Experimental Study of Shorebird Response to New Trail Use in the South Bay Salt Pond Restoration Project

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Introduction. Providing public access while protecting the abundance and diversity of waterbirds are two important objectives of the South Bay Salt Pond Restoration Project (Project) (SPBP FEIS/R 2007). These are potentially-competing goals as recreational activities have been found to have a range of impacts on species. A major focus of the Project's first phase is to develop a number of new trails and amenities, such as overlooks and interpretive displays, and to enhance some existing trails. Based on concerns about the potential impacts of trail use on endangered California clapper rails and salt marsh harvest mice, species that live in vegetated tidal marsh, trails are not being placed next to existing or restoring tidal marsh habitat. Rather, trails are being located on levees next to ponded habitat, which is used by numerous other species including wintering shorebirds. Given the proximity of trails to ponded habitat, public access in the Project is expected to have the greatest effect on shorebirds and other pond-dependent species. Managers need more information on how wintering shorebirds in these ponds respond to trail use. This study assessed the short-term impacts of new trail use on foraging shorebirds and provides managers with information useful in the design of trails that protect species while allowing public appreciation of wetlands and wildlife.

San Francisco Bay is one of only a few sites in the world where more than 1 million migratory shorebirds stop or over-winter (Bishop and Warnock 1998, Page et al. 1999). This estuary provides seasonal habitat for greater than 50% the Pacific Flyway population of numerous migratory shorebird species, including western (*Calidris mauri*) and least (*C. minutilla*) sandpipers, short- (*Limnodromus griseus*) and long-billed dowitchers (*L. scolopaceus*), and marbled godwits *(Limosa fedoa*), as well as resident American avocets (*Recurvirostra americana)* and black-necked stilts (*Himantopus mexicanus*)(Page et al. 1999).

Research has shown impacts to foraging birds from recreational activities. For example, abundance (Tarr, et al. 2009), spatial distribution (Pfister et al. 1992) and time foraging (Burger and Gochfeld 1991) can be negatively affected by human use, both by walkers (Burger and Gochfeld 1991) and by vehicles (Tarr, et al. 2009).

Several studies have characterized foraging shorebird response to existing trails or public access. In a study of shorebird response to beach activities, Lafferty (2001) did not find "an association between the spatial distribution of birds and the spatial distribution of people along the transects" and found that, although human activity varied primarily between weekdays and weekends, bird density varied most strongly with season and tide. Trulio and Sokale (2008) studied wintering shorebirds in foraging habitat at 3 tidal locations around the San Francisco Bay. Despite major differences in the level of human activity at trail versus non-trail sites, they found the number of shorebirds, species richness, or proportion of shorebirds foraging did not differ between trail and non-trail site. Tangential rather than direct approach to birds, lack of motorized approach, and the small size of shorebirds relative to other waterbirds may have contributed to these results (Trulio and Sokale 2008). At other locations where foraging shorebirds have exhibited few adverse responses to overall trail use, local or landscape-level factors, such as habitat quality or predation risk, seemed to be greater factors in bird presence and foraging than trail use (Gill et al. 2001*a*; Yasue 2005, 2006).

While these studies provide information on sites with existing public access, studies have not characterized shorebird response to new trail use at sites not previously open to the public. Research is also needed using an experimental approach to assess shorebird response to trail use, as multiple variables may have affected bird responses found in previous studies (Hill, et al. 1997, Tarr, et al. 2008).

This study examined how bird abundance, species richness and bird behavior were affected by trail users walking adjacent to shallow-water, ponded sites where wintering shorebirds forage. All of the study sites, former salt evaporation ponds, had been closed to public use. We also collected data on flight initiation distance (FID), the distance at which animals first react to disturbance (move, walk, fly) (Glover, et al. 2011). FID is often considered a good method for estimating for buffer distances (Blumstein et al. 2003, Glover, et al. 2011). Recently, Glover, et al. (2011) studied factors that influence the flight initiation distance (FID) of shorebirds. They found two key factors resulting in shorter flight distances were the size of the bird and the starting distance of the approaching human. Their findings indicated that the FID of very small to moderately small shorebirds, considering different approach starting distances, was under 40m. Blumstein (2003) found similar starting distance results and other studies have documented the effect of bird size (Blumstein, et al. 2003, Rodgers and Schwiekert 2003).

We determined shorebird responses to trail walkers on levees adjacent to ponds with borrow ditches and to walkers on boardwalks without borrow ditches. Borrow ditches, moats of water approximately 1-3m deep and 10-30m wide, exist next to most levees around the San Francisco Bay, because the material used to make the levees was originally dredged from the ponds, producing these landscape features. Thus, trails located on levees in the San Francisco Bay typically have a borrow ditch next to them. Because shorebirds are very small, most of the borrow ditches are too deep for them to use for foraging. Birds are most likely to forage at the edges of the ditch and further out into the pond where the water is shallow. Thus, borrow ditches, especially wide ones, may function as de facto shorebird buffers for trails on levees or at least reduce the amount of foraging area near levees. Boardwalks, which extend through the ponds to supply maintenance access to power transmission lines, do not have borrow ditches next to them and these sites provide a clearer indication of the distance at which birds will respond to trail walkers where there is no borrow ditch or obvious buffer. The water depth adjacent to the boardwalks varied as the bathymetry of the pond bottom mirrored the dendritic channels of the salt marsh habitat that was drown to create the salt evaporation ponds.

Our study sites had two general borrow ditch widths, wide (~16-30m) and narrow (~6-10m). We hypothesized that birds would respond differently at wide borrow ditch patches compared to sites with a narrow or no borrow ditch. We expected birds at narrow borrow ditch sites to behave similarly to those at the boardwalk patches as both conditions allowed shorebirds to be closer than 30-40m from the levee, at typical flight initiation distance of these birds.

<u>Research Objectives</u>. We addressed the general question: How do shorebirds respond to new trail use—as measured by numbers of birds, species richness and behavior—before, during and after experimental trail walker use?

Specifically, we tested these hypotheses (H) and research questions (RQ):

H1: There is no difference in the number of birds or species richness before versus after control observations at either wide borrow ditch sites or narrow/no borrow ditch sites.

H2: There is no difference in the numbers of birds and species richness before versus after experimental trail walks at either wide borrow ditch sites or narrow/no borrow ditch sites.

H3: There is no difference in the number of birds by species before experimental walker approach versus during approach (i.e., in response to approaching trail walkers).

H4: Birds will not be found at greater distances from trail users on levees with wide borrow ditches compared to levees with narrow borrow ditches or boardwalks with no borrow ditch.

RQ1: How far do birds of different species stay from an active trail levee?

RQ2: At what distance from trail users do birds first exhibit flight responses (FID)?

RQ3: What behaviors did birds exhibit in response to experimental trail walkers?

Based on our findings, we provide recommendations for how trails next to foraging shorebird habitat can be designed and managed to protect shorebirds in the Project Area.

<u>Study Sites</u>. We studied shorebird response to experimental trail use at 8 different sites, 5 on non-trail levees at ponds E6B and R4, and 3 boardwalk locations in ponds E6A and A22 (Table 1 and Figure 1). Four levee sites had wide borrow ditches (~16-30m wide) next to the levee and one had a narrow borrow ditch (~6-10m wide). Borrow ditch widths were measured using Google Earth. There were no borrow ditches next to any of the boardwalks. All sites were at shallow, non-tidal, managed, saltwater ponds. Ponds used were known areas of high shorebird use, based on previous research (Takakawa, et al. 2006).

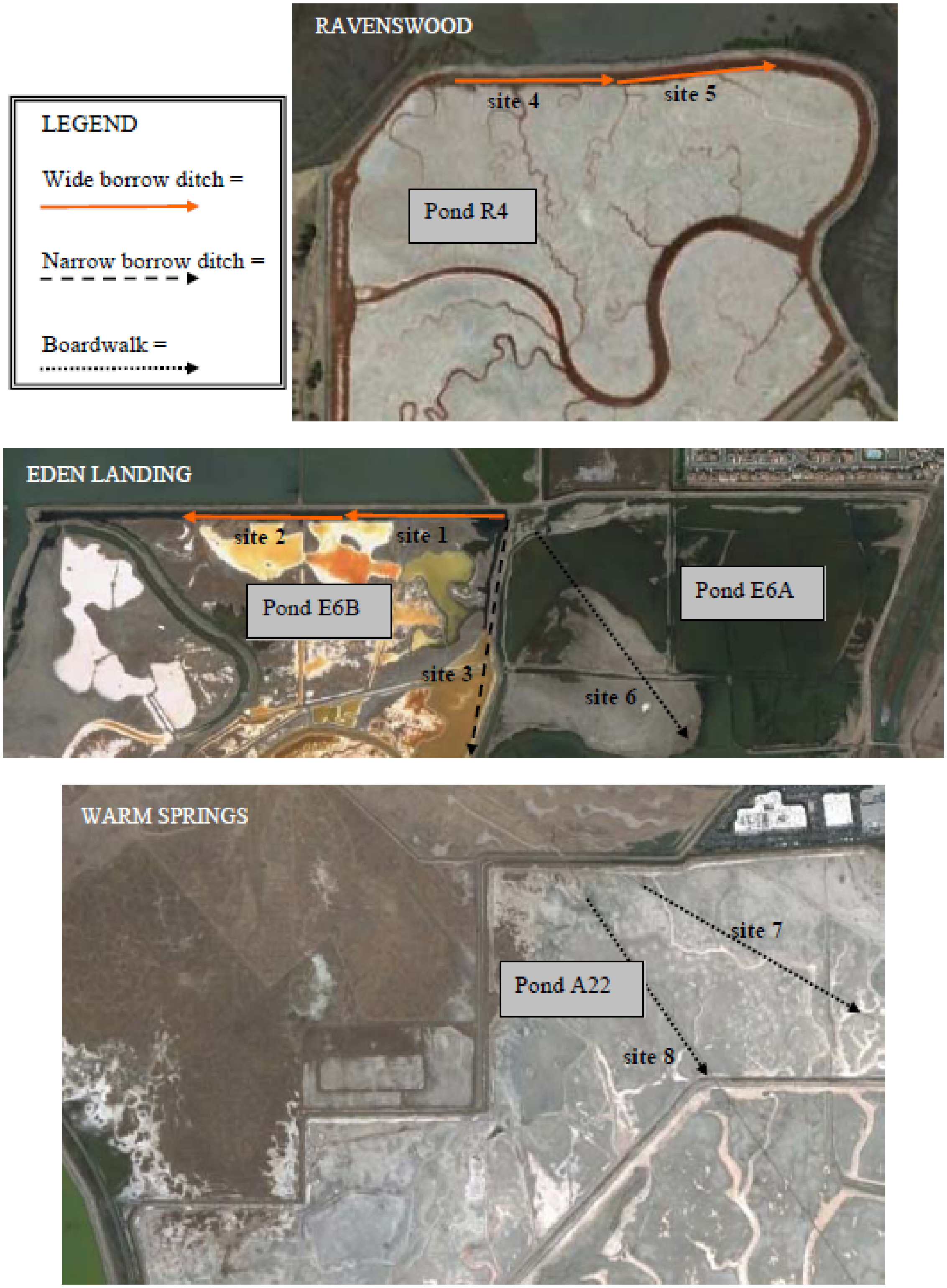
Each levee and boardwalk site was marked every 30m with short wooden stakes or mounted numbers on the boardwalk support beams visible to an observer with a scope. These markers delineated "observation patches", the areas in which data were collected. The number of patches varied by site based on the length of the levee/boardwalk and observation conditions, such as obscuring vegetation, change in levee direction, absence of adjacent water, or poor boardwalk conditions.

Table 1. List of Study Sites and Key Qualities

Site	*Pond*	*Number of Patches*	*Levee* (borrow ditch width)*	*Boardwalk*	*Number of Trials Obtained*
1	E6B	10	√ - W		11
2	E6B	9	√ - W		10
3	E6B	10	√ - N		13
4	R4	10	√ - W		9
5	R4	13	√ - W		11
6	E6A	18		√	8
7	A22	20		√	8
8	A22	20		√	6

* Borrow ditch widths: W = Wide (~16-30m wide) or N = Narrow (~6-10m wide)

Figure 1. Locations of study sites in Ponds R4, E6A, E6B, and A22



Methods. From November 2010 to May 2011, we collected data on bird numbers, species richness (number of different species per observation), and bird behavior at 30m observation patches. No boardwalk or levee was visited two days in a row. Each visit included an observer using a scope to count birds at a distance and 2 trail walkers. For each observation session, we randomly selected a 30m observation patch for the trial. If there were <5 birds in the 30m patch selected, another patch within the site was randomly selected. We tried to observe no patch more than once during the study, but because of the way the birds used the sites, we did sample 7 levee and 3 boardwalk patches more than once. The area observed included the levee toe, the entire borrow channel (if there was one), and at least 10m beyond the borrow channel into the pond. The size of the observation area was approximately the same size for each trial, 30m long and approximately 30-50m wide depending on daily conditions. During any particular trial, before and after observation areas were the same size as the observations were conducted by the same person. The observer on the scope was at least 60m from the near end of the observation patch to avoid disturbing the shorebirds. We determined this distance was adequate to avoid disturbing birds based on pilot trials at the site and flush distances found for other *Calidris* species (Glover, et al. 2011), knowing that the starting distance of walkers can influence FID (Blumstein 2003). We never collected data if there were predators present or if birds exhibited fleeing behavior. We waited at least 10 minutes after our arrival before conducting experimental walks.

We collected data on bird response to new trail use as simulated by experimental walks in which two people walked down a levee or boardwalk and then back. For each observation session, an observer using a scope counted the birds by species, noting behavior, in the observation patches immediately before and immediately after we conducted experimental trail walks.

At the request of peer reviewers, before each experimental trial, the observer on the scope conducted "control observations" by counting the birds in the selected patch without walkers, waiting 10 minutes (the approximate time for an experimental walk) and then counting the birds again. There were no walkers during these control observations. The purpose of the control "before and after" observations was to assess whether ambient factors might affect the number of birds or species richness over the 10-minute observation period.

To determine how far birds stayed from trail-use levees, on their return walk the walkers stopped within each third of the patch and, using a Bushnell Elite 1500-7 x 26 Rangefinder (accurate to ± 1m), measured the perpendicular distance to the closest birds they saw in that third of the patch.

To estimate the distances at which birds first responded to walkers (FID), the walkers recorded each species and the number of birds before the initial response; then they recorded the number of birds by species that initially responded to the disturbance. We called this "flock response" data. When the first bird in the patch responded (run, fly, call), the walkers used the 30m patch markers to determine their distance to that bird, as measured along the levee perpendicular to the bird's location. If the entire flock flushed, the distance to the closest bird in the flock was recorded. The walkers recorded response behavior and distance moved by the first bird or the flock responding to their approach.

We determined the responses for individual birds of five common species in the study area using focal animal observations. The observer on the scope selected an individual bird or flock of a particular species before walkers started their walk. The observer recorded species, location in patch, the bird's initial behavior, and the behavior of the bird(s) and distance to walkers in response to the outbound walk.

Analysis. The data were analyzed with Systat 13 (Systat Software, Inc., Chicago, IL). The number of birds was log transformed (log + 1) to meet assumptions for normality and equality of variances. To test for differences between before and after control observations (H1) and between before and after experimental trail walks (H2) at wide versus narrow/no borrow ditch sites, we used paired t-Tests. Species richness could not be transformed to meet the normality assumption, so hypotheses 1 and 2 were tested using non-parametric Wilcoxon Signed-Rank tests. Wilcoxon Signed-Rank tests were used to compare whether the number of birds before approach differed from the number of birds during approach by species (H3). Kruskal-Wallis tests assessed if borrow ditch width influenced how far birds were from trail users (H4).

We used the average distances (means ± SE) birds stayed from trail users during the experimental walks adjacent to narrow or no borrow ditch sites to assess avoidance distance of different species during walks (RQ1). Flock response data were used to estimate flight initiation distance (FID) as trail users approached birds (RQ2). In the field, walkers estimated the straight line distance along the levee/boardwalk from the trail users to the point perpendicular to the responding bird. This distance is relatively accurate for birds located next to the levee or boardwalk, but not for birds out in the pond. To estimate maximum flight initiation distances, using 30m as the farthest distance birds would be from the levee in the pond (a typical limit of our observation zone), we used the hypotenuse of the right angle formed by the estimated distance along the levee/boardwalk to the responding bird and the 30m leg. Behavioral responses were analyzed qualitatively (RQ3).

Results. We conducted 76 observations, 41 at wide, 13 at narrow at borrow ditch patches and 22 at boardwalk patches. For each of these observations, we conducted control observations (before and after 10 minutes without walkers) and experimental trail walks (before and after trail walkers). At the levee sites (wide and narrow borrow ditch patches), we sampled 38 unique patches and 17 unique patches at the boardwalks. We collected data for 68 focal animal observations.

By far, the most common species we observed were western/least sandpiper (*Calidris mauri and C. minutillai*) and dunlin (*Calidris alpina*). Of the birds we counted before our trail walks, 84% belonged to these species. Other relatively common species were: American avocet (*Recurvirostra americana)*, long-billed curlew (*Numenius americanus*), willet (*Tringa semipalmata*), semi-palmated plover (*Charadrius semipalmatus*) and greater/lesser yellowlegs (*Tringa flavipes* and *T. melanoleuca*). Species we saw infrequently to rarely were: black-necked stilt (*Himantopus mexicanus*), marbled godwit *(Limosa fedoa*), long/short-billed dowitcher (*Limnodromus griseus* and *L. scolopaceus*), red-necked phalarope (*Phalaropus lobatus*), black-bellied plover (*Pluvialis squatarola*), snowy plover (*Charadrius nivosus*), killdeer (*Charadrius vociferus*), and sanderling (*Calidris alba*).

Hypothesis 1: Control Observations at Wide versus Narrow/No Borrow Ditch Sites. We found no difference in the number of birds before versus after for all control observations (t=-1.743, df=1, p=0.085, n=76) or when analyzed by wide (t=-1.711, df=1, p=0.095, n=41) or narrow/no borrow ditch (t=-0.720, df=1, p=0.565, n=35). At wide borrow ditches, the species richness was lower in after versus before observation (z=-2.675, p=0.007; n=41), but was greater at narrow/no borrow ditch sites (z=0.058, p=0.130; n=35) patches. For all patches combined, species richness did not differ before versus after control observations (z=0.452, p=0.651, n=76).

Table 2 gives the untransformed means (SE). The control observations were not used in further analyses.

Hypothesis 2: Experimental Trail Walks at Wide versus Narrow/No Borrow Ditch Sites. For experimental trail walks, the difference in bird number before versus after walks was significant (t=-2.758, df=1, p=0.007, n=76); the average number of birds was approximately 2.1% lower after (37.9±7.4) walks versus before (38.7±5.3). At wide borrow ditch sites, the difference in numbers was not significant (t=-1.182, df=1, p=0.244, n=41), while at narrow/no borrow ditch sites it was (t=-2.758, df=1, p=0.015, n=35) (Figure 2).

The narrow borrow ditch patches had a strong effect on these findings. Analyzed alone, narrow borrow ditch sites had significantly fewer birds after walks versus before (t=-2.208, df=1, p=0.046, n=13). When these were removed from the overall analysis, the level of significance changed from p=0.007 (n=76) to p=0.062 (n=63). When patches at the boardwalks (no borrow ditches) were analyzed without the narrow borrow ditch patches, the number of birds before versus after walks was not significantly different (t=-1.533, df=1, p=0.140, n=22).

There were significantly fewer species for all patches combined before versus after walks (z=-2.698; p=0.007; n=76). At wide borrow ditch patches the difference was not significant (z=-1.213; p=0.225; n=41), while it was significant at narrow/no borrow ditch sites (z=-2.461; p=0.014; n=35). When analyzed without the narrow borrow ditch patches, the difference in species richness before versus after walks at the boardwalk patches remained significant (z=-1.903, p=0.057, n=22). Table 2 gives the means and SEs for the untransformed data.

Figure 2. Mean (SE) for number of birds (log transformed) before and after experimental trail walks past patches with wide (n=41) and narrow/no (n=31) borrow ditches.

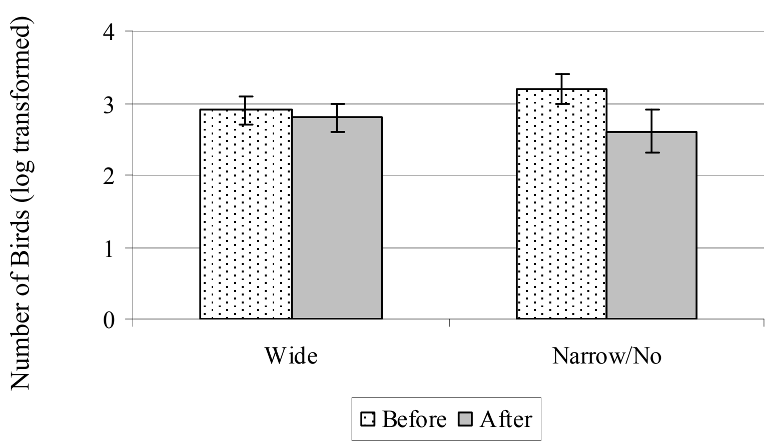


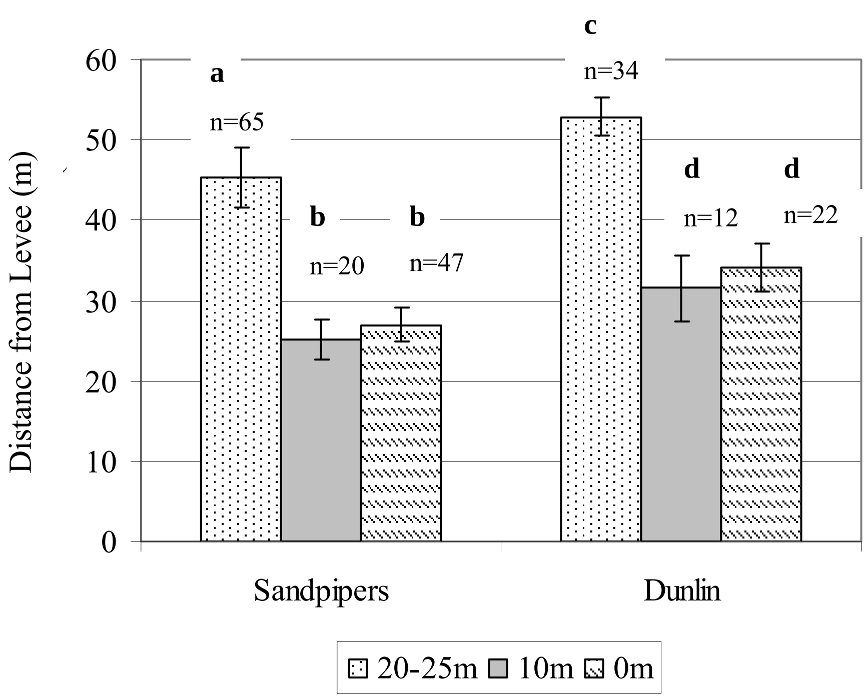
Table 2. Mean (SE) numbers of birds and species richness (untransformed data) for levees and boardwalks, before and after for control and experimental trail walks

		Control		*Experimental Trail Walk*	
		Before	*After*	*Before*	*After*
Number of Birds	Wide (n=41)	36.9±6.5	34.6±6.7	34.6±6.7	35.2±7.5
	Narrow/No (n=35)	42.8±8.9	43.2±8.3	43.5±8.2	41.2±13.5
Species Richness	Wide (n=41)	2.4±0.2	2.2±0.2	2.1±0.2	1.9±0.2
	Narrow/No (n=35)	2.1±0.2	2.4±0.2	2.5±0.2	2.0±0.2

Hypothesis 3: Differences in bird numbers during experimental trail walks. The number of birds differed significantly before the walk compared to during the walk for sandpipers (z=-5.773, p=0.000, n=69) and dunlin (z=-3.933, p=0.000, n=41). The means (SE) before and during walks for sandpipers were 23.9 (±3.6) and 18.3 (±3.4), respectively, and for dunlin were 20.5 (±4.5) and 13.6 (±3.8), respectively. Numbers before and during walks differed for yellowlegs (z=-2.236, p=0.025, n=12), but not for willets (z=-1.732; p=0.083, n=15). Results for black-necked stilts (z=-1.633, p=0.102, n=7), semi-palmated plovers (z=-1.342, p=0.180, n=7), and avocets (z=-1.826, p=0.068, n=9) were not significant and for long-billed curlews (z=-1.890, p=0.059, n=8) were nearly so, but the sample sizes were quite small for these species.

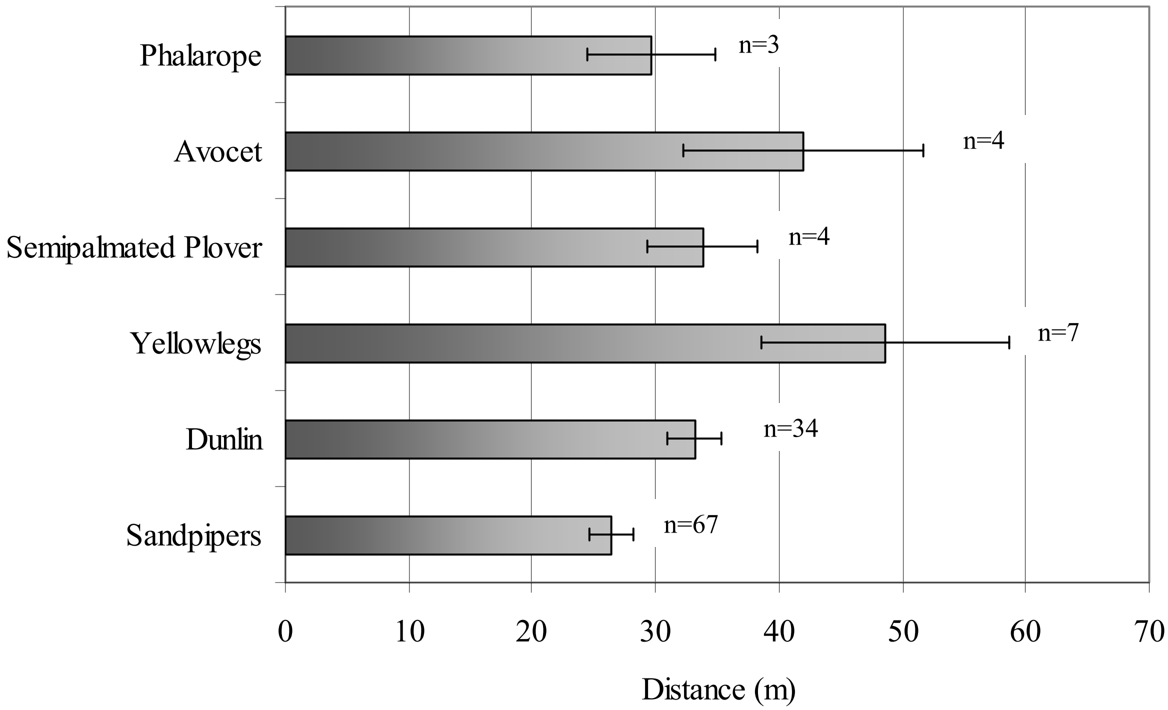
Hypothesis 4: The influence of borrow ditch width on bird distances. The width of borrow ditches next to where walkers were passing had a significant impact on the distances sandpipers (Kruskal-Wallis=34.6; p=0.000) and dunlin (Kruskal-Wallis=24.1; p=0.000) stayed from trail users. Specifically, we found that birds of both taxa were significantly farther from trail users when there was a wide borrow ditch (20-25m) compared to when then when there was a narrow borrow ditch (10m) or no borrow ditch, as occurred at the boardwalks (Figure 3).

Figure 3. Distances of sandpipers and dunlin (mean±SE) during experimental trail walks for different borrow ditch widths (20-25m, 6-10m and 0m). Letters show means that were different and the same for sandpipers and dunlin.



Research Question 1: How far did birds stay from trail users during trail walks? As the results for hypothesis 4 showed, at patches with wide borrow ditches, birds were further from trail users than at patches with narrow or no ditches. Given this, the narrow/no ditch conditions provided a better test of bird avoidance distances. Combining data collected during the trail walks for boardwalk and narrow borrow ditch patches only, we found sandpipers and dunlin stayed 26.4m (±1.9) and 33.3m (±2.2), respectively, from active trails. Other species may stay further from active trails, but more data are needed to more reliably determine the avoidance distances for these species (Figure 4).

Figure 4. Distances (means ± SE) that different species stayed from trail users during walks at boardwalk and narrow borrow ditch sites.



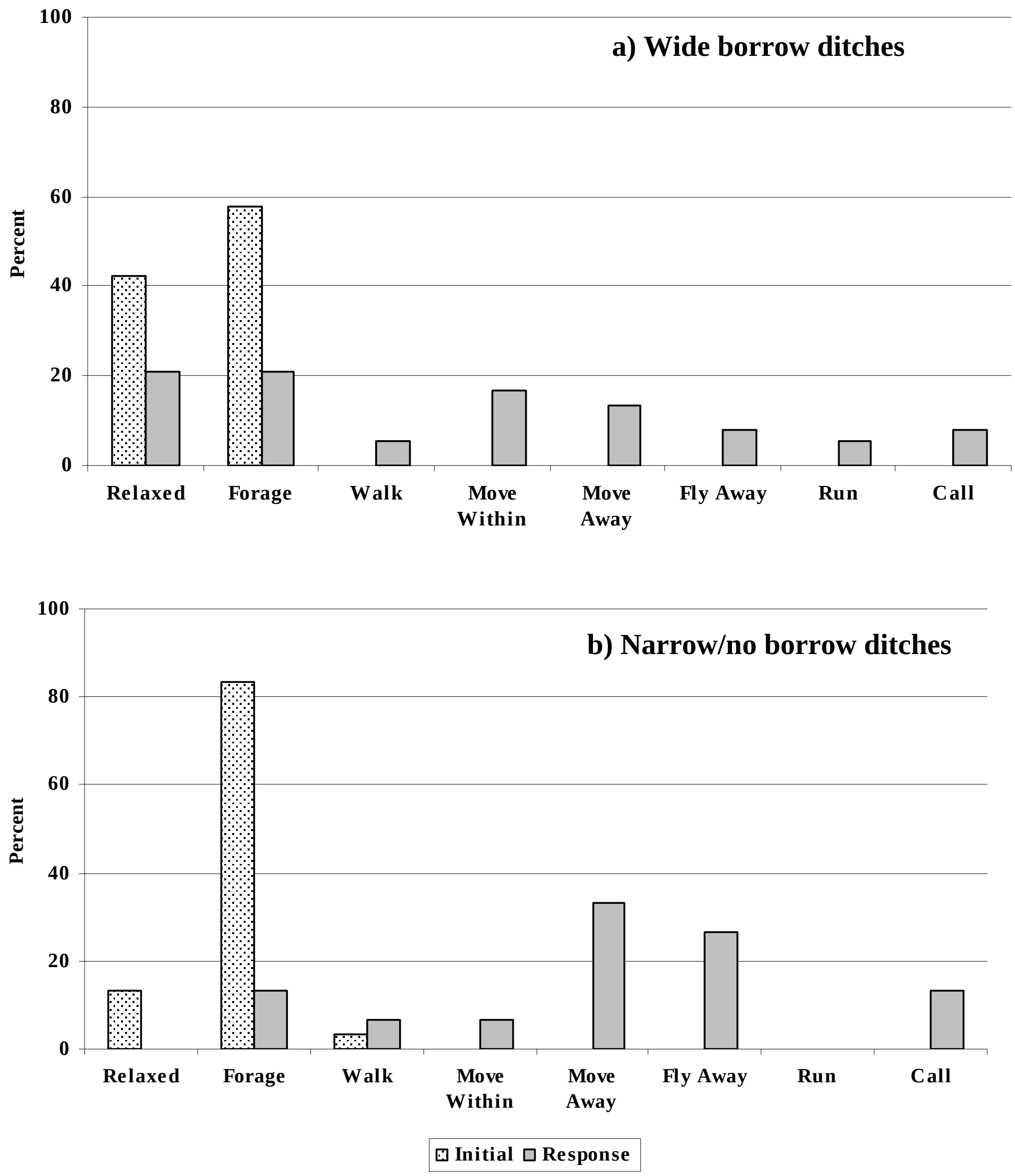
Research Question 2: At what distance from trail users do birds first exhibit flight responses? Flight initiation distances (FID) in response to trail walkers were based on observations at boardwalk and narrow borrow ditch patches only. The mean straight-line distance from walkers to the birds first responding to walkers was 39.2m (±3.9) (n=51). Assuming birds were 30m into the pond when they responded, the average maximum distance from the walkers would have been 49.4m.

Research Question 3: What behavioral responses to trail use did birds exhibit? There was very little difference in bird behavior before versus after experimental walks (Table 3). However, focal animal observations for walkers passing birds for the first time showed differences during walks. For both wide and narrow/no ditches nearly all birds before experimental walks were either foraging or exhibiting relaxed behaviors (sit, stand, sleep or preen) (Figure 5a, b). However, in response to approaching walkers, only 42% of birds at wide borrow ditch sites exhibited these behaviors; the remainder flew or moved away from the patch (21%), moved within the patch, walked, ran, or called (Figure 5a). At narrow/no borrow ditch sites, 13% of birds foraged during trail walks, none exhibited relaxed behaviors; 60% of birds moved or flew away (Figure 5b).

Table 3. Bird behavior before vs. after experimental trail walks at all sites.

Behavior	*Initial Percent (n=170)*	*After Walk Percent (n=143)*
Relaxed	26.4%	26.6%
Forage	72.4%	70.6%
Walk	0.5%	1.4%
Fly Out	0.5%	0 %
Move/Fly Within	0 %	0.7%
Move Away	0 %	0 %
Run	0 %	0 %
Call	0 %	0 %
Swim	0 %	1.4%

Figure 5. Behavioral responses of birds to approaching trail walkers at sites with a) wide borrow ditches (n=38) versus those with b) narrow/no borrow ditches (n=30).



Summary and Discussion. This study characterized the response of shorebirds to new trail use by conducting experimental trail walks at locations where trails did not exist. The results of this study are most applicable to western sandpipers, least sandpipers and dunlin, as they constituted the vast majority of the birds (84%) at our sites. This dominance by sandpipers and dunlin is typical for these ponds. These species constituted 83-84% of the birds Takakawa et al. (2005) counted from 2002 to 2005 in ponds B6A and B6B, where we had four of our eight sites. The results apply best to small shorebirds as our observation distance might have been too close not to disturb larger birds such as herons and egrets. At our sites, the water was extremely shallow and did not tend to attract these larger species. We did, however, regularly see long-billed curlews, one of the largest shorebirds in the area and a bird that forages in habitats from deeper water to uplands. We found our observation distance was adequate to observe this larger shorebird. Further, the control observations did not show differences, overall, in the number of birds or species richness before versus after. These results indicate that, during a 10-minute period, ambient factors were not significantly affecting the birds. One trend we noted was more birds (but not significantly so) at narrow/no borrow ditch patches versus wide ditch sites both before and after walks. This difference may have been due to the greater foraging area available to birds at sites where borrow channels did not occupy part of the area.

We found that the number of birds and species richness differed significantly before versus after we introduced 2 trail walkers; the decrease in bird numbers was only about 2.5% while species richness decreased 18%. Much of the decrease in numbers was due to patches from the narrow borrow ditch site. The behavior of birds did not differ before versus after walks. However, we found the bird numbers and behaviors before walks differed greatly from those *during* walks. For example, the number of sandpipers decreased by over 23% during walks. However, we found that bird numbers and behavior had nearly recovered to pre-walk levels by the time the walkers returned to their starting position (a period of about 10 minutes), indicating that existing birds had either recovered to their original behaviors or new birds had flown in.

It is worth noting that the narrow borrow ditch site had a few qualities that made it different from all the other sites in this study. The levee surface was irregular and bumpy, which did not permit vehicle traffic, unlike the other levees. The levee was not as straight as the other levees or the boardwalks and there was some ruderal vegetation on the levee slope. These factors may have screened walkers from birds until they got relatively close. At all other sites, birds had a clear and open view up and down the levee and boardwalk. Finally, water at this site was most often found close to the levee and was not distributed as regularly out into the pond. These factors may have resulted in more birds flushing and not returning as quickly as at the other sites. These factors suggest the need to study bird response at levees with no vehicle traffic and/or sites with vegetative screening.

The width of the borrow ditch next to the trails had a major effect on the distance birds were from walkers during experimental trials. At wide borrow ditch sites, sandpipers and dunlin were an average of 45m and 52m, respectively, from the levee during trail use. At narrow/no ditch sites, sandpipers and dunlin stayed approximately 25-35m from trail users; other common shorebird species stayed approximately 30-50m away. It seems the wide borrow ditch acted as a buffer, keeping birds further from walkers.

The distances at which birds took flight in response to trail walkers (FID) were approximately 39-50m at narrow/no borrow ditch sites. FIDs are often cited as appropriate buffer distances for avoiding bird response from human disturbance, although many factors influence FIDs (Blumstein 2003). Glover, et al. (2011) found the mean FID for direct approach to sanderlings (*Calidris alba*) was 32±3.5m, to pectoral sandpipers (*C. melanotos*) was 23±7m and to sharp-tailed sandpipers (*C. acuminate*) was 20.3±1.4m at sites in south-eastern Australia. These distances are somewhat shorter than our FID estimates, but fit well with the distances we found birds stayed from us during our walks; sandpipers stayed 26.4±1.9m from active trails with narrow or no borrow ditches and dunlin averaged 33.3±2.2 from walkers. Researchers have found a strong relationship with body mass and FID; the smaller the bird the shorter the FID (Blumstein 2006, Glover et al. 2011). The dominant species at our sites were extremely small body mass birds and would be expected to have an FID of 40m or less, based on Glover et al. (2011). Our findings accorded well with this literature.

During trail walks, we found that bird numbers were significantly lower than before the walk. Sandpiper and dunlin numbers were 23% and 34% lower during walks compared to numbers before. The percent of birds foraging and exhibiting relaxed behaviors at patches next to wide borrow ditches was approximately 60% lower than before the walk; at narrow/no borrow ditch patches, the number was approximately 85% lower. At wide ditch sites, 60% of birds moved/flew away/called in response to trail walkers; this number was approximately 80% at narrow/no borrow ditch sites. Decreased feeding and increased movement caused by walkers at new trail sites could reduce birds' fat stores needed for migration. The energetic costs of short flights for small birds can be great (Nudds and Bryant 2000). In European oystercatchers (*Haematopus ostralegus*), mortality rates rose due to human disturbance more as a result of energy expenditure due to movement rather than reduced foraging (West et al. 2002).

The disturbance caused during walks could be a negative factor as birds were precluded from part of the foraging area and they changed their behavior from foraging to moving. Infrequent trail use may cause more frequent and/or more intense responses than regular, sustained use, to which birds could become habituated. Habituation is a behavioral response in which animals no longer view a particular disturbance as a threat due to repeated exposure. In their study of San Francisco trails, Trulio and Sokale (2008) found no differences in bird numbers, species richness or behavior at trails during trail use compared to locations without trails; these results indicate foraging shorebirds at regularly used trails may habituate to human activity given the tangential approach of walkers (Burger and Gochfeld 1981), lack of motorized vehicles (Rodgers and Schwikert 2003), and the small size of shorebirds (Blumstein 2006). A number of studies have documented foraging and nesting shorebird habituation to human activities (Ikuta and Blumstein 2003). For example, two-banded plover (*Charadrius falklandicus*) flush distances for nesting birds decreased in areas of higher human activity (St. Clair et al. 2010). Thus, continual, tangential, and non-motorized trail use may cause less disturbance—as measured by immediate behavioral responses--than infrequent or high-intensity activities (Hill et al. 1997). It is important to note that, although birds may appear to be habituated, they may still experience impacts from disturbance, such as altered physiological conditions.

The threshold for trail use between levels that disturb shorebirds and those at which they become habituated is not known and can be difficult to determine. Many factors, such as rate of disturbance by predators, poor weather, prey quality/availability, competition and the health of the bird, can change the threshold at which human disturbance will impact bird mortality (Stillman and Goss-Custard 2010). Trail uses such as jogging and the presence of dogs can increase flight distance (Lafferty 2001, Glover, et al. 2011). We found a stronger response (more flying and calling versus walking) by birds closer to levees than those further out in the pond, suggesting that, if people are able to approach birds more closely, birds may respond more strongly. St. Clair et al. (2010) found that the distance at which nesting two-banded plovers responded to approaching walks was less when mammalian predators were present. Also, responses can be species-specific (Blumstein, et al. 2003). Modeling of European oystercatcher behavior indicated this species is not affected by human disturbance up to a critical threshold, after which mortality increases rapidly (Goss-Custard et al. 2006). Such factors should be considered in overall disturbance analyses.

Researchers underscore the importance of quantifying prey availability and quality in order to understand the effect of human disturbance on shorebirds. Birds must balance the intensity of the threat with the quality of the resource they would forego due to their decision to flee (Beale and Monaghan 2004). Gill (2007) recommends assessing the quality and quantity of food resources in the context of risk in order to determine the number of animals that can be supported in an area under various disturbance levels. Stillman and Goss-Custard (2010) note that models of bird response to different conditions requires data on prey energy content and food supply throughout the tidal cycle, among other factors.

Human disturbance is one of many potential stressors shorebirds face. If birds' responses to human disturbance reduce their physical condition, mortality can increase. Even relatively small increases in wintering shorebird mortality can have population level effects (Stillman and Goss-Custard 2010). Quantifying shorebird responses to public access provides managers tools to avoid increasing mortality while providing the public with high quality outdoor experiences. To assist managers with these decisions, researchers have developed a number of models that can be used to predict waterbird responses to habitat changes, and are seeking to make them more user-friendly and accessible to managers (West, et al. 2011). Gathering the appropriate data for such a model to assess the effects of human activity could provide managers with a valuable predictive tool.

Recommendations. Based on our findings we make these recommendations:

1. At new trail locations, based on data from narrow borrow ditch and boardwalk locations, sandpipers, dunlin and other small to medium shorebirds responded to trail uses at approximately 40-50m and stayed approximately 25-55m from trail walkers during their walk, depending on the species. Thus, keeping trail users approximately 50m from foraging habitat will prevent nearly all trail walker disturbances to the dominant wintering foraging shorebirds, especially western and least sandpipers, dunlin, willets and yellowlegs. We did not test bird response to other trail uses such as bicycling, jogging, or presence of dogs or the response of larger waterbirds, such as herons and egrets.
2. Levees adjacent to wide borrow ditches are better locations for trails than those adjacent to narrow ditches or boardwalks; wider borrow ditches provide a buffer between levees and foraging habitat and since wide ditches reduce the foraging area available to birds near levees, there may be fewer birds foraging near levees with wide borrow ditches.
3. Shorebirds showed disturbance responses during walks, including reduced foraging and increased movement. Infrequent trail use may result in such disturbances to birds. Studies suggest that infrequent trail use is more disruptive than very regular trail use. Given this, we recommend focusing trail use in areas of high human demand and limiting the number of trails that may have infrequent trail use.
4. Plan for significant areas without trails to provide adequate shorebird foraging and roosting habitat.
5. Increase quality forage in areas more than 30m from trails.

6. Conduct research on how screening at trail sites affects shorebird response.
7. Conduct research on other factors that affect shorebird mortality in response to human disturbance, in particular the quality and quantity of forage in ponds managed for shorebirds and the rate of predator disturbance.
8. Conduct research on the response of shorebirds to varying intensity and type of use at trail sites, in conjunction with information on predator disturbance and prey availability.
9. Conduct research on the impacts of trails in tidal marsh areas to assess whether the assumptions associated with human disturbance on listed species in this habitat are accurate.
10. Develop a model for predicting shorebird responses to changing habitats to specifically assess the effects of human activity on shorebird mortality and other vital demographic factors that link to population-level effects.

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