

Research Article

Modeling Foraging Behavior of Piping Plovers to Evaluate Habitat Restoration Success

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ABSTRACT Habitat restoration projects are often deemed successful based on the presence of the target species within the habitat; however, in some cases the restored habitat acts as an ecological trap and does not help to improve the reproductive success of the target species. Understanding wildlife–habitat relationships through precise measurements of animal behavior can identify critical resources that contribute to high quality habitat and improve habitat restoration practice. We evaluated the success of a restored piping plover (*Charadrius melodus*) breeding habitat in New Jersey, USA. We identified the major factors influencing foraging rates, compared foraging activity budgets over 3 yr at restored and natural habitats, and explored the potential of artificial tidal ponds as a viable restoration alternative. Adult foraging rates were higher in artificial pond and ephemeral pool habitats, during low tide, and after breeding activity ended. Adult foraging rates were impeded by the presence of people and vehicles within 50 m. Chick foraging rates were highest at artificial ponds and bay shores and lowest in dunes and on sand flats. Chick foraging rates were strongly hindered by the presence of corvids and the number of people within 50 m. In addition, at artificial tidal ponds, piping plovers spent more time foraging and less time engaged in defensive behaviors (vigilance, crouching, and fleeing) compared to other potential habitats. Our findings support the hypothesis that artificial tidal ponds are a valuable, perhaps superior, foraging habitat. Future beach restoration projects should include this feature to maximize habitat quality and restoration success. © 2011 The Wildlife Society.

KEY WORDS beach restoration, *Charadrius melodus*, ecological traps, evidence-based conservation, foraging behavior, habitat quality, piping plover, restored tidal ponds, wildlife–habitat relationships.

The ecological health of sandy beach ecosystems is highly compromised as a consequence of direct and indirect anthropogenic stressors, such as beach replenishment (placement of sand onto the beach to increase its elevation and width), the introduction of harmful non-native species, and the escalation of intrusive recreational activities (De Ruyck et al. 1997, Carlton and Hodder 2003, Defeo et al. 2008, Nordstrom 2008). Human encroachment on the beach ecosystem makes land preservation and habitat restoration critical strategies to ensure the persistence of beach-dependent species. Because opportunities for land acquisition are limited in the coastal zone, restoration projects are under great pressure to be successful in attracting target species and increasing their survival or reproductive success. Restoration of high quality habitat is imperative to achieve this conservation objective.

However, many current methods of evaluating the success of a wildlife restoration project, such as the use of presence–absence data or vegetation monitoring, may not adequately reflect the quality of the habitat or provide information on a species' use of critical resources within it (Morrison 2001,

Johnson 2007). The simple presence of a species within a restored habitat is not always indicative of the quality of a habitat (e.g., Gates and Gysel 1978, Pidgeon et al. 2003, Ries and Fagan 2003). In addition, other factors such as predation or human disturbance can lower the habitat's quality, despite it having some appropriate niche axes (e.g., vegetation composition, substrate, food requirements; Morrison 2002). Several studies have reported that in these cases, the habitat may become an ecological trap, attracting the target species to an area where it will experience low survival or reproductive success (Schlaefter et al. 2002, Battin 2006). Examples include lowered reproductive success for wood ducks (*Aix sponsa*) nesting in unhidden artificial nest boxes (Semel and Sherman 2001), higher egg predation of indigo buntings (*Passerina cyanea*) nesting in edge-dominated habitat patches (Weldon and Haddad 2005), and significant human-induced mortality of grizzly bears (*Ursus arctos*) in protected areas (Nielson et al. 2006).

Behavioral observations can identify how sites differ in quality, which niche factors are valued by target species, and what resources may be lacking in a given restoration effort (Lindell 2008). Although conducting behavioral studies is more effort-intensive than directly measuring habitat-based parameters, the results are often much more

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conclusive and can lead to effective long-term management strategies (Morrison 2006). Linking behavioral observations to habitat variables may provide the most accurate evaluation of a restored habitat.

Piping plovers are federally listed in the United States and Canada, and the restoration of high quality breeding habitat is a leading directive of the United States Fish and Wildlife Service (USFWS) Atlantic Coast Piping Plover Recovery Team (2009). Since the species was first listed, there have been over 15 documented piping plover habitat restoration projects along the Atlantic Coast (B. Maslo, Rutgers, The State University of New Jersey, unpublished data); however, in most cases, precise evaluations of these efforts have not been published (but see McIntyre and Heath 2011). Within a breeding habitat, the creation of appropriate foraging areas is equally as important as the creation of suitable nesting sites. Piping plover foraging habitats include the intertidal zone and wrack line, but studies have shown that chicks prefer to feed in non-ocean tidal habitats when available (Haig and Elliott-Smith 2004). Access to prime foraging habitats (ephemeral pools, bay shores, and mud flats) has been suggested to increase fledging success of young plovers (Loegering and Fraser 1995, Goldin and Regosin 1998, Elias et al. 2000). These studies support the idea that construction of artificial tidal ponds may also improve reproductive success, but further explorations of the causal mechanisms behind higher productivity levels is required. In addition, other

factors may negate the benefits of presumably prime foraging areas if their influence is sizeable or continuous. For example, human disturbance forces shorebirds to feed in less rewarding foraging habitats or at lower rates (Burger 1994, Thomas et al. 2003, Burger et al. 2007). The real or perceived risk of predation from gulls, crows, foxes, or dogs also lowers normal foraging rates of shorebirds (Lafferty 2001, Burger et al. 2004, Peters and Otis 2005). Finally, foraging rates can be impacted by weather variables, such as wind speed and air temperature (Pienkowski 1983, Beauchamp 2006). Design of an effective foraging habitat restoration project must mitigate the factors most influential on foraging rates. Our objectives were to identify the primary factors influencing foraging rates of piping plovers, test whether the foraging activity budgets of piping plovers at both restored (artificial ponds) and natural foraging habitats were comparable, and explore the potential of artificial tidal ponds as a viable restoration alternative.

STUDY AREA

In 2004, the United States Army Corps of Engineers (Corps) launched a large-scale ecosystem restoration project in the Lower Cape May Meadows of Cape May, New Jersey, USA (38°56'4.74"N, 74°56'23.24"W; Cape May; Fig. 1). Specific design features for piping plover habitat included the creation of unvegetated nesting habitat, 3 artificial foraging tidal ponds, and plover walkovers, sections of the protective dune



Figure 1. Photographic representation of potential piping plover foraging habitats at the 4 study sites between 2007 and 2009: (a) ephemeral pool and dunes in Avalon, (b) ephemeral pool and wrack line at Barnegat Light State Park, (c) sand flat, ephemeral pool, and intertidal zone at Brigantine Natural Area, and (d) the restored site, artificial tidal ponds and dunes at Lower Cape May Meadows, New Jersey.

with a gentler slope and no vegetation to allow the precocial plover chicks to access the foraging ponds (Smith et al. 2005). Additional foraging areas included the intertidal-swash zone, wrack line, and dunes. Reproductive success, estimated by the USFWS as chicks fledged per nesting pair, during the study period of 2007–2009 was 2.00, 1.75, and 1.00, respectively (Table 1). These values were markedly higher than the site’s pre-restoration average of 0.83 chicks fledged per nesting pair and in 2 of 3 yr exceeded the USFWS recovery goal of 1.5 chicks fledged per nesting pair (USFWS 1996).

The remaining 3 sites in this study were Barnegat Light (39°45′29.50″N, 74°5′42.80″W), North Brigantine Natural Area (Brigantine; 39°26′45.23″N, 74°19′46.84″W), and Avalon (39°5′4.70″N, 74°43′40.24″W), New Jersey, USA (Fig. 1). These sites consisted of a sandy beach backed by dunes or tidal marsh and contained at least 4 foraging alternatives—intertidal-swash zone, wrack line, dunes, and a tidally-influenced non-ocean water source (tidal pond, ephemeral pool). The tidal pond at Barnegat Light occurred naturally as the result of a breached jetty lining Barnegat Inlet and was fed semi-diurnally by high tide. Brigantine also contained a bay shore with low waves and sand flats (dry sandy substrate). Annual reproductive success varied considerably across sites (Table 1).

METHODS

We conducted behavioral observations from April to August of 2007–2009, during the hours of 0600–2100. We visited each site at least twice per week at different times and walked a regular transect traversing all available foraging habitats. The transects at each site spanned approximately 2.0 km,

2.5 km, 4.5 km, and 1.5 km for Cape May, Barnegat Light, Brigantine, and Avalon, respectively.

When we encountered a feeding piping plover, we digitally videotaped the focal animal for 2 min from an unobtrusive distance (>75 m). Burger (1991) suggested that a 2-min sampling period is sufficient time for a piping plover to display the usual foraging behaviors. If the individual, during its usual foraging behavior, moved out of sight (e.g., behind vegetation or a dune), we continued the observation if it moved into view within 1 min. In few instances, the individual remained out of view for longer periods of time, and we aborted the sampling attempt. If the bird obviously altered its behavior due to observer presence (e.g., gave a distress call, demonstrated excessive vigilance with no other probable cause), we discarded the sample. For each observation, we recorded the date, time of day, foraging habitat, reproductive stage (pre-nesting, nesting, brooding, fledging, and non-breeding) as determined by routine monitoring of pairs, and age (adult, chick, and fledge). We logged environmental variables of wind speed and air temperature at each foraging habitat using a Kestrel[®] 2000 pocket wind meter (Nielsen-Kellerman, Boothwyn, PA) and noted the tidal stage (low tide = approx. 3 hr before and after the predicted low tide; high tide = approx. 3 hr before and after the predicted high tide) using a Global Positioning System (GPS) unit. Our behavioral variables included the number of people, number of moving vehicles (for adults only), and the number and type of potential predators (gulls [*Larus* spp.], crows [*Corvus* spp.], canids [*Canis* spp.]) that existed or passed within 50 m of the focal bird for each sample. At each site, we recorded individuals only once per day and treated each observation as an independent sample. A moratorium on banding Atlantic Coast piping plovers exists; however, due to the territorial behavior of this species, we are confident in our ability to identify specific pairs.

Using Adobe[®] Premiere[®] Pro 2.0 software (Adobe Systems Incorporated, New York, NY), we downloaded the videos and played back each sample at half-speed to analyze the activity of the bird in each recording. We prepared a foraging time budget for each observation, recording both the amount of time and the percentage of the 2-min sequence an individual spent foraging (pecking at the ground, tapping the ground with a foot, or visually scanning for prey items), being vigilant (standing erect, visually scanning the surroundings, or watching a potential predator), running or walking away (from a perceived threat), flying away (from a perceived threat), or crouching (a typical anti-predator response in plovers). Time spent engaged in any additional activities, such as preening, was also recorded and categorized as other. We then calculated the foraging rate of each bird as pecks/min.

We ran 2 iterations of multiple linear regression analysis to model the foraging rates of the plovers. We first examined the effect of site, year, and age class on foraging rates by developing 6 a priori models consisting of either 1 variable alone or in various combinations. The global model included all 3 variables. We used Akaike’s Information Criterion corrected for small sample size (AIC_c) to rank the models

Table 1. Piping plover productivity for the Lower Cape May Meadows (restoration site), Barnegat Light, North Brigantine Natural Area, and Avalon (reference sites), New Jersey, 2007–2009.

| Site | Chicks fledged per nesting pair |
|--|---------------------------------|
| Lower Cape May Meadows (restored site) | |
| 2007 | 2.00 |
| 2008 | 1.75 |
| 2009 | 1.00 |
| Average | 1.58 |
| Barnegat Light | |
| 2007 | 1.75 |
| 2008 | 0.33 |
| 2009 | 1.00 |
| Average | 1.03 |
| North Brigantine Natural Area ^a | |
| 2007 | 0.50 |
| 2008 | 0.50 |
| Average | 0.33 |
| Avalon | |
| 2007 | 0.60 |
| 2008 | 0.25 |
| 2009 | 0.50 |
| Average | 0.45 |

^a All nests at North Brigantine Natural Area failed due to flooding in 2009; therefore, productivity could not be calculated. In this case, we provided average reproductive success for 2007–2008 (data provided by the New Jersey Division of Fish and Wildlife—Endangered and Nongame Species Program).

according to their relative likelihood (Johnson and Omland 2004).

Based on the results of the first regression analysis, we separated individuals by age class and modeled the foraging rates of adults and chicks using the behavioral and environmental data collected at the 4 study sites. The sample size of fledglings was too small for reliable inference. For this iteration, we developed 10 a priori candidate models for both the adult and chick data sets that potentially explained variation in their foraging behavior (Burnham and Anderson 2002), including a global model, which contained all variables (Tables 2 and 4). To account for unmeasured variation between study sites, we included site as a random effect in all candidate models (Bolkin et al. 2009). We ranked the models according to their AIC_c value and averaged all models exhibiting $\Delta AIC_c < 2$ (difference in AIC_c value between each model and the top-ranked model) according to Johnson and Omland (2004). We based the resulting calculated parameter estimates on the weighted averages of the parameters that occurred in the top models (Burnham and Anderson 2002).

To validate the regression model, we used an external data set that we collected from foraging plovers at 7 other sites in New Jersey in 2009. We collected all foraging observations for the external data set in the same way described above and used the model-averaged parameter estimates from above analyses to predict the foraging rate for each case in the external data set. We compared the actual versus predicted foraging rates by calculating the mean squared prediction error and compared it to the mean squared error of the regression model to determine if the model was robust enough to be applied on a broader scale (Neter et al. 1996, Peksen 2007).

RESULTS

Foraging Rates and Time Budgets

We recorded 460 2-min video sequences from a group of 151 adult piping plovers. On average, adults spent 71% of their

time foraging, 22% of their time being vigilant, 4% running or walking away from a perceived threat, and 1% of their time flying away, crouching, or engaged in other non-foraging activities. However, there were differences in the foraging time budget among habitats. At artificial tidal ponds, adults spent considerably more time foraging (73%) and less time being vigilant (20%) than along the wrack line (53% and 36%, respectively), and less time running or walking away from a perceived threat (2%) than in the intertidal zone (6%).

Adults primarily foraged along the intertidal zone ($n = 210$), at artificial tidal ponds ($n = 125$), and along the wrack line ($n = 41$). To a lesser extent, adults foraged in dry sand flats ($n = 36$), ephemeral pools ($n = 26$), and bay shores ($n = 18$), and very rarely in dunes ($n = 4$). On average across sites, piping plover adult foraging rate was highest in artificial ponds, ephemeral pools, and bay shores at 16.9 pecks/min, 14.6 pecks/min, and 14.1 pecks/min, respectively (Fig. 2).

We recorded 161 2-min video sequences from 83 chicks, predominantly at tidal ponds ($n = 63$), along the wrack line ($n = 30$), on sand flats ($n = 25$), and in dunes ($n = 25$). Chicks spent 82% of their time foraging, 11% of their time being vigilant (looking for predators or their parents), 4% of their time running or walking away from a perceived threat, 1% of their time crouching, and 2% of their time preening or being brooded. Similar to the adults, chicks dedicated more time to foraging when at artificial ponds (86%) than along the intertidal zone (59%) and wrack line (69%), and much less time being vigilant (11%) than along the wrack line (21%). Conversely, chicks spent a larger amount of time walking and running away from perceived threats along the intertidal zone (15%) than in any other foraging habitat. Average chick foraging rates across sites were also higher at artificial ponds (20.5 pecks/min) than along any other potential foraging habitat (Fig. 2).

Foraging Behavior Models

The first iteration of multiple regression analysis resulted in 2 models with a $\Delta AIC_c < 2$, site only and site + age class.

Table 2. Model selection results for the top 9 models of foraging adult piping plovers ($n = 471$)^a in Lower Cape May Meadows, Barnegat Light, North Brigantine Natural Area, and Avalon, New Jersey, 2007–2009.

| Model | AIC_c^b | ΔAIC_c^c | ML ^d | K^e | w^f |
|--|-----------|------------------|-----------------|-------|-------|
| Habitat + reproductive stage + tidal stage + people + vehicles | 3328.45 | 0.00 | 1.00 | 6 | 0.42 |
| Habitat + reproductive stage + tidal stage + wind speed + people + vehicles | 3330.30 | 1.85 | 0.40 | 7 | 0.17 |
| Habitat + reproductive stage + tidal stage + wind speed + people | 3330.67 | 2.22 | 0.33 | 6 | 0.14 |
| Habitat + reproductive stage + tidal stage + people | 3330.75 | 2.30 | 0.32 | 5 | 0.13 |
| Habitat + reproductive stage + tidal stage + wind speed + air temperature + people + gulls + crows + vehicles (global) | 3332.44 | 3.98 | 0.14 | 10 | 0.06 |
| Habitat + reproductive stage + people + vehicles | 3332.93 | 4.48 | 0.11 | 5 | 0.05 |
| Habitat + reproductive stage + wind speed + people + vehicles | 3332.89 | 6.44 | 0.04 | 6 | 0.02 |
| Habitat + reproductive stage + people | 3335.24 | 6.79 | 0.03 | 4 | 0.01 |
| Habitat + people | 3358.99 | 30.5 | 0.00 | 3 | 0.00 |
| Habitat + tidal stage + wind speed + air temperature | 3360.78 | 32.3 | 0.00 | 5 | 0.00 |

^a Total observations from a pool of 151 adults.

^b Akaike's Information Criterion corrected for small sample size.

^c Difference between the AIC_c value between each model and the top model.

^d Model likelihood.

^e Number of parameters within the model (site was included as a random effect in all models).

^f Akaike weight.

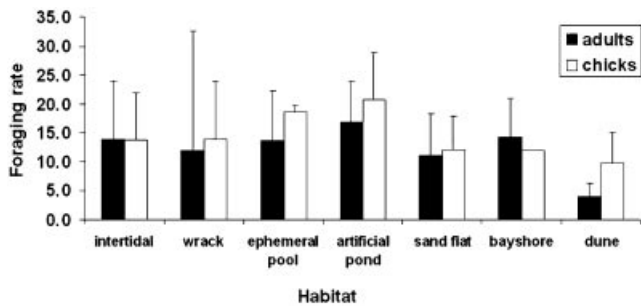


Figure 2. Mean foraging rates (pecks/min) and standard deviations for piping plover adults and chicks in each foraging habitat within New Jersey during the 2007–2009 study. Absence of error bars indicates that only 1 individual was observed in that habitat.

Because age class was deemed to be an important explanatory variable, we ran all further regressions on adults and chicks separately. Differences among sites explained a large proportion of the variation in foraging rates in this regression model as well. Because the level of human disturbance, predator community, vegetation composition, and geomorphology were similar at the 4 study sites, we contend that the availability of high quality foraging habitat was the most influential difference in study sites. Our second set of regression models teased apart environmental and behavioral influences on foraging rates, so we included site as a random effect in all models (Bolkin et al. 2009).

The top-ranked model in the second regression analysis included foraging habitat, reproductive stage, tidal stage, and number of people and moving vehicles present within 50 m and explained the most variation in adult foraging rates (Table 2). A second model including these variables and wind speed reported a ΔAIC_c score < 2 ; therefore, we model-averaged the parameter estimates included in these 2 best models (Table 3). Of the 5 habitats in which we observed plovers feeding, effect size was highest at artificial tidal ponds

Table 3. Model-averaged parameter estimates and relative importance values for variables affecting adult piping plover foraging rates in New Jersey, 2007–2009.

| Parameter | Estimate | 95% CI | |
|--------------------|----------|--------|-------|
| Intercept | 11.78 | 10.07 | 13.49 |
| Habitat | | | |
| Intertidal | 3.97 | 2.45 | 5.49 |
| Wrack | 1.37 | -0.46 | 3.20 |
| Ephemeral pool | 2.65 | -4.62 | 9.92 |
| Tidal pond | 5.52 | 3.84 | 7.20 |
| Bay shore | 2.32 | 0.03 | 4.61 |
| Sand flat | -2.30 | -4.34 | -0.26 |
| Reproductive stage | | | |
| Pre-nesting | -1.66 | -3.52 | 0.20 |
| Nesting | -0.65 | -1.52 | 0.22 |
| Brooding | 0.57 | -0.41 | 1.55 |
| Fledging | -0.65 | -2.19 | 0.89 |
| Post-breeding | 4.49 | 2.69 | 6.29 |
| People | -0.80 | -1.06 | -0.54 |
| Vehicles | -1.87 | -3.26 | -0.48 |
| Tidal stage | | | |
| Low | 3.98 | 3.05 | 4.91 |
| High | 1.62 | -1.36 | 4.60 |
| Wind speed | 0.01 | -0.02 | 0.04 |

(5.52), followed by the intertidal zone (3.97). Positive effects of ephemeral pools (2.65) and bay shores (2.32) on adult foraging rates were 48% and 42% lower than artificial ponds, respectively. Conversely, sand flats (-2.30) had an equal but opposite effect on foraging rate, when compared to bay shores. The results also indicated that foraging rate was highest for adults during the post-breeding stage. In addition, vehicles had a 2.3 times larger effect on foraging adults than people. Finally, foraging rates during low tide were higher than at high tide by a factor of 2.5, as would be expected.

Factors explaining chick foraging rates varied somewhat from the adults. The top models for this age group did include foraging habitat and number of people; however, the presence of avian predators also clearly affected chick foraging rates (Table 4). The model-averaged parameter estimates for the 2 top-ranked models indicated that bay shores, artificial tidal ponds, and ephemeral pools all had similar positive effects on chick foraging rates (Table 5). Effect sizes for dunes (-4.33) and sand flats (-3.58) were also strong, but negative. People and gulls had modest negative effects on chick foraging rates, with effect sizes of -1.64 and -0.08, respectively. Finally, crows reduced chick foraging rates by a factor of 10 times greater than the number of people.

The calculated mean squared prediction error for the validation data was 67.2, on the same order of the mean squared error of the regression model (74.7). For the chick external data set, the mean squared prediction error was 61.3, similar to the mean squared error of 54.9 for the regression model. These data suggest that the regression models reliably predict piping plover foraging rates.

DISCUSSION

We identified significant drivers of foraging rates and used them to evaluate the success of the Lower Cape May Meadows habitat restoration project. Our top-ranked models may potentially be applied to the broader Atlantic Coast piping plover population. The analysis quantified the negative effect of human disturbance on foraging piping plovers, as number of people appeared in the top models for both adults and chicks. As expected, chicks are impacted more severely than adults by human activities, due to chicks' increased vulnerability as flightless animals. Vehicles have a greater negative impact on adult plovers than people on foot, presumably due to their large size, noise, and speed. Although vehicles were not included in the chick foraging models because most vehicles are banned from New Jersey beaches by the time the chicks hatch, destructive impact of vehicles has been clearly documented (Flemming et al. 1988, Melvin et al. 1994).

Environmental variables play a role in defining adult foraging rates. In our study, higher wind speed appears to increase foraging rates, which is not supported by other foraging studies where environmental factors are largely influential (Pienkowski 1983, Beauchamp 2006). Both the ephemeral pools at our study sites and the artificial ponds at Cape May are generally closer to dunes than is the intertidal

Table 4. Model selection results of the top 10 models of foraging piping plover chicks ($n = 83$)^a in Lower Cape May Meadows, Barnegat Light, North Brigantine Natural Area, and Avalon, New Jersey, 2007–2009.

| Model | AIC _c ^b | ΔAIC _c ^c | ML ^d | K ^e | w ^f |
|---|-------------------------------|--------------------------------|-----------------|----------------|----------------|
| Habitat + people + crows | 1112.45 | 0 | 1.00 | 4 | 0.53 |
| Habitat + people + gulls + crows | 1113.23 | 0.79 | 0.68 | 5 | 0.36 |
| Habitat + tidal stage + wind speed + air temperature + people + gulls + crows | 1117.78 | 5.33 | 0.04 | 8 | 0.04 |
| Habitat + people | 1117.81 | 5.36 | 0.04 | 3 | 0.04 |
| Habitat + people + gulls | 1118.84 | 6.40 | 0.02 | 4 | 0.02 |
| Habitat + tidal stage + crows | 1120.72 | 8.27 | 0.01 | 4 | 0.01 |
| Habitat | 1124.21 | 11.8 | 0.00 | 2 | 0.00 |
| Wind speed + crows + people | 1132.30 | 19.9 | 0.00 | 4 | 0.00 |
| People + crows | 1141.79 | 29.3 | 0.00 | 3 | 0.00 |
| People + crows + gulls | 1143.77 | 31.3 | 0.00 | 4 | 0.00 |

^a Number of total observations from a pool of 108 chicks.

^b Akaike's Information Criterion corrected for small sample size.

^c Difference between the AIC_c value between each model and the top model.

^d Model likelihood.

^e Number of parameters within the model, including year as a random effect (site was included as a random effect in all models).

^f Akaike weight.

zone and may be somewhat protected from prevailing winds. Because foraging rates were higher at both ephemeral pools and artificial ponds, the effect of wind speed in our study may be skewed. Low tide increased foraging rates, which supports the literature suggesting that shorebirds primarily forage at low tide when low-lying areas are exposed (Burger 1991, Fraser et al. 2005, Jing et al. 2007).

Reproductive stage also largely influences adult foraging rates, but because the confidence intervals for most of these variables straddled 0, reliable inferences of effects cannot be made (Burnham and Anderson 2002). The exception was the post-breeding stage, where confidence intervals were relatively narrow. As expected, post-reproductive adults no longer must fight for a prime territory, guard a nest, or look after chicks (Haig and Elliott-Smith 2004). The lack of breeding constraints naturally leaves more time for foraging.

Although chick foraging behavior is affected by human disturbance, our analysis suggests that the presence of avian predators had a much greater influence. Presence of crows had a remarkably large impact on chick foraging rates, >10 times that of people and orders of magnitude greater than gulls. Crows are large, intelligent, and persistent predators (Marzluff and Angell 2005) that were often

observed perched somewhere within the foraging habitat. In addition, they seemed to ignore adult piping plover attempts to mob or distract them. Even a crow flying overhead elicited a defense call from brooding adults and a prolonged fleeing response from the chicks. Although crows are an established predator of piping plovers, their role as human commensals has led to rapidly expanding populations worldwide (Marzluff et al. 2001), potentially decreasing reproductive success in ground-nesting birds. In contrast, gulls lowered chick foraging rates only slightly, most likely because most gulls in the vicinity of foraging chicks were flying overhead in transit, foraging on invertebrates, or resting. Most gulls had no apparent interest in the plovers, and chick foraging behavior was not affected by presence of gulls in most cases.

The foraging habitat itself had a significant impact on the foraging behavior of both adults and chicks. Adults foraged at high rates at the artificial ponds, intertidal zone, and bay shore and at low rates on sand flats. Chicks foraged at high rates along bay shores, artificial ponds, and ephemeral pools and at low rates on sand flats and in dunes. The intertidal zone offers an important food source for shorebirds due to the density of marine invertebrates (Defeo et al. 2008); however, this habitat is also the site of the most active human recreation at the beach. Because adults are less vulnerable than chicks to human traffic because of their ability to fly away quickly, adults can forage in this zone at normal rates for a much longer period of time than can chicks. Unless the disturbance is constant, adult piping plovers can still take advantage of this valuable foraging habitat. Sand flats negatively impact foraging rates for both adults and chicks, most likely due to a combination of factors. First, sand flats are dry and cannot support the diversity and abundance of marine or freshwater invertebrates that moist substrates can (Collazo et al. 2002, Fraser et al. 2005). Also, this habitat is expansive with little refuge available, so adults must be much more vigilant against predators. Dunes greatly reduce chick foraging rates because of limited prey items in this dry habitat. Dunes do offer refuge for chicks within the vegetation, and

Table 5. Model-averaged parameter estimates and relative importance values for variables affecting piping plover chick foraging rates in New Jersey, 2007–2009.

| Parameter | Estimate | 95% CI | |
|-----------------|----------|--------|-------|
| Intercept | 15.7 | 14.4 | 17.0 |
| Habitat | | | |
| Intertidal | 0.59 | -1.61 | 2.71 |
| Wrack | -0.11 | -1.77 | 1.54 |
| Ephemeral pool | 5.16 | 1.83 | 8.49 |
| Artificial pond | 5.37 | 3.89 | 6.84 |
| Bay shore | 6.16 | 4.13 | 8.19 |
| Sand flat | -3.58 | -5.37 | -1.78 |
| Dune | -4.33 | -6.09 | -2.57 |
| People | -1.64 | -2.15 | -1.13 |
| Gulls | -0.08 | -0.11 | -0.05 |
| Crows | -11.84 | -16.0 | -7.64 |

the choice to forage in this habitat reflects the tradeoff between safety and sustenance (Burger 1994). Finally, the large standard error associated with the parameter estimates for chick foraging rates along the intertidal zone and wrack line, and the estimates for adult foraging rates along the wrack line and at ephemeral pools prevents reliable inference.

We conclude that the Lower Cape May Meadows restoration project was initially successful but did not sustain its early benefits to piping plovers. Productivity levels at Cape May exceeded the USFWS recovery goal of 1.5 chicks fledged per nesting pair for 2007 and 2008 and far exceeded the productivity levels of the 3 reference sites (Table 1). This elevated reproductive success can be linked to the presence of the artificial ponds in Cape May, which offered high quality foraging habitat for piping plovers. Both adults and chicks exhibited higher mean foraging rates here than in any other habitat. In addition, they spent considerably lower amounts of time being vigilant or running away from perceived threats. The importance of this habitat is further supported by the behavior of brooding adults, bringing their chicks to the tidal ponds almost exclusively in 2007 and 2008.

Although characteristics of the artificial tidal ponds themselves were not directly measured in this study, we suggest that the location of the ponds and the immediate landscape around them may contribute to their quality. The ponds are located behind the protective dune, so they are somewhat isolated from the disruptive recreational activities on the beachfront. In addition, in 2007 and 2008 moderate vegetative cover existed near the pond edge, which provided an almost immediate refuge for chicks. However, in the intertidal zone or wrack line, chicks must traverse the entire beach in search of cover. In the presence of a predator, we repeatedly observed chicks quickly moving into the vegetation and reemerging as soon as the threat passed. If little energy is expended on predator avoidance behaviors at these ponds, chicks may be able to forage at a higher rate for proper growth and development.

During a winter beach replenishment initiative in early 2009, the Corps removed all the vegetation surrounding the artificial ponds, eliminating these refuge sites along pond edges. In addition, fish crows (*Corvus ossifragus*) were presumably responsible for >75% of chick loss during the breeding season (T. Pover, New Jersey Division of Fish and Wildlife, personal communication). During that year, we observed plover broods predominantly foraging within the dunes at Cape May, presumably as a response to both the presence of the crows and the absence of suitable cover at their preferred foraging habitat. Productivity declined dramatically at Cape May in 2009, falling below the USFWS recovery goal for the first time since the completion of the restoration project. These events further support the concept that the presence of high quality non-ocean foraging habitat increases piping plover reproductive success.

MANAGEMENT IMPLICATIONS

Artificial tidal ponds are an effective restoration initiative to improve habitat quality of sandy beach ecosystems. Artificial tidal ponds may even be superior to naturally occurring

foraging habitats if they are adaptively managed to maximize both chick protection and mobility. Moderate vegetative cover surrounding the perimeter of the artificial ponds may be critical to maximize chick foraging potential. More research is required to precisely define factors such as the appropriate placement of ponds within the landscape, the target density for vegetation, and the thresholds at which predation is likely or chick mobility is restricted. Further behavioral and habitat research on artificial foraging ponds elsewhere may refine the findings documented here.

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