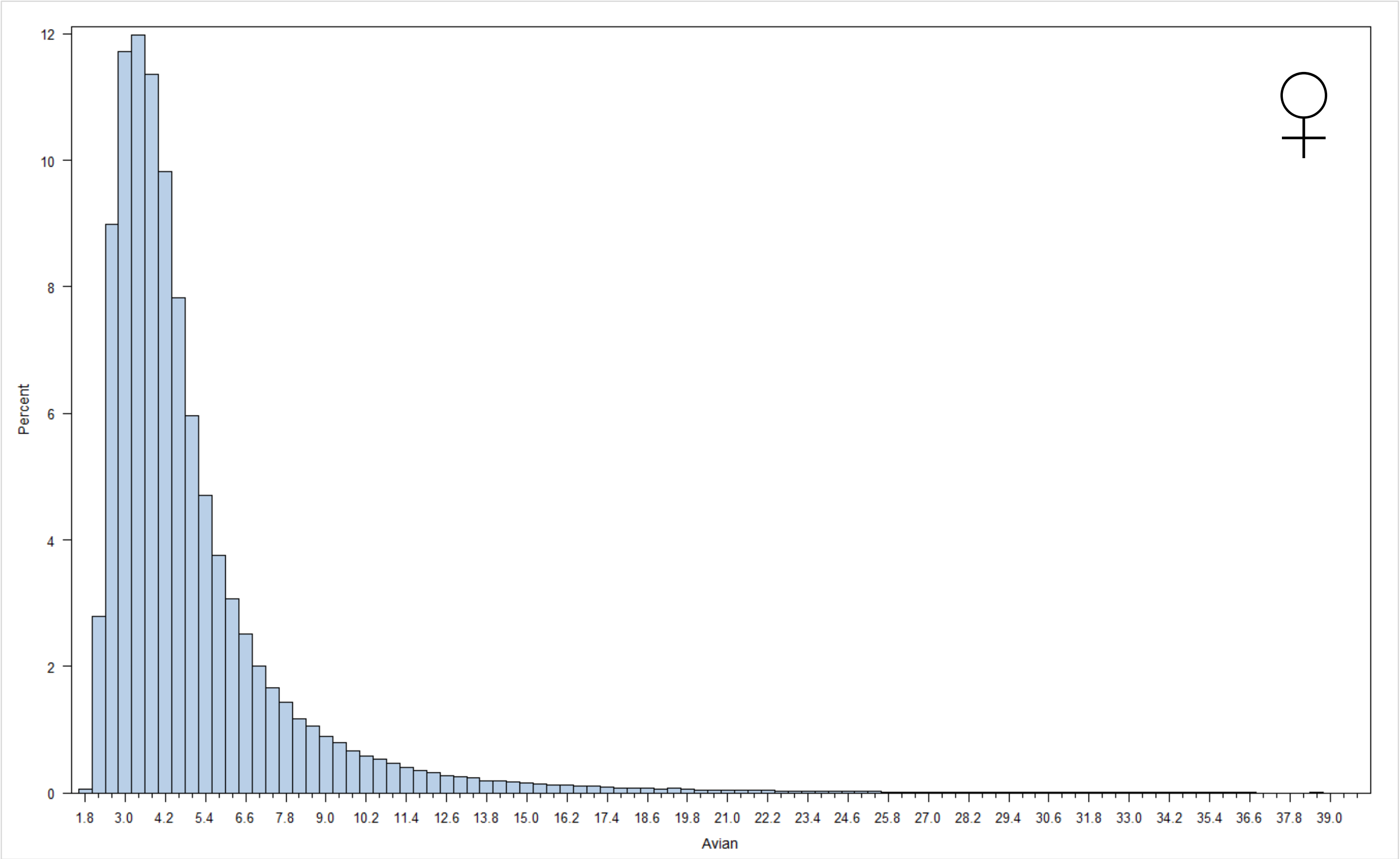
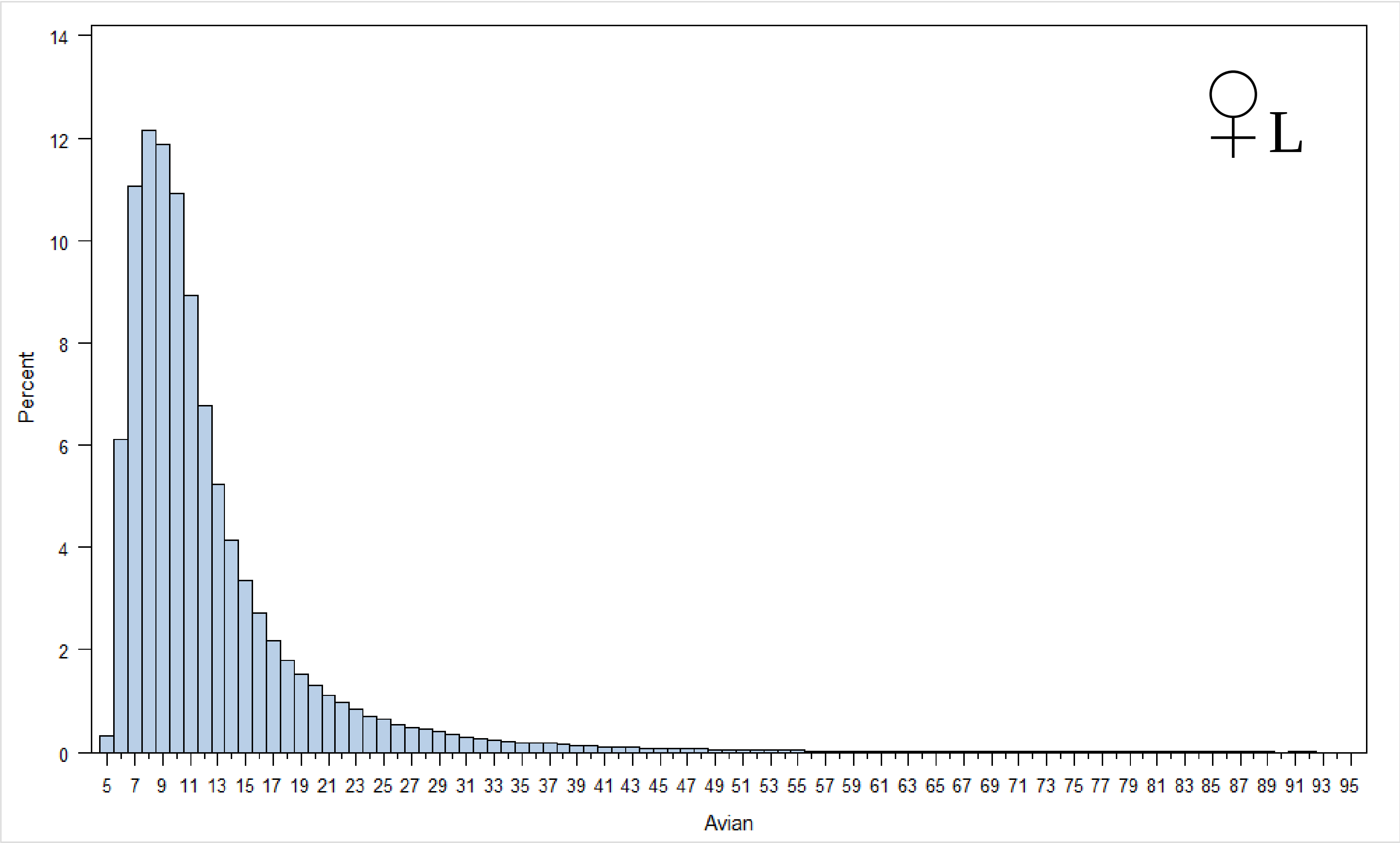


Figure B-5: Lactating Female Bioenergetics Model Output for Avian Consumption



Appendix C

95% Fixed Kernel Home Ranges and 50% Core Use Areas (50% Kernel) for 7 radio-monitored female American mink in Cape Romain National Wildlife Refuge, South Carolina

Figure C-1: 95% Kernel & Core Area for Female Mink 1, F1 (2010)

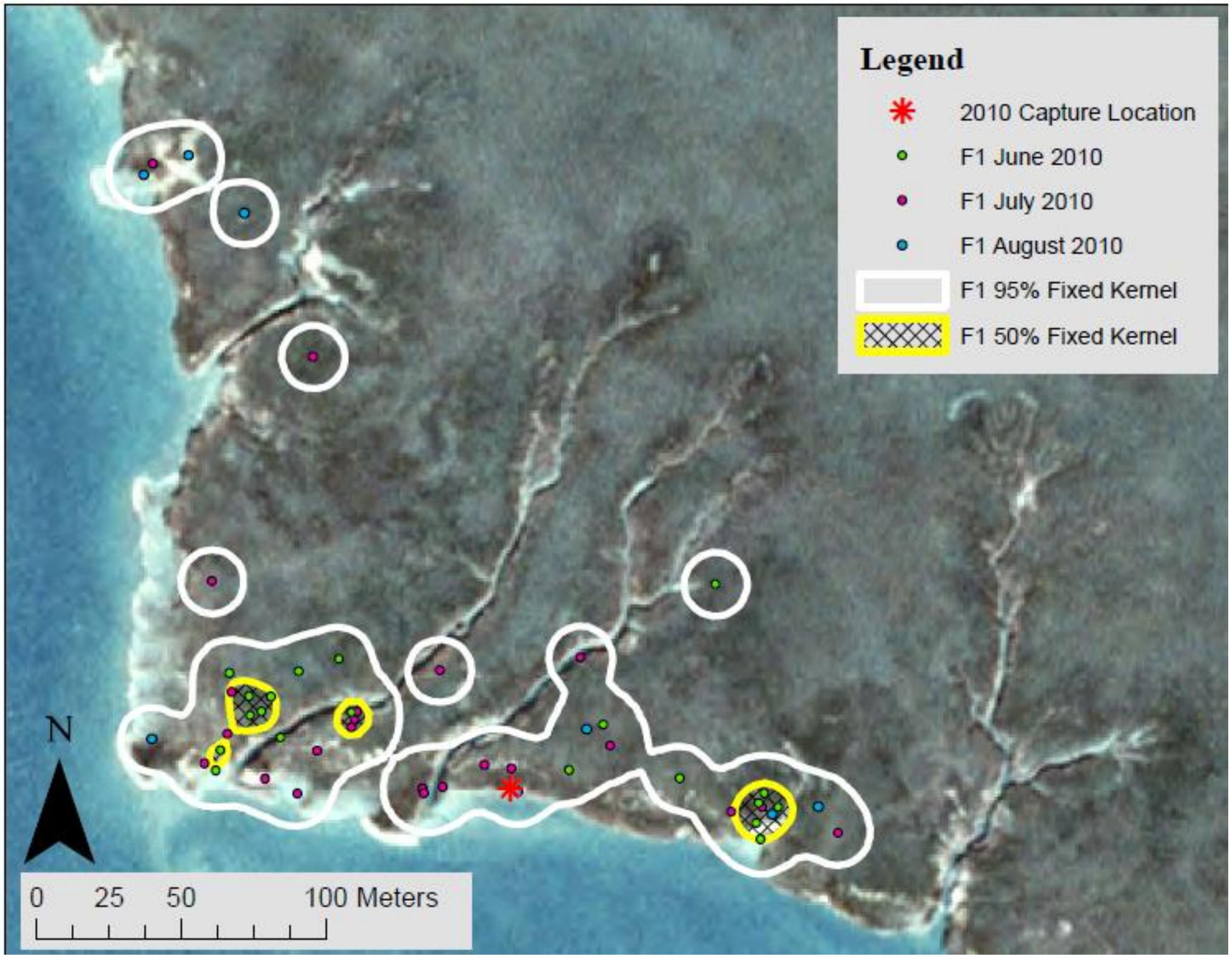


Figure C-2: 95% Kernel & Core Area for Female Mink 2, F2 (2010, 2011)

Figure C-3: 95% Kernel & Core Area for Female Mink 3, F3 (2010, 2011)

Figure C-4: 95% Kernel & Core Area for Female Mink 6, F6 (2011)

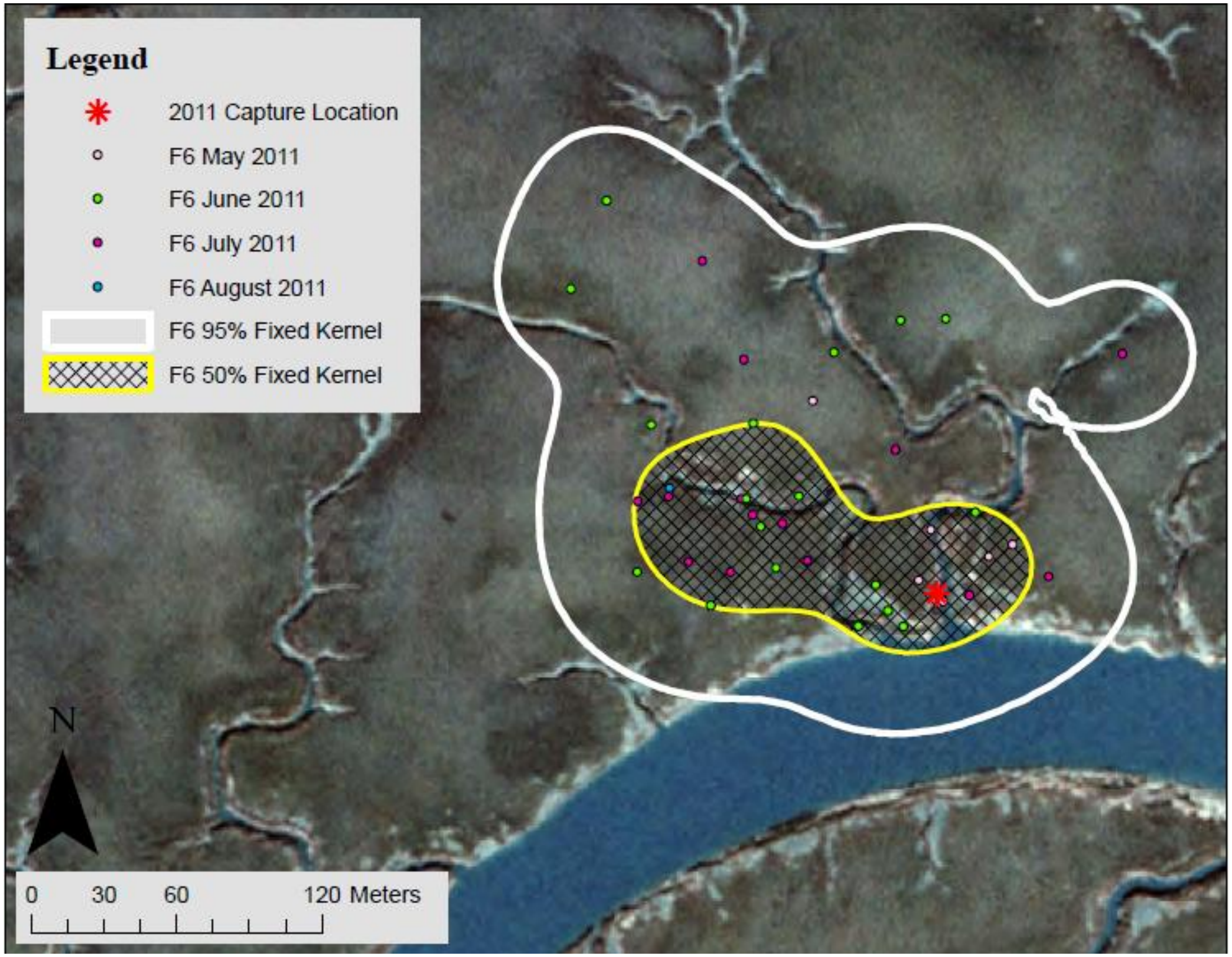


Figure C-5: 95% Kernel & Core Area for Female Mink 7, F7 (2011)

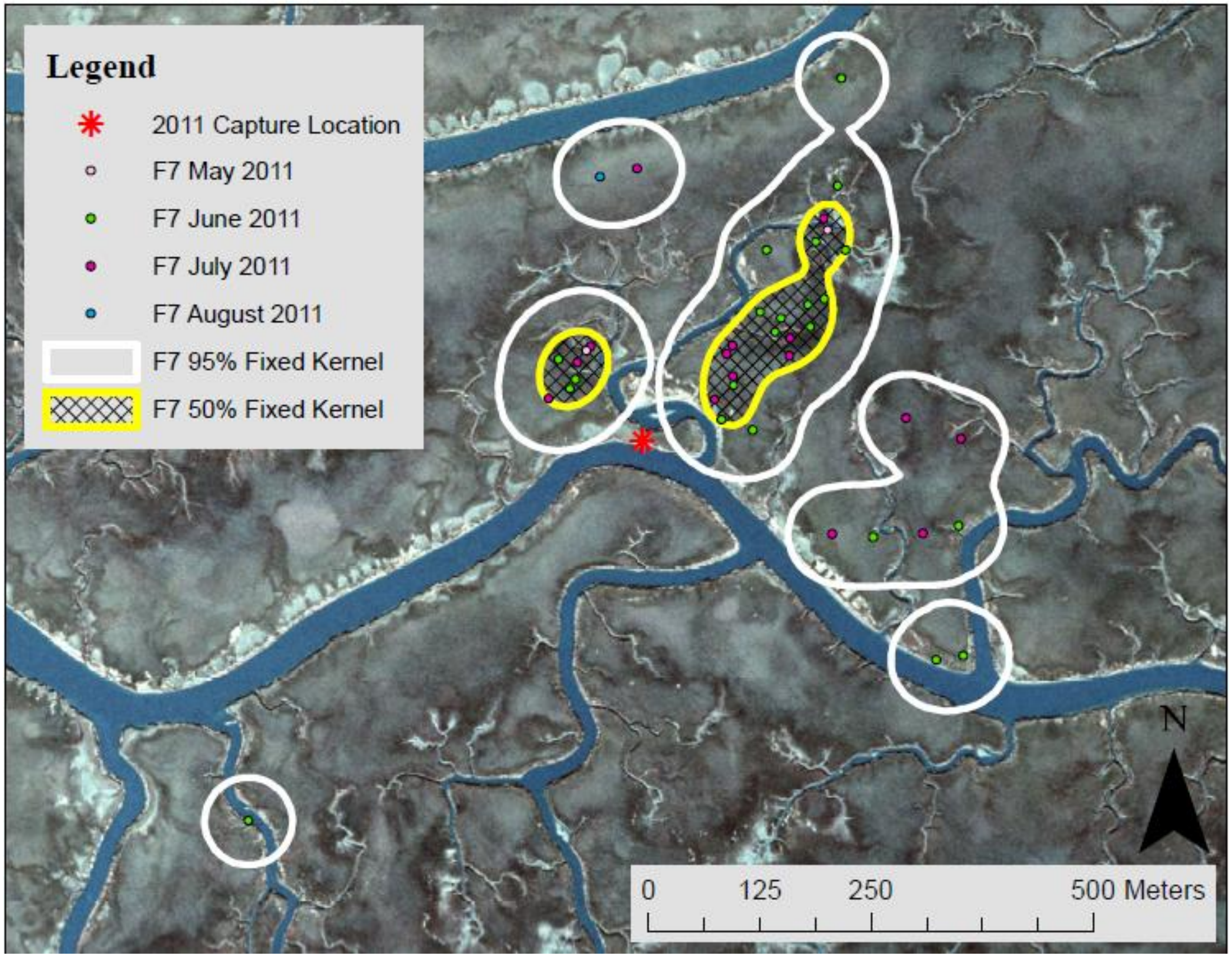


Figure C-6: 95% Kernel & Core Area for Female Mink 8, F8 (2011)

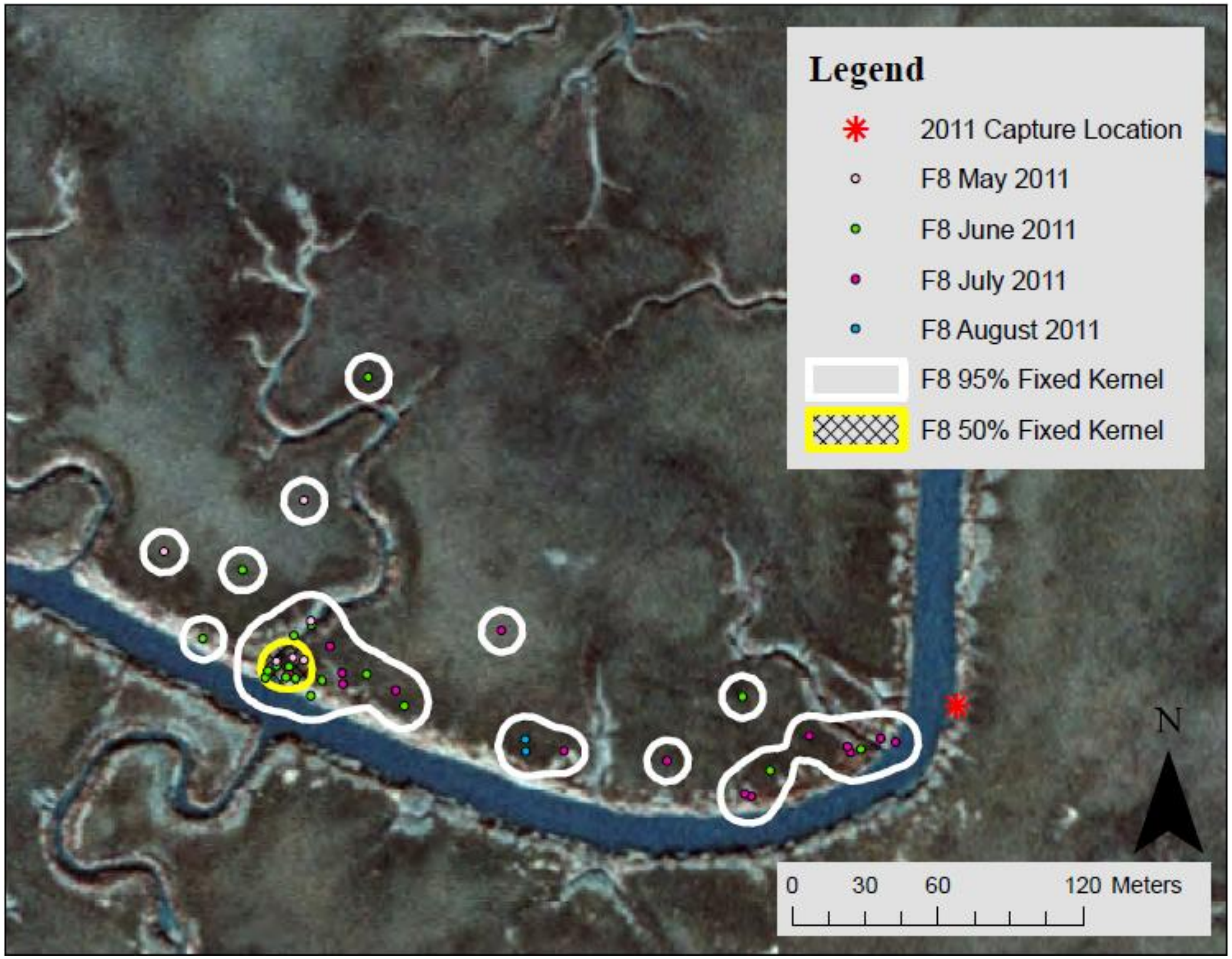


Figure C-7: 95% Kernel & Core Area for Female Mink 9, F9 (2011)