Impact of Raccoons on Breeding Success in Large Colonies of Great Black-backed Gulls and Herring Gulls

JULIE C. ELLIS[1,6], MYRA J. SHULMAN[2], HOLLY JESSOP[3], REBECCA SUOMALA[4], SARA R. MORRIS[5], VIRGINIA SENG[1], MAUREEN WAGNER[1] AND KATHARINE MACH[1]

[1]Shoals Marine Laboratory, Cornell University, Ithaca, NY 14853, USA

[2]Department of Ecology and Evolutionary Biology, Cornell University, Ithaca, NY 14853, USA

[3]Tropical Conservation Biology and Environmental Science, University of Hawai`i at Hilo, Hilo, HI 96720, USA

[4]New Hampshire Audubon Society, Concord, NH 03301, USA

[5]Department of Biology, Canisius College, Buffalo, NY 14208, USA

[6]Internet: julie.ellis@tufts.edu

Abstract.—For most ground-nesting seabirds, offshore islands usually serve as refuges from mammalian predators, however, introduced predators pose a substantial threat to many species. In New England, thousands of Herring Gulls (*Larus argentatus*) and Great Black-backed Gulls (*L. marinus*) breed on hundreds of coastal islands. The Isles of Shoals (New Hampshire/Maine) archipelago has some of the largest colonies of both gull species in New England. In 2004, we noted unusually large numbers of failed nests on Appledore Island, Maine and hypothesized that Raccoons (*Procyon lotor*) were the cause. Therefore, we quantified egg and chick mortality and documented the presence of Raccoons. We trapped Raccoons on Appledore and Smuttynose islands and conducted nest surveys on these and two other islands in the Isles of Shoals. Surveys of marked nests on Appledore Island revealed high levels of egg and chick mortality in early June 2004; by late June 58% of nests were empty. We also found that on Appledore and Smuttynose, where Raccoons were observed, the odds that a nest would be empty were 17 times greater than on Lunging or Duck Islands where no Raccoons were observed. During 2004, eleven Raccoons were trapped off of Appledore and Smuttynose Islands. A survey of nests in 2005 showed that gull breeding success increased significantly on Appledore and Smuttynose islands, whereas there was no significant change in the relatively high ratio of chicks to nests from 2004 to 2005 on Lunging Island where Raccoons were not observed. Thus, we concluded that the presence of a few Raccoons on Appledore and Smuttynose islands was sufficient to cause substantial breeding failure in large colonies of larids. *Received 20 May 2006, accepted 25 November 2006.*

Key words.—seabird, nest success, predator, Raccoon, *Procyon lotor*, island, Gulf of Maine, New England, population decline, conservation.

Waterbirds 30(3): 375-383, 2007

Predation risk and mortality have been implicated as a major force driving the behavioral evolution of animals. These evolutionary adaptations may include antipredatory behaviors and predator avoidance (e.g., Kruuk 1964; Lima and Dill 1990). Predation risk varies in space and time, but many animals are most vulnerable to the threat of predation very early in life and/or during their reproductive season. For ground-nesting seabirds, islands serve as refuges or "enemy-free sites" from natural mammalian predators (Ahlén and Andersson 1970). However, many bird species breeding on islands are currently threatened by introduced predators such as rodents, mustelids, foxes, pigs, and dogs (Burger and Gochfeld 1994; Atkinson 1996; Dickman 1996; Short *et al.* 2002). Predation has caused the extinction of at least one seabird species within the past century (Guadalupe Storm Petrel, *Oceanodroma macrodactyla*), and has resulted in the reduction or local extirpation of many other seabirds worldwide (Moors and Atkinson 1984; Blackburn *et al.* 2004). Despite knowledge of the effects of introduced predators, relatively few studies have attempted to directly quantify seabird losses while such losses are occurring (Hartman *et al.* 1997).

Several factors influence the severity of mammalian predation on seabirds including the relative sizes of predators and seabirds, location and phenology of seabird breeding, and the magnitude and type of anti-predator behaviors. In general, the larger the predator, the larger the seabird it can attack (Crox-

all *et al.* 1984). Thus, small seabirds are at greater risk from a wider variety of mammalian predators than are large seabirds (Wilson 1975; Martin *et al.* 2000; Nordstrom *et al.* 2003). However, unprotected eggs and chicks of both small and large seabirds may be vulnerable to a wide range of predators (e.g., Cuthburt and Hilton 2004). Seabirds may lessen the risk of predation by nesting on inaccessible cliffs (Burger and Gochfeld 1994) or on isolated offshore islands (Hartman and Eastman 1998; Nordstrom and Korpimaki 2004) where terrestrial predators have limited access to colonies. Seabirds are at greater risk of predation when chick hatching coincides with reproduction of predators; earlier chick hatching can confer reduced risk (Nordstrom *et al.* 2003). Aggressive mobbing and attack behavior can deter mammalian predators (Burger and Gochfeld 1994). For instance, rats regularly prey on docile Laysan Albatross (*Phoebastria immutabilis*) adults and chicks, but rarely attack the aggressive Black-footed Albatross (*P. nigripes*) and then only its chicks (Kepler 1967; Woodward 1972). Several species of terns and gulls aggressively mob, "dive-bomb," and attack intruders in their colony, including humans, often succeeding in driving them away (e.g., Stenhouse *et al.* 2005). Thus, a seabird can reduce the risk of mammalian predation by being large, nesting on isolated islands, breeding early, and exhibiting aggressive anti-predator behaviors.

In New England, thousands of Herring Gulls (*Larus argentatus*) and Great Black-backed Gulls (*L. marinus*) currently breed on hundreds of islands. The Herring Gull is a medium-sized gull (800-980 g; Pierotti and Good 1994) and the Great Black-backed Gull is the largest gull in North America (1,300-2,000 g; Good 1998); both aggressively defend their nesting territories from predators and conspecifics. Extensive hunting during the 1800s severely reduced populations of both species. However, with legal protection from hunting in the early 1900s, the number of gulls increased dramatically. In the Isles of Shoals (New Hampshire/Maine), populations of Herring Gulls reached over 7,000 breeding pairs and Great Black-backed Gull numbered over 1,100 pairs by 1972 (Drury 1973; Borror and Holmes 1990). From 1975 through the mid-1990s the number of breeding Herring Gulls declined, while the number of breeding Great Black-backed Gulls steadily increased in the Gulf of Maine (Ellis and Good 2006). Smuttynose Island, Maine (in the Isles of Shoals), is one of the major breeding colonies of Great Black-backed Gulls in the U.S. (Good 1998).

In the Isles of Shoals, gulls have very few natural predators, and most mortality of adults and chicks results from attacks by conspecifics and congeners (McGill-Harelstad 1985; Ellis and Good 2006). However, during the spring of 2004, we noted unusually large numbers of failed nests on Appledore Island, Maine. We also found a female Raccoon (*Procyon lotor*) with kits on the island during early spring of the same year. Therefore we initiated a study to quantify egg and chick mortality while it was occurring, and to quantify the extent to which Raccoons could negatively affect breeding in sizeable colonies of large, aggressive gulls. Compared to other mammalian predators, there are few quantitative studies of the impact of Raccoons on seabird colonies (Burger and Gochfeld 1994). Kadlec (1971) described breeding failure caused by the presence of Raccoons (and foxes) in colonies of Herring and Great Black-backed Gulls, but these colonies were small compared to those in the Isles of Shoals. Other studies of Raccoon predation on seabirds have focused on small, burrow-nesting seabirds rather than large, ground-nesting species (Hartman *et al.* 1997; Hartman and Eastman 1998).

In this study we: 1) quantified egg and chick mortality at marked nests in 2004/2005 on Appledore Island, 2) compared ratios of chicks to nests in 2004/2005 on four breeding islands in the Isles of Shoals (Appledore, Smuttynose, Duck, and Lunging), 3) conducted multi-year nesting censuses on Appledore Island, and 4) initiated a Raccoon trapping program in 2004 on Appledore and Smuttynose Islands where Raccoons were suspected to occur. We then compared ratios of nests to chicks between the

years 2004 and 2005 to determine whether removal of Raccoons resulted in increased chick survival.

METHODS

Study Area

The Isles of Shoals (Fig. 1) is an archipelago of nine islands situated ten km off the coast of New Hampshire, USA (42°59'N, 70°37'W). The islands comprise a total of 122 ha, with the largest 38.4 ha in size; they are low and flat with a maximum elevation of 21 m. The shorelines are rocky, and interior areas are covered in low shrubs and grasses. Great Black-backed Gulls and Herring Gulls breed on all but two islands from which they are actively excluded. Human occupation in the archipelago consists of the Shoals Marine Laboratory and four private residences on Appledore Island, a small encampment at a historical site on Smuttynose Island, two private homes on Lunging Island, a large summer conference center on Star Island, a private residence on Cedar Island, and a few field biologists on White and Seavey Islands during the summer.

Herring and Great Black-backed Gulls nest in a variety of habitats in the Isles of Shoals: exposed inland ridges, cobble beaches, bare rock ledges on the island's periphery, around shrubs, and near buildings. Both species inhabit the islands from March through September; however Great Black-backed Gulls begin nesting approximately two weeks earlier than Herring Gulls and move to the mainland two-four weeks prior to Herring Gulls (McGill 1977; Ellis, pers. obs.).

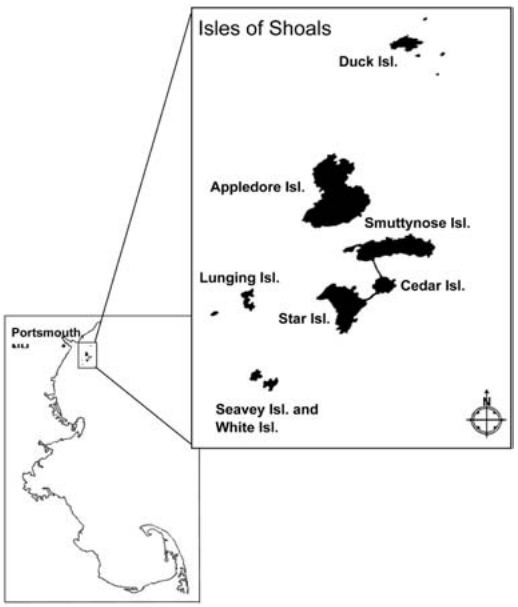

Figure 1. Map of study sites in the Isles of Shoals. Detailed investigations were conducted on four islands: Appledore, Duck, Lunging, and Smuttynose Islands. Raccoons were trapped on Appledore and Smuttynose Islands.

Breeding Success of Pairs at Marked Nests on Appledore Island, 2004/2005

In mid-May 2004, active nests on Appledore Island of 59 Great Black-backed and 28 Herring Gull pairs were marked with numbered stakes and the number of eggs were recorded. One adult from each pair was captured using a walk-in nest trap and fitted with a numbered leg band (United States Fish and Wildlife) and color bands.

At the beginning of June, a Raccoon was sighted on the northwest end of Appledore Island (see next section) and gulls in this area were observed frequently leaving their breeding territories and exhibiting defensive aerial behaviors. Therefore, from 2-4 June 2004 28 marked nests located in this region of the island were surveyed, quantifying the numbers of eggs and/or chicks and the presence and behavior of adult parents. Three weeks later, on 23-27 June 2004, a similar survey of 78 of the total 87 marked nests was conducted on Appledore Island. In 2005, additional nests were marked and more gulls banded. On 14-18 June, a total of 129 nests (both species) were surveyed for eggs and/or chicks. Nominal logistic regression was used to compare the distribution of marked nests with and without chicks in June 2004 and 2005.

Breeding Success Throughout the Isles of Shoals in 2004 and 2005

The June surveys on Appledore Island revealed unusually high rates of breeding failure (see Results). To determine whether this was due to the presence of one or more Raccoons on Appledore, comparative censuses were conducted on four of the breeding islands (Appledore, Smuttynose, Duck, and Lunging) from 9-12 July 2004. During each survey, six to 16 observers walked systematically through the colony for 0.5-1.5 hours and recorded empty nests, nests with eggs, and the number of chicks. Observers thoroughly searched for dead adults and chicks. The data were combined for both Herring and Great Black-backed Gulls because empty nests, eggs, and/or chicks could not always be reliably identified to species.

On Appledore Island, the ~1,200 m long eastern coast was surveyed, including both the rocky ledges and the adjacent vegetated areas to a distance of ~50 m from water. A separate one hectare nesting area in a flat, vegetated portion of the island was also surveyed. On Smuttynose Island, the survey included nearly the entire 1,800-m shoreline, a 600 × 10 m transect along an east-west trail that bisects the island, and a 0.2 ha flat, grassy area near the eastern end. On Duck Island, 200 × 25 m of shoreline was surveyed on the south side; the census was restricted to the rocky perimeter to avoid disturbing the large colony of breeding Double-crested Cormorants (*Phalacrocorax auritus*) in the central part of this uninhabited island. On Lunging Island, 100 × 25 m of the northwestern shoreline was surveyed; due to the presence of breeding cormorants, other portions of this island were not surveyed.

These surveys were repeated the following year on 13-16 July 2005. On Appledore and Smuttynose, the large areas that had been surveyed in 2004 were subsampled. On Lunging, the 2005 survey included about twice the length of rocky shore than was surveyed in 2004.

Nominal logistic regression was used to determine whether the probability of a nest being empty in 2004

was a function of island and the presence of Raccoons. In this analysis, islands were nested within Raccoon presence (Appledore, Smuttynose) or absence (Duck, Lunging). The same analytical approach was used to examine the distribution of nests with and without eggs. Another logistic regression was performed to determine whether the probability of a nest being empty was a function of year (2004 vs. 2005) and/or island.

Multi-Year Censuses of a Gull Sub-colony on Appledore Island

Herring and Great Black-backed gull nests were censused during the years 1998-2003 and 2005 along the northeast coast of Appledore Island (Fig. 1). Observers walked between the shrubs and the water and counted the number of Herring and Great Black-backed gull nests detected. The species associated with each nest was easily determined by observing adults that remained on nests or by watching to see which species returned as the observers moved a few meters away. S. R. Morris was one of the observers in each of these years to ensure comparative results across years.

Sightings of Raccoons and Trapping Efforts

Raccoons (an adult with two kits) were first sighted on Appledore Island in mid-May 2004 and a trapping program was initiated on 28 June 2004 and continued through the end of September 2005. The mid-July gull surveys revealed total breeding failure on Smuttynose as well as Appledore Island, with contrasting high success on Lunging and Duck Islands (see Results). Suspecting the presence of Raccoons, scat was found and a trapping program on Smuttynose Island was started on 9 August, which was continued through September, 2004. All Raccoons caught in traps were removed from the Isles of Shoals.

RESULTS

Breeding Success of Pairs at Marked Nests on Appledore Island, 2004/2005

The 2-4 2004 June survey of marked nests in the region where a Raccoon had been sighted and gull defensive behaviors were observed showed a high level of egg and chick mortality. Of 28 formerly active nests, 13 (46%) no longer contained either eggs or chicks. Adults were still present at eleven of the 13 (85%) failed nests.

During June 2004, the complete survey of all 78 marked nests revealed that 58% were empty, many with broken eggshells in or near the nest. Of these failed nests, 31% still had adults present. Chicks were present in 27% of nests and eggs in 15%. The mean number of chicks per nest was 0.46 for all nests and 1.7 for nests with at least one chick.

The June survey in 2005 showed that 24% of nests were empty; chicks were present in 66% of nests and eggs in 23%. The mean number of chicks per nest was 1.2 for all nests and 1.8 for nests with at least one chick. Data analysis revealed that the odds a marked nest would have no chicks by mid- to late June was 4.9× higher in 2004 than in 2005 (likelihood ratio test: $P < 0.001$).

Breeding Success Throughout the Isles of Shoals in 2004 and 2005

The multi-island surveys in mid-July 2004 of nests and chicks revealed strongly contrasting patterns of low chick survivorship on Appledore and Smuttynose versus high survivorship on Lunging and Duck (Table 1; Fig. 2). No live chicks were found on Smuttynose in 2004 despite the large survey area on that island and only twelve were seen along the eastern coastline of Appledore. The percent of nests with eggs was 9% for both Appledore and Smuttynose. During surveys of nesting colonies on both of these islands, adult gulls were present in large numbers and readily lifted off upon our approach; however, very few gulls exhibited aggressive behaviors associated with nest territory and/or chick defense, although many pairs remained near empty nests. No remains of dead adults or chicks were discovered on Appledore. On Smuttynose, one dead chick was recovered and only a few dead adult remains were observed, all in advanced stages of decomposition. In contrast, on Duck and Lunging Islands in 2004, gull breeding success measured as the ratio of chicks to nests was significantly higher ($\chi^2_3 = 406$, $P < 0.0001$; Fig. 2) as was the percent of nests with eggs ($\chi^2_3 = 28$, $P < 0.0001$; Fig. 2). Upon approach, adult gulls actively and persistently engaged in aggressive nest and/or chick defense behavior. No remains of dead adults or chicks were found on Lunging, but two dead chicks were recovered from Duck Island.

Data analysis revealed that on Appledore and Smuttynose, the islands where Raccoons were observed (see below), the odds that a nest would be empty was 17 times higher than for a nest on Lunging or Duck in 2004 (likeli-

Table 1. Surveys made of gull nests and chicks on four islands in the Isles of Shoals on 9-12 July 2004 and on 13-16 July 2005.

Date of surveys	Island	Approximate area surveyed (hectares)	Approximate % of island surveyed	Total nests found	Number (%) empty nests	Number (%) of nests with eggs	Number (%) of nests with chicks	Total chicks
9-12 July 2004								
	Appledore	4	12	542	482 (89)	49 (9)	11 (2)	12
	Smuttynose	10	65	412	376 (91)	36 (9)	0 (0)	0
	Lunging	0.25	10	47	21 (45)	8 (17)	18 (38)	30
	Duck	0.5	33	98	25 (26)	25 (26)	48 (49)	83
13-16 July 2005								
	Appledore	2	6	216	70 (32)	16 (7)	133 (62)	208
	Smuttynose	3	22	146	46 (31)	6 (4)	94 (64)	133
	Lunging	1.5	60	74	45 (61)	4 (5)	26 (35)	43

hood ratio test: $P < 0.001$). A nest on Lunging was 2.4 times more likely to be empty than a nest on Duck Island (likelihood ratio test: $P = 0.022$). The odds that a nest would contain eggs was 2.7 times higher on Duck and Lunging than on Appledore and Smuttynose Islands (likelihood ratio test: $P < 0.001$).

In 2005, surveys showed that gull breeding success had increased to a large and significant extent on the two islands from which Raccoons had been removed (likelihood ratio tests: both $P < 0.0001$). The odds of a nest being empty in 2004 compared to 2005 were 16.8 times higher for Appledore and 22.7 times higher for Smuttynose. In contrast, on Lunging Island, where Raccoons were not present, there was no significant change in the frequency of empty nests from 2004 to 2005 ($P = 0.082$). Additionally, the ratio of chicks to nests (Fig. 2) had increased significantly between years on both Appledore and Smuttynose, but did not change significantly on Lunging (Appledore: $\chi^2_1 = 303$, $P < 0.0001$; Smuttynose: $\chi^2_1 = 243$, $P < 0.0001$; Lunging: $\chi^2_1 = 0.1$, n.s.). The chances of finding nests with eggs did not differ between the islands in 2005 (likelihood ratio test: n.s.).

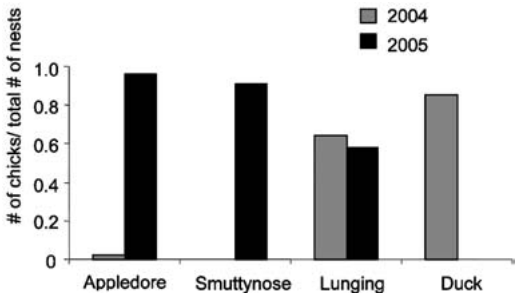

Figure 2. Ratio of the total number of gull (both Great Black-backed and Herring gull) chicks to the total number of nests on each of four islands Appledore, Duck, Lunging, and Smuttynose in 2004 and three islands (Appledore, Lunging, and Smuttynose Islands) in 2005.

Multi-Year Censuses of a Gull Sub-colony on Appledore Island

During the years 1998-2003, gull abundances were relatively constant (Fig. 3) with a mean of 382 ± 36 Herring Gull and 147 ± 8 Great Black-backed Gull nests in the census area. Gulls dropped dramatically in 2005, with declines in nest abundance of 55% for Herring Gulls and 43% for Great Black-backed Gulls.

Sightings of Raccoons and Trapping Efforts

Eight Raccoons (two kits, six adults) were captured on Appledore and three (adults) on Smuttynose Islands between June and August, 2004. No Raccoons were observed or captured in the Isles of Shoals during the spring or summer 2005.

DISCUSSION

Catastrophic breeding failure occurred in the gull colonies on Appledore and Smuttynose Islands during 2004. By late June (six

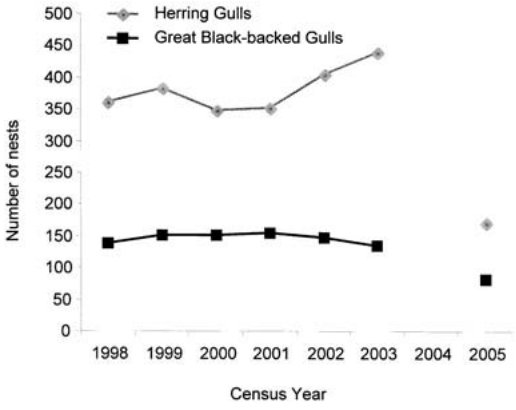

Figure 3. Gull nest census data from the northeast section of Appledore Island from 1998-2003 and in 2005.

to eight weeks after egg-laying), over half (58%) of the nests were empty. On average, nests contained 0.46 chicks, and the numbers of chicks were only 16% (Great Black-backed Gulls) and 33% (Herring Gulls) of the number of eggs present at the time nests were marked in mid-May. This contrasts strikingly with 2.1 chicks/nest in late-June 1991 (Ellis and Good 2006 and unpubl. data) and the mean hatching success of 63-82% among Great Black-backed Gulls and 70-78% among Herring Gulls observed on Appledore Island in other years (McGill 1977; Ellis and Good 2006). This pattern continued later into the breeding season; our extensive survey on Appledore Island in mid-July 2004 showed near-total breeding failure (0.02 chicks/nest) compared to 0.75 chicks/nest in 1975 and 1976 (McGill 1977).

Colony-wide breeding failure in island nesting seabirds can occur due to a number of causes: low food availability, weather extremes, diseases and parasites, pollutants, and predation (Burger and Gochfeld 1994). Several lines of evidence strongly support a conclusion that the presence of Raccoons was the main cause of widespread breeding failure in gulls on Appledore Island during 2004. Disease and mortality from environmental contaminants would have produced high numbers of adult carcasses (W. Lord, pers. comm.); very few were found. More importantly, adverse weather, exposure to pollutants, reduced food resources, and/or a disease epidemic would presumably affect all the Shoals islands equally because of their close proximity. In contrast, catastrophic breeding failure due to predators would occur only on those islands where the predators were present. Our mid-July surveys of four islands documented colony-wide breeding failure only on Appledore and Smuttynose. In addition to successful trappings of animals on both islands, we had visual sightings of Raccoons on Appledore and found scat on Smuttynose. In contrast, we saw no sign of Raccoons on Lunging and Duck Islands, where the chick survivorship in mid-July was high (0.85 and 0.64 chicks/nest) and similar to that found on Appledore Island in years when Raccoons were not present (McGill 1977).

It is extremely unlikely that predators other than Raccoons were responsible for gull breeding failure on the two islands. Other mammals including Norway Rats (*Rattus norvegicus*), Deer Mice (*Peromyscus leucopus*), and Muskrats (*Ondatra zibethicus*) are present in the archipelago but have not been observed attacking gull eggs or chicks (McGill 1977). In fact, gulls attack and eat rats and Muskrats on Appledore Island (S. R. Morris, pers. obs), and mice and rats have been found in gull regurgitates (J. C. Ellis, unpubl. data). Additionally, these species have been present in the Isles of Shoals for at least 40 years, including years of high breeding success in the gull colonies. These other mammals are therefore unlikely predators of gulls.

The final evidence that Raccoons were responsible for gull breeding failure in 2004 was the high reproductive success following the removal of eleven Raccoons from Appledore and Smuttynose. In 2005, the ratios of chicks to nests on these islands were similar to those on Lunging and Duck Islands, and slightly higher than on Appledore Island in the 1970s (McGill 1977). In 2004, almost 60% of marked nests on Appledore Island were empty by June, whereas in 2005 fewer than 25% were empty. Similarly, chicks were present in 66% of nests in June 2005 compared to 27% in 2004. Finally, there were also more chicks per nest in June 2005 compared to 2004.

Raccoons could cause breeding failure by either killing (direct mortality) and/or changing the behavior of gulls (indirect effects). Up-flights by gulls were frequently observed on both Appledore and Smuttynose Islands throughout the breeding season in 2004. Up-flights can entail either defensive swoop-and-soar attacks on ground predators or panic flights to escape predators (e.g., Shugart 1977; Southern *et al.* 1979; Southern *et al.* 1985). Frequent up-flights can reduce egg hatching rates and chick survivorship due to thermoregulation failure (e.g., Southern and Southern 1978). Panicked up-flights occur more frequently when predators disturb gulls at night, and increase the risk of predation because offspring are left unattended. For instance, Ring-billed Gulls (*Larus delawaris*) and Herring Gulls may completely abandon their colonies until daybreak (e.g., Emlen *et al.* 1966; Conover and Miller 1978). Thus, the presence of only a few predators in a large colony, especially at night, could indirectly cause breeding failure by reducing adult attendance of eggs and chicks.

The presence of Raccoons could also cause adult gulls to attack and kill chicks more frequently. When gulls leave their nests, undefended eggs and chicks face greater predation risks from neighboring adults (Petersen 1982; Bukacinska *et al.* 1996). Great Black-backed and Herring Gulls frequently exhibit high levels of aggression toward eggs and chicks of neighboring pairs; conspecific aggression is often a major source of mortality in gull colonies (Butler and Janes-Butler 1982; Kilpi 1989; Good 1998). At the Isles of Shoals, some pairs specialize on chick predation (McGill-Harelstad 1985; Ellis and Good 2006). When adults lose their offspring, they are more likely to attack neighboring chicks (Davis and Dunn 1974; Pierotti 1980; Butler and Trivelpiece 1981). In 2004, we observed many pairs attending empty nests for days or weeks after losing eggs and chicks. We also observed several chicks with injuries to their heads typical of gull attacks (McGill 1977); it is possible that pairs without offspring were responsible for these attacks.

Breeding and colony site fidelity may be influenced by the presence of predators or breeding failure due to nest predation in the previous year (Kilpi 1995; Bried and Jouventin 1999; Hakkarianen *et al.* 2001). The multi-year census of the northeast end of Appledore Island, suggests that in 2005, there were far fewer adult gulls present. Similarly, in 2005, we conducted a census of breeding waterbirds in the entire Isles of Shoals and found that there were far fewer pairs of gulls (2,804 pairs, J. C. Ellis, unpubl. data) than in the previous census conducted in 1995 (4,465 pairs, A. Borror, unpubl. data).

We do not know how or when Raccoons were originally introduced at the Isles of Shoals, which is approximately ten kilometers from the nearest mainland. Raccoons readily make water crossings <400 m, but are less likely to cross distances >900 m (Hartman and Eastman 1998). Therefore, the most likely mode for the arrival of Raccoons was by deliberate or accidental introduction. Staff at the conference center on Star Island first reported that a Raccoon over-wintered on the island between 2001 and 2002. Numbers of wading birds [Snowy Egrets (*Egretta thula*), Glossy Ibises (*Plegadis falcinellus*), Black-crowned Night Herons (*Nycticorax nycticorax*)] on Appledore Island declined precipitously between 2001 and 2002 and have remained low through 2005 (S. R. Morris, unpubl. data). Staff on Smuttynose Island observed high rates of gull chick mortality on the island during 2003. Smuttynose and Star Islands are physically connected via Cedar Island and breakwaters, thus, movement of Raccoons from Star to the large gull colony on Smuttynose is highly probable. A narrow waterway of about 200 m separates Appledore from Smuttynose, which is a distance easily traversed by Raccoons (Hartman *et al.* 1997). Thus, while the site and date of the initial introduction of Raccoons cannot be determined with certainty, it is clear that Raccoons can readily move among adjacent islands within the Shoals archipelago.

That only a few Raccoons could devastate such a large colony of two species of large, aggressive gulls was unexpected. A previous study found that Great Black-backed Gulls showed no increase in breeding densities in

response to mink removal, possibly because the gulls were much larger than the Mink and thus may have had a size refuge from predation (Nordstrom *et al.* 2003). Kadlec (1971) found that as few as two Raccoons could rapidly induce complete breeding failure in colonies of Great Black-backed and Herring Gulls. However, the colonies in that study were much smaller (234-614 nests) than those at the Isles of Shoals (Smuttynose Island: 1,417 nests, Appledore Island: 1,924 nests in 1995, A. Borror, unpubl. data). Emlen *et al.* (1966) observed that a large gull colony (~1,000 nests) experienced similar catastrophic results from just a single Raccoon, but the colony consisted solely of Ring-billed Gulls. Great Black-backed and Herring Gulls are much larger than Ring-billed Gulls, and are more aggressive, so might be expected to exhibit superior anti-predator defense. However, our observation that massive breeding failure can occur in very large colonies of the biggest larids demonstrates a lack of effective defenses against such ground predators.

Raccoons are a growing threat to bird species throughout North America, including Atlantic coastal areas (e.g., Crooks and Soulé 1999; Erwin *et al.* 2001; Schmidtt 2003). In the Isles of Shoals, these predators pose a significant conservation risk to endangered species of terns nesting on Seavey's Island (~900 m from Star Island). To protect populations of threatened and endangered Atlantic seabirds, monitoring programs that focus on rapid detection of mammalian predators and effective methods of control are urgently needed.

ACKNOWLEDGMENTS

We thank the staff of the Shoals Marine Laboratory for logistical support, and especially Tom Davis for extensive assistance with Raccoon trapping. Earthwatch team volunteers, along with Ben Shulman and Lea Shulman, helped with gull colony surveys in both years. L. Shulman prompted inquiries into the possible indirect effects of predators in gull colonies, with the initial suggestion of conspecific predation mechanisms. We also are grateful to Wayne Lord for consultations regarding gull and chick remains, and the staff of Star and Smuttynose Islands for reporting Raccoon sightings and information on gull breeding parameters during the prior breeding season. This paper is contribution number 130 of the Shoals Marine Laboratory.

LITERATURE CITED

Ahlén, I. and Å. Andersson. 1970. Breeding ecology of an eider population in Spitsbergen. Ornis Scandinavica 1: 83-106.

Atkinson, I. A. E. 1996. Introductions of wildlife as a cause of species extinctions. Wildlife Biology 2: 135-141.

Blackburn, T. M., P. Cassey, R. P. Duncan, K. L. Evans and K. J. Gaston. 2004. Avian extinctions and mammalian introductions on oceanic islands. Science 305: 1955-1958.

Borror, A. C. and D. W. Holmes. 1990. Breeding Birds of the Isles of Shoals. Shoals Marine Laboratory, Ithaca, NY.

Bried, J. and P. Jouventin. 1999. Influence of breeding success on fidelity in long lived birds: and experimental study. Journal of Avian Biology 30: 392-398.

Bukacinska, M., D. Bukacinski and A. L. Spaans. 1996. Attendance and diet in relation to breeding success in Herring Gulls (*Larus argentatus*). Auk 113: 300-309.

Burger, J. 1982. The role of breeding success on colony-site selection and abandonment in Black Skimmers (*Rhynochops niger*). Auk 99: 109-115.

Burger, J. and M. Gochfeld. 1994. Predation and effects of humans on island-nesting seabirds. Pages 39-67 *in* Seabirds on Islands: Threats, Case Studies and Action Plans (D. N. Nettleship, J. Burger and M. Gochfeld, Eds.). BirdLife International, Cambridge.

Butler R. G. and W. Trivelpiece. 1981. Nest spacing, reproductive success, and behavior of the Great Black-backed Gull (*Larus marinus*). Auk 98: 99-107.

Butler, R. G. and S. Janes-Butler. 1982. Territoriality and behavioral correlates of reproductive success of Great Black-backed Gulls. Auk 99: 58-66.

Conover, M. R. and D. E. Miller. 1978. Reaction of Ring-billed Gulls to predators and human disturbances at their breeding colonies. Pages 41-47 *in* Proceedings of the Colonial Waterbird Group.

Crooks, K. R. and M. E. Soulé. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400: 563-566.

Croxall, J. P., P. G. H. Evans and R. W. Schreiber (Eds.). 1984. Status and conservation of the world's seabirds. International Council for Bird Preservation (Technical Publication 2), Cambridge.

Cuthburt, R. and G. Hilton. 2004. Introduced House Mice *Mus musculus*: a significant predator of threatened and endemic birds on Gough Island, South Atlantic Ocean? Biological Conservation 117: 483-489.

Davis, J. W. F. and E. K. Dunn. 1974. Intraspecific predation and colonial breeding in Lesser Black-backed Gulls *Larus fuscus*. Ibis 118: 65-77.

Dickman, C. R. 1996. Impact of exotic generalist predators on the native fauna of Australia Wildlife Biology 2: 185-195.

Drury, W. H. 1973. Population changes in New England seabirds. Bird Banding 44: 267-313.

Ellis, J. C. and T. P. Good. 2006. Nest attributes, aggression, and breeding success of gull in single and mixed species subcolonies. Condor 108: 211-219.

Emlen, J. T., D. E. Miller, R. M. Evans and D. H. Thompson. 1966. Predator-induced parental neglect in a Ring-billed Gull colony. Auk 83: 677-679.

Erwin, R. M., B. R. Truitt and J. E. Jimenez. 2001. Ground-nesting waterbirds and mammalian carnivores in the Virginia barrier island region: running out of options. Journal of Coastal Research 17: 292-296.

Good, T. P. 1998. Great Black-backed Gull (*Larus marinus*). *In* The Birds of North America, No.330 (A. Poole and F. Gill, Eds.). The Birds of North America, Inc., Philadelphia, PA.

Hartman, L. H., A. J. Gaston and D. S. Eastman. 1997. Raccoon predation on Ancient murrelets on East Limestone Island, British Columbia. Journal of Wildlife Management 61: 377-388.

Hartman, L. H. and D. S. Eastman. 1998. Distribution of introduced Raccoons *Procyon lotor* on the Queen Charlotte Islands: implications for burrow-nesting seabirds. Biological Conservation 88: 1-13.

Kadlec, J. A. 1971. Effects of introducing Foxes and Raccoons on herring gull colonies. Journal of Wildlife Management 35: 625-636.

Kepler, C. B. 1967. Polynesian rat predation on nesting Laysan Albatrosses and other Pacific seabirds. Auk 84: 426-430.

Kilpi, M. 1989. The effect of varying pair numbers on reproduction and use of space in a small Herring Gull *Larus argentatus* colony. Ornis Scandinavica 20: 204-210.

Kilpi, M. 1995. Breeding success, predation and local dynamics of colonial common gulls *Larus canus*. Annales Zoologici Fennici 32: 175-182.

Kruuk, H. 1964. Predators and anti-predator behavior of the black-headed gull *Larus ridibundus* (L.). Behaviour Supplement 11: 1-129.

Lima, S. L. and L. M. Dill. 1990. Behavioral decisions made under the risk of predation: a review and prospectus. Canadian Journal of Zoology 68: 619-640.

Martin, J. -L., J. -C. Thubault and V. Bretagnolle. 2000. Black Rats, island characteristics, and colonial nesting birds in the Mediterranean: consequences of an ancient introduction. Conservation Biology 14: 1452-1466.

McGill, P. A. 1977. Breeding biology and competition between Great Black-backed and Herring Gulls. MS Thesis, Cornell University, Ithaca, NY.

McGill-Harelstad, P. A. 1985. Mechanisms and consequences of interspecific interactions among gulls. Unpublished thesis, Cornell University, Ithaca, NY.

Moors, P. J. and I. A. E. Atkinson. 1984. Predation on seabirds by introduced animals, and factors affecting its severity. International Council for Bird Preservation Technical Publication 2: 667-690.

Nordstrom, M., J. Hogmander, J. Nummelin, J. Laine, N. Laanetu and E. Korpimaki. 2003. Effects of feral mink removal on seabirds, waders and passerines on small islands in the Baltic Sea. Biological Conservation 109: 359-368.

Nordström, M. and E. Korpimäki. 2004. Effects of island isolation and feral Mink removal on bird communities on small islands in the Baltic Sea. J. Animal Ecology 73: 424-433.

Petersen, M. R. 1982. Predation on seabirds by Red Foxes at Shaiak Island, Alaska. Canadian Field-Naturalist 96: 41-45.

Pierotti, R. 1980. Spite and altruism in gulls. The American Naturalist 115: 290-300.

Pierotti, R. J. and T. P. Good. 1994. Herring Gull (*Larus argentatus*). *In* The Birds of North America, No.124 (A. Poole and F. Gill, Eds.). The Birds of North America, Inc., Philadelphia, PA.

Schmidt, K. A. 2003. Nest predation and population declines in Illinois songbirds: a case for mesopredator effects. Conservation Biology 17: 1141-1150.

Short, J., J. E. Kinnear and A. Robley. 2002. Surplus killing by introduced predators in Australia- evidence for ineffective anti-predator adaptations in native prey species? Biological Conservation 103: 283-301.

Shugart, G. W. 1977. Resident Red Fox predation upon an island gull colony. Jack-Pine Warbler 55: 199-205.

Southern, L. K and W. E Southern. 1978. Absence of nocturnal predator defense mechanisms in breeding gulls. Proceedings of the Colonial Waterbird Society Conference 2. pp. 157-162.

Southern, W. E., S. R. Patton and L. A. Hanners. 1979. Differential response of Ring-billed Gulls and Herring Gulls to fox predation. Proceedings of the Colonial Waterbird Group Conference 3: 119-127.

Southern, W. E., S. R. Patton, L. K. Southern and L. A. Hanners. 1985. Effects of nine years of fox predation on two species of breeding gulls. Auk 102: 827-833.

Stenhouse, I. J., H. G. Gilchrist and W. A. Montevecchi. 2005. An experimental study examining the anti-predator behavior of Sabine's Gulls (*Xema sabini*) during breeding. Journal of Ethology 23: 103-108.

Wilson, D. A. 1975. The adequacy of body size as a niche difference. American Naturalist 109: 769-84.

Woodward, P. W. 1972. The natural history of Kure Atoll, northwestern Hawaiian islands. Atoll Research Bulletin 164: 1-318.