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John Tanacredi Ph.D.
Molloy College, jtanacredi@molloy.edu

Brook Lauro
Saint Johns University, laurob@stjohns.edu

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BROOK LAURO[1] AND JOHN TANACREDI[2,3]

[1]Department of Computer Science, Mathematics and Science, St. John's University, Jamaica, NY 11439, USA
E-mail: laurob@stjohns.edu

[2]Division of Natural Resources, Gateway National Recreation Area, National Parks Service
Staten Island, NY 10305, USA

[3]Present address: Division of Natural Sciences and Mathematics, Dowling College, Oakdale, NY 11769, USA

Abstract.—This study examines predatory threats to Piping Plovers (*Charadrius melodus*) nesting at Breezy Point, Gateway National Recreation Area, New York. Several methods used include: 1) an evaluation of reproductive success data with documentation of predation to eggs and chicks, 2) predator surveys, and 3) an artificial nest study. The range of breeding pairs nesting from 1988-1996 was 11-19, with an average of 15.8 (SE ± 0.79) pairs/season. The average number of eggs hatched and chicks fledged per year for pairs was 2.2 ± 0.23 and 0.8 ± 0.16 respectively. Reasons for egg losses often went undetected (68%) but known sources included: tidal flooding (2%), human disturbance (4%), and predation (26%). Reasons for chick loss were generally not detected (99%). For eggs in artificial nests, overall egg removal was 84% and the two main predators based on visible footprints in sand were avian: gulls and crows. Results suggested that gulls predated significantly fewer eggs at artificial nests than crows, although they were more numerous in the area. With artificial nests, the highest egg removal occurred at a gull colony (100%), although losses were similarly high on adjacent beaches and at interior locations (greater than 90%). During the nesting season, highest removal occurred early in the field season (April—93%) when nesting Common Terns (*Sterna hirundo*), which mob potential predators, had yet to arrive. Once terns arrived, rates of egg loss at artificial nests in their colony were significantly lower than that at other habitats. It is suggested that crow control, including nest removal, be added to the existing management plan that already involves gull control. *Received 18 March 2002, accepted 20 June 2002.*

Key words.—Artificial nests, *Charadrius melodus*, crows, gulls, Piping Plover, predation, terns.

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The Revised Recovery Plan for Atlantic nesting Piping Plovers (*Charadrius melodus*) suggests that to stabilize this threatened population (Federal Register 1985) it will be necessary to achieve a five-year average productivity of 1.5 chicks fledged per pair (Fish and Wildlife Service 1996). However, a complex of factors relating to human encroachment continue to contribute to the low average productivity for plovers including: habitat loss, recreational use of beaches, and water regulation policies that endanger nesting habitats (Cairns and McLaren 1980; Haig 1991; Patterson *et al.* 1991; Goldin 1993; Melvin *et al.* 1994; Plissner and Haig 2000).

Another important factor contributing to low Piping Plover productivity is predation on eggs and chicks (Haig 1991; Patterson *et al.* 1991). A special concern is predation by species whose numbers have increased because they eat human refuse (e.g., gulls, crows, raccoons, rats), resulting in increased predatory pressure. Management techniques, including predator exclosures around open ground nests, and symbolic fencing to reduce human harassment, are being utilized to increase hatching and fledging success (Dyer *et al.* 1988; Rimmer and Deblinger 1990; Deblinger *et al.* 1992; Melvin *et al.* 1992; Vaske *et al.* 1994; Johnson and Oring 2002). However, the effectiveness of exclosures is currently being re-evaluated (Mabee *et al.* 2000; Johnson and Oring 2002) and chicks become vulnerable to predation once they leave exclosures (Cairns 1982; Burger 1987; Haig 1991). Thus, it is important that predation be assessed on a site-specific basis to develop a balanced management plan to protect Piping Plovers.

The purpose of this study is to use several different methods to evaluate predation on Piping Plovers nesting at Breezy Point, New York. Methods of evaluation included an examination of reproductive success data with documentation of predation to eggs and chicks, predator surveys and an artificial nest study. Artificial nest studies, although they

may have weaknesses (Major and Kendal 1996; Wilson *et al.* 1998; King *et al.* 1999), when used in combination with other methods, provide a cost effective, management technique to measure potential predatory threats. The artificial nest study was designed to provide a comprehensive measure of predatory threats throughout the breeding season, examining egg loss relative to the habitats that Piping Plovers breed and or feed. The paper evaluates predatory risks and makes management suggestions for Piping Plovers nesting at this New York City location.

Study Area and Methods

Study Area

The study location was Breezy Point, a district of Gateway National Recreation Area, a unit of the National Parks System, in New York City, New York. This urban study area is located at the western tip of Long Island, in the borough of Queens, approximately 16 km southeast of Manhattan, and extending into New York Harbor. This site is part of the barrier island system of Long Island (Rockaway Peninsula) and is flanked by Jamaica Bay to the north and the Atlantic Ocean to the south.

The tip of Breezy Point is composed of 81 ha of coastal habitat. Dunes lie adjacent to the beach and are dominated by American Beachgrass (*Ammophila breviligulata*). The center of the tip is covered by woody shrubs, primarily Bayberry (*Myrica pensylvanica*), and has scattered, small trees including Black Cherry (*Prunus serotina*) and Eastern Red Cedar (*Juniperus virginiana*).

Breezy Point is an important nesting area for shorebirds and seabirds in New York City. In 1996 there was a large Common Tern (*Sterna hirundo*) colony of over 1,000 pairs, a Least Tern colony (*Sterna antillarum*) of 45 breeding pairs, and a gull colony of about 110 pairs of Herring Gulls (*Larus argentatus*) and ten pairs of Great Black-backed Gulls (*Larus marinus*). In addition, nonbreeding gulls congregated on beaches.

Piping Plover Management, Reproductive Success and Predator Censuses

National Parks staff actively manage Piping Plovers nesting at Breezy Point, applying beach restrictions to vehicles and beach bathers, symbolic fencing, exclosures (since 1993), predator management and reproductive success record keeping. Exclosures are used selectively depending upon location. Sites likely to be vandalized are not exclosed for fear of drawing attention to nests.

Programs to manage potential predators of Piping Plovers included a gull management program and mammal trapping program. In the gull colony, nests and their eggs were removed over several years, resulting in reduced numbers of breeding gulls (Olijnyk and Brown 1999). The mammal removal program was designed to capture larger mammals, mainly cats and raccoons, not smaller mammals such as rats or mice. We report findings of the mammal trapping program (1992-1996).

We present data on the reproductive success of Piping Plovers collected by National Parks Staff for the years 1988-1996, including causes for egg and chick loss (1992-1996 only). All means for data are accompanied by standard error in the form ($\bar{x} \pm SE$). The areas where reproductive success data were recorded include, the tip of Breezy Point, the main nesting area, and two smaller eastern beaches, West Beach and Riis Park.

In 1996, daytime censuses of potential predators were conducted on days of the artificial nest study (see below). No distinction was made between American Crow (*Corvus brachyrhynchos*) and Fish Crow (*Corvus ossifragus*). In addition, in 1996, to assess mammalian predation, five nighttime surveys were conducted during the field season. The same route and region observed on daytime surveys was used for nighttime surveys. In 1997 based upon results of the 1996 artificial nest study, a census of crow nests was conducted for the tip of Breezy Point.

Artificial Nest Study

An artificial nest study was conducted to gain an understanding of predatory pressures on Piping Plovers at areas where they nest and forage. We aimed at quantifying the identity of potential predators, which habitats had the most potential threat, and how the time of season influenced predatory pressure. It was believed that the primary predator of Piping Plover eggs and chicks at the study area would be gulls since they were more numerous than other threatening species, i.e., crows (*Corvus* spp.), Norway Rats (*Rattus norvegicus*) and Raccoons (*Procyon lotor*).

It was also expected that predation of Piping Plover eggs and chicks would be highest at the gull colony, intermediate at nesting beaches and interior dunes, while lowest in the tern colony. There may be a disadvantage to nesting near a gull colony because of the proximate predatory threat. Conversely, there may be an advantage to nesting at or near a tern colony since the aggressive defense by adults of their own eggs and chicks may provide a protective effect to nearby waterbirds.

Quail eggs used in artificial nests were placed at test sites at Breezy Point on a monthly basis. Monthly trials were conducted during the weeks of 1 April, 20 May, 24 June and 15 July 1996. Tests were carried out along nine parallel transects, every 160 m, running at right angles to the beach, in a north-south direction. Along a transect clutches were set every 90 m and altogether 57 were used on each occasion. No test clutches were placed within the center region of the peninsula since dense shrub dominated this area and was unsuitable for Piping Plovers.

Each monthly trial took place over three days. To minimize habituation by predators to test sites, artificial nests were placed 5m from the marking stake in a randomly selected direction (north, south, east or west). A nest scrape was made at the site in the sand and four quail eggs added. A 1-m × 1-m area of sand around the nest was cleared so that predator footprints could be identified. Quail eggs were used for trials since they were small and cryptically colored, providing a close match to Piping Plover eggs. To attempt to minimize human scent that may attract predators to test sites, biologists wore rubber gloves and rubber soled shoes. Nests were checked twice a day, weather permitting, starting on the day the eggs were set out.

Habitats for test sites were categorized as follows: beach (no tern or gull colony), gull colony, tern colony,

and interior sites (no gull or tern colony). The beach, where plovers nest, was defined as the area from the base of the primary dune to the high tide line. The interior habitat occurred from the base of the primary dune to the center of the peninsula, but not in the gull or tern colony.

To examine differences in egg loss, *G* tests, with a small sample correction, were used, and for multiple comparisons, Gabriel's Simultaneous Test Procedure was used (Sokal and Rohlf 1994).

RESULTS

Reproductive Biology

Reproductive success for Piping Plovers from 1988 to 1996 are presented in Table 1. The number of breeding pairs at the study area ranged from nineteen in 1990 to eleven in 1996, with an average of 15.9 (±0.79) pairs per year. From 1988-1996, the proportion of eggs hatched ranged from 31% in 1995 to 72% in 1989. For all data combined, hatching success was 50% and 19% of eggs laid produced fledged young. Over the years, the average number of eggs hatched and chicks fledged per pair was 2.2 (±0.23) and 0.8 (±0.12) respectively.

Known causes for plover egg loss were available from 1992-1996 (Table 2) and included tidal flooding (7%), human disturbance (13%) and predation (80%). Rats were documented to take more eggs than crows and gulls, although these levels were low for statistical comparison (Table 2). This pattern may be related to the fact that rats were able to get through exclosures, while larger birds such as crows and gulls could not. The majority of eggs were lost for unknown causes.

The causes of chick loss were not detected in almost all cases (Table 2). However in 1995, one chick was captured by a gull, while another was taken and dropped into the ocean by a Common Tern (S. Gilmore, pers. comm.). In 1996, one chick was taken by a crow (S. Gilmore, pers. comm.).

Predator Censuses

In 1996, daytime censuses located only potential avian predators: gulls and crows (Table 3). The two most numerous gull species were Herring Gull and Great Black-backed Gull with the former being more common (Table 3). Laughing Gull (*Larus atricilla*) and Ringed-billed Gull (*Larus delawarensis*) were seen less frequently (Table 3). During nighttime surveys in 1996 no known potential mammalian predators were seen.

From 1992-1996, Parks Staff trapped and removed one dog, raccoons, and cats, with the last being captured most frequently (Table 4). Cats reach Breezy Point from adjacent residential areas. The numbers trapped in the area suggests that they may be a problem. However it may be that the trapping program is helping, since the number of cats trapped has decreased over years.

A survey for crow nests conducted in 1997 found two Fish Crow pairs and two American Crow pairs maintaining nesting territories. The only non-breeding crows observed were offspring of the American Crow pairs.

Table 1. Comparison of Piping Plover annual reproductive success at Breezy Point, 1988-1996.

Year	Total pairs	Total eggs[1]	Total hatching	% hatching	Chicks hatched/pair	Total fledging	% fledging	Fledging/ pair
1988	18	44	25	57	1.4	6	14	0.3
1989	14	67	48	72	3.4	20	30	1.4
1990	19	94	43	46	2.3	20	21	1.1
1991	17	66	33	50	1.9	20	30	1.2
1992	17	76	28	37	1.7	12	16	0.7
1993	15	65	41	63	2.7	23	35	1.5
1994	16	88	48	55	3.0	12	17	0.8
1995	16	84	26	31	1.6	5	6	0.3
1996	11	41	22	54	2.0	2	5	0.2

[1]This includes re-nests.

Table 2. Reasons for egg loss from Piping Plover nests, 1992-1996.

Year	Total eggs lost	Reason for egg loss (%)						
		Flooding	Human disturbance	Predation				Unknown
				Total	Gull	Crow	Rat	
1992	48	0	0	21	0	8	13	79
1993	24	0	0	79	13	50	17	21
1994	40	0	20	10	5	0	5	70
1995	58	7	0	17	9	0	9	76
1996	19	0	0	32	11	0	21	68
Combined	189	2	4	26	6	9	11	68

Artificial Nest Study

Overall removal of eggs from artificial nests was 84%, with a significant effect found for habitat and month (Table 5; 3-way interaction: habitat, month, removal; $G_9 = 23.5$, $P < 0.005$). Results suggested that the primary predators, based upon track identification, were gull and crow (Tables 6 and 7); no species distinctions for gulls and crows could be made. It was not possible to identify predator tracks in all cases, since wind and rain removed some prints and certain individuals did not leave distinctive foot impressions in the sand; these egg losses were categorized as unknown (Table 6).

Other less common species, which removed eggs at artificial nests, included the American Oystercatcher (*Haematopus palliatus*), an unidentified passerine species, Norway Rat (*Rattus norvegicus*), and an unidentified mammal species (Table 6). Red-winged Blackbirds (*Agelaius phoeniceus*) were the suspected passerines, since they were observed around a recently predated plover nest (M. Hake, pers. comm.). Mice may have been predators of eggs at artificial nests, explaining some of the unknown mammal losses. They are light and may not leave an impression in the sand. However we had no documented evidence, such as visual sightings or feces, to indicate mouse predation.

Crows took significantly more eggs than gulls for data combined (Table 7; $G_1 = 39.7$, $P < 0.001$). This was especially striking given that there were appreciably more gulls than crows observed in the censuses (Table 3; $F_{1,26} = 23.3$, $P < 0.001$). Further, crows took more eggs than gulls in May, June and July although in April gulls took more eggs than crows (Table 7; two way interaction [month × species], $G_3 = 56.0$, $P < 0.001$).

Although crows generally took more eggs than gulls, they were more likely to leave some eggs behind at a nest. Over test days, for all data combined, complete versus partial clutch loss for nests predated by crows was 76% and 24% and for nests predated by gulls was 97% and 3%, a significant difference ($G_1 = 13.3$, $P < 0.001$).

As expected, overall egg removal by predators at artificial nests was highest at the gull colony (100%, Table 5) adjacent to beaches where plovers nested. Predation was similarly high at beach and interior sites (greater than 90%, Table 5) while lowest in the tern colony (less than 20%, Table 5). Gabriel's Simultaneous Test Procedure found only losses at the gull colony and beach to be homogeneous. The pattern of removal, from

Table 3. The number of gulls and crows observed during predator censuses on test days (N = 14).

	Gull species					
	Herring	Great Black-backed	Ring-billed	Laughing	Total gulls	Crows
$\bar{x}$	611	52	2	8	672	13
SE	131	19	1	7	137	3

Table 4. Number of large mammals trapped at Breezy Point.

Year	1992	1993	1994	1995	1996
Cat	80	34	26	32	9
Raccoon	—	2	—	2	1
Dog	—	—	—	1	—

lowest to highest percentage, was tern colony < interior < beach < gull colony (Table 5). Crows, compared to gulls, took more eggs at the gull colony, as well as at the beach and interior sites, while losses were similarly low by both crows and gulls at the tern colony (Table 7, two way interaction [habitat × species], $G_3 = 8.6$, $P < 0.04$).

Egg removal at artificial nests by predators was influenced by the timing of nesting terns (Tables 5 and 7). Egg removal was significantly higher in April, when terns had yet to arrive, than in subsequent months, when terns were active in their colony (Table 5). Gabriel's Simultaneous Test Procedure found removal for April to be significantly higher than that in May and June while for July the direction of the pattern was similar but not different from April. To evaluate whether the habitat of the tern colony alone or the terns themselves impacted egg removal a comparison was made for test sites at the tern colony before and after the arrival of nesting birds. Test sites within the tern colony were compared (predated versus not predated) when adults were absent in April and when present during May, June and July. A significant effect was found between months ($G_3 = 92.1$, $P < 0.001$) and Gabriel's Simultaneous Test Procedure found May, June and July to be homogeneous and significantly different from April. This suggests that the terns themselves and not the habitat they nested on influenced egg removal.

DISCUSSION

Piping Plover reproductive success at Breezy Point has been low over years with an overall average of 0.8 chicks fledged per pair, below the goal set by the Resource Recovery Plan (Fish and Wildlife Service 1996). Results suggest that a number of factors are affecting known causes for egg loss including, human disturbance, tidal flooding and predation with the last being the highest source (80%). However, a high percentage of eggs (68%) and especially chicks (99%) overall were lost for unknown reasons. Food availability has been shown to be important elsewhere (Loegering and Fraser 1995; Goldin and Regosin 1998; Elias *et al.* 2000), but was not studied during this investigation. The focus of this study was to gain insight into predation in the hope that additional management proposals would be made to help meet established goals.

It was expected that gulls would be the leading potential predator, given their strong presence and known reputation as egg and chick predators (Bent 1929; Nelson 1979; Croxall *et al.* 1984). Gulls were more numerous than other recorded predators and they utilized all habitats studied including the beaches where Piping Plovers nested. A Herring and Great Black-back Gull colony bordered a plover nesting area and loafing gulls from the colony occurred here and elsewhere. In 1995, a gull was observed to take a plover chick and on several occasions over years gulls were seen to capture tern chicks (S. Gilmore, pers. comm.). Yet gulls took fewer eggs than crows from artificial nests, suggesting they are a relatively lower threat to plovers. However, a fairly high percentage of eggs at artificial nests (26% overall) were lost to unknown causes and, if known, may have altered the proportions recorded.

If it is assumed that unknown egg losses to predators at artificial nests are proportional to known egg losses, then crows may be a more serious potential predator of eggs at nests that are not exclosed and to free-roaming chicks. Crows were observed hunting throughout the study area including beach sites where plovers nested and one was witnessed capturing a plover chick. Crows are well known predators of bird eggs and chicks (Bent 1946; Goranson *et al.* 1975; Goodwin 1976; Yahner and Cypher 1987; Madge and Burn 1994). Factors influencing the efficiency of corvids as predators may be their high intelligence (Coburn 1914; Koehler 1951), their abilities to develop a search

Table 5. A comparison of eggs removed (R) to the number of eggs placed in artificial nests (N) by month and habitat.

	Tern colony		Interior		Beach		Gull colony		Combined		G-test and significance		
	R/N	%	R/N	%	R/N	%	R/N	%	R/N	%	G	df	P
April	—[1]	—[1]	97/104	93	68/80	85	40/40	100	205/224	92	10.7	2	<0.005
May	4/24	17	68/88	77	68/72	94	44/44	100	184/228	81	74.9	3	<0.001
June	9/48	19	77/84	92	56/56	100	40/40	100	182/228	80	132.1	3	<0.001
July	7/36	19	92/96	96	60/60	100	36/36	100	195/228	86	116.2	3	<0.001
Combined	20/108	19	334/372	90	252/268	94	160/160	100	766/908	84	315.0	3	<0.001
G	0.1		17.9		21.5		0.0		15.8				
df	2		3		3		3		3				
P	n.s.		<0.001		<0.001		n.s.		<0.001				

[1]Since terns had not arrived in April the locations that were later categorized as tern colony in May, June and July were categorized as either interior or beach for this month.

Table 6. A comparison of the number (R) and percentage of eggs removed for different predators, habitats combined, by months.

		Unknown		Gulls		Crow		Gull + crow		Oystercatcher		Unidentified passerine		Rat		Unidentified mammal	
	N[1]	R	%[1]	R	%[1]	R	%[1]	R	%[1]	R	%[1]	R	%[1]	R	%[1]	R	%[1]
April	224	74	33	72	32	44	20	4	2	0	0	5	2	4	2	2	1
May	228	43	19	51	22	88	39	2	1	0	0	0	0	0	0	0	0
June	228	57	25	23	10	88	39	1	1	0	0	9	4	4	2	0	0
July	228	59	26	22	10	84	37	16	7	2	1	4	2	8	4	2	1
Combined	908	233	26	168	19	304	34	23	3	2	1	18	2	16	2	4	1

[1]Percentages are out of total number of eggs (N) set out.

Table 7. A comparison of eggs removed from artificial nests by crow and gulls by habitats by months.

	Tern colony			Interior			Beach			Gull colony			Combined		
	N[1]	Crow %	Gull %	N[1]	Crow %	Gull %	N[1]	Crow %	Gull %	N[1]	Crow %	Gull %	N[1]	Crow %	Gull %
April	—	—	—	104	12	12	80	38	41	40	5	68	224	20	32
May	24	17	0	88	32	15	72	50	38	44	46	25	228	39	22
June	48	0	8	84	38	13	56	50	7	40	70	10	228	39	10
July	36	0	0	96	38	4	60	53	17	36	44	22	228	37	10
Combined	108	4	4	372	29	11	268	47	28	160	41	31	908	34	19

[1]Number of eggs placed out for a trial.

image for prey (Croze 1970), their ability to remember nest sites (Sonerud and Fjeld 1987) and to learn to use humans as cues for locating nests (Gotmark *et al.* 1990).

As expected, results of the artificial nest study indicated that the gull colony had the highest rates of predation (100% overall). Interestingly, crows took more eggs overall at the gull colony, although the pattern varied seasonally. In April, predation by gulls was higher than crows but in May, June and July crows took more eggs than gulls. In 1996 and 1997, a pair of Fish Crows nested in the center of the gull colony and they probably took the majority of eggs, since they defended territory here against other crows (pers. obs.). Perhaps in April the Fish Crow pair spent less time on their territory prior to nesting, explaining the higher removal rate by gulls in this month.

The artificial nest study also suggested that the timing of tern nesting might influence predation. Common Terns arrived after the April trial but prior to the May trial, and appeared to provide a protective effect to eggs at artificial nests in their colony. Egg removal from artificial nests was higher in April when terns had yet to arrive, than in May and June when tern nesting activity was at its peak. This is to be expected, given the mobbing behavior used by colonial nesting Common Terns to protect their eggs and chicks from predators (Lemmetyinen 1971; Burger and Gochfeld 1990, 1991; Clode *et al.* 2000). A number of studies have shown that other bird species may gain protection from predators when nesting near colonial seabirds (Wittenberger and Hunt 1985). Peak egg laying by Piping Plovers at Breezy Point is mid-May, when terns are also nesting. Thus, the aggressive behavior used by Common Terns to deter predation upon their own eggs and chicks may provide a protective effect to plover eggs and chicks.

Although there may be possible benefits to Piping Plovers when nesting near a tern colony, there may also be costs. Common Terns were physically aggressive to Piping Plover chicks and in one case were observed to kill a chick by picking it up and dropping it in the ocean. Thus, it would be valuable to

further examine the benefits and costs to Piping Plovers nesting near tern colonies.

This study suggests that factors affecting predation of Piping Plovers at Breezy Point were complex and changed over time in ways that were not predicted. It is suggested that, in addition to the predator management programs already in place (see methods), an additional program to control crows be established. It is advised that nests of the crows be removed. This may have the advantage of keeping crow numbers down and encourage territory abandonment.

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