2009

Wintering duck response to trail use at former San Francisco Bay salt ponds

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DOI: <https://doi.org/10.31979/etd.hyvm-4ayk>
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WINTERING DUCK RESPONSE TO TRAIL USE AT FORMER
SAN FRANCISCO BAY SALT PONDS

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Heather Renee White

May 2009

UMI Number: 1470961

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SAN JOSE STATE UNIVERSITY

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WINTERING DUCK RESPONSE TO TRAIL USE AT FORMER
SAN FRANCISCO BAY SALT PONDS

by
Heather Renee White

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ABSTRACT

WINTERING DUCK RESPONSE TO TRAIL USE AT FORMER SAN FRANCISCO BAY SALT PONDS

by Heather Renee White

Little is known about the impact of trail use on wintering ducks, especially in the San Francisco Bay Area. As outdoor recreation continues to grow in popularity and expand into new areas, it becomes increasingly important to understand the impact of trail use on the wildlife that currently use those areas. As part of the South Bay Salt Pond Restoration Project (SBSPRP), certain locations that have never experienced public access will be opened to recreational trail use. Before this happens, it is imperative to have an understanding of this action's potential repercussions for the wintering ducks that currently use the ponds where trail use will be focused.

I completed 30 trials during the 2006-2007 and 2007-2008 fall and winter seasons by walking along levees next to three ponds in South San Francisco Bay. Data collection involved measuring the distance of wintering ducks from the levees before and after each experimental disturbance as well as collecting data on the distances of ducks from the levee during trail use.

Diving ducks dominated the ponds, with the ruddy duck (*Oxyura jamaicensis*) being the most common species seen. Areas up to 120 m from the levee had fewer ducks after the disturbance than before; distances moved varied by species. It is recommended that trails be placed at least 144 m from ponded wintering waterfowl habitat to reduce the likelihood of disturbance response.

ACKNOWLEDGEMENTS

I would like to thank the San Francisco Bay Joint Venture who provided a research grant for both seasons of my data collection. Thanks are also due to the U.S. Fish and Wildlife Service for providing access to Don Edwards San Francisco Bay National Wildlife Refuge lands, and specifically to Clyde Morris for his assistance with the permit process. I would also like to thank Melissa Pease and Shannon Bros who provided many helpful comments on the design of this study.

I am particularly appreciative of the assistance and guidance of my committee members. Rachel O'Malley provided assistance with the design of this study and many helpful comments on this document. Rick Kos was a great help in the GIS analysis portion of this project, and in fostering my interest in GIS and its application to a multitude of environmental issues. Lynne Trulio has been of great assistance throughout the entire process of this research, from helping me choose this topic, to providing much-needed encouragement when fieldwork frustration set in, to data analysis and the completion of this document. I cannot express my level of gratitude for all of her support.

Lastly, I would like to thank all of my research assistants, without whom this project would not have been possible. Galli Basson, Li Xuezhi, Caitlin Robinson, and Lissa Derugina approached the challenges of fieldwork with diligence, persistence, a good sense of humor, and a gracious attitude and for that I am very grateful.

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Introduction and Background

The South Bay Salt Pond Restoration Project (SBSPRP or the Project), at over 15,000 acres, is the largest tidal wetland restoration project on the West Coast of the United States. One of the explicit goals of this project is to “provide wildlife oriented public access and recreation opportunities” (South Bay Salt Pond Restoration Project, 2006, About Us section, para. 2). An anticipated result of this goal is that some areas that have never experienced human trail use will be opened to the public. Many of the areas that will accommodate these new trails border ponds that are prime habitat for wintering ducks. Little is known about the potential impact of this trail use on the wintering ducks that use these ponds. Land managers require information on the potential repercussions of trail use on waterfowl to determine effective design and implementation approaches before new trails are established.

The Project uses an adaptive management approach that allows a phased implementation of restoration actions. With this approach, a restoration action is taken and then monitored for effectiveness before subsequent actions are taken. Currently, the Project is planned to take place via phased actions over the next 50 years (2008-2058) (Trulio et al., 2007). Implementation of Phase 1 actions began in 2008, with expected continued implementation over the next two to ten years. Phase 1 actions include a 95% increase in trail access and the conversion of four ponds to tidal marsh habitat. Since Phase 1 actions are currently being implemented, it is essential to collect data on human-wildlife interactions so

Project managers can provide recreation opportunities that do not significantly harm wildlife.

The impact of recreationists upon wildlife is a concern in all habitats but it is of increased importance for habitats and wildlife that are currently on the decline. According to Erwin et al. (2000), no other ecosystem in North America has experienced a level of degradation as significant as that of wetlands. Related to this trend is the current decline in many waterfowl populations in North America (North American Waterfowl Management Plan Committee, 2004). This trend is of particular concern in an area such as the San Francisco Bay region, which has been identified as one of the areas of “continental significance” to North American waterfowl in the 2004 North American Waterfowl Management Plan.

Early accounts of the San Francisco Bay area frequently mention the “hordes of waterfowl” which once dominated its marshes and wetlands (Skinner, 1962). However, as early as 1900, California saw large population declines due to habitat loss and market hunting. The loss of a significant portion of South Bay marshland to salt production played a major role in this decline (Skinner, 1962). Subsequent wildlife protection legislation and refuge establishment helped slow population declines, but current population levels are lower than what they once were. As wetlands continue to be lost to human development throughout California, the San Francisco Bay area, with its thousands of acres of wetland habitat, will continue to be vital to wintering waterfowl.

Recent surveys by the United States Fish and Wildlife Service (USFWS) have found more than 700,000 waterfowl using the San Francisco Bay and Delta wetland habitats (Olofson, 2000). Within the Bay area, the salt ponds in the South Bay are especially important to waterfowl. According to Takekawa et al. (2000), these salt ponds support up to 76,000 waterfowl, 27% of the Bay's entire waterfowl population.

Species that may be found in the salt ponds of the South Bay include northern shoveler (*Anas clypeata*), American wigeon (*Anas Americana*), northern pintail (*Anas acuta*), greater and lesser scaup (*Aythya marila*, and *A. affinis*), canvasback (*Aythya valisineria*), common goldeneye (*Bucephala clangula*), bufflehead (*Bucephala albeola*), ruddy duck (*Oxyura jamaicensis*), and common merganser (*Mergus merganser*).

The northern shoveler, American wigeon, and northern pintail are dabbling ducks, feeding mainly on vegetation in the top portion of the water column and along the water's edge, frequently tipping up in shallow areas; they rarely dive for food. American wigeon, for example, feed at depths up to 20 cm and have never been known to dive for food (Mowbray, 1999). The other species are diving ducks that feed mainly by diving, subsisting largely on mollusks, aquatic plants, and/or fish (Gooders and Boyer, 1986). Diving depths vary by species, with the bufflehead tending to feed in shallow water up to 3 m deep (Gauthier, 1993) and the canvasback occasionally diving to depths beyond 9 m (Mowbray, 2002).

All species have similar migratory behaviors. Within North America, they tend to breed in Alaska, Canada, and the northern United States and come to the San Francisco Bay area during winter (October through March). For most species, their winter range extends along the Pacific, Atlantic, and Gulf coasts of the United States and Mexico, with some winter ranges extending to South America (Gooders and Boyer, 1986).

Migratory ducks use the winter months for flocking, feeding, and eventually forming pair bonds in preparation for spring migration to their breeding grounds. For waterfowl, the amount of energy reserves built up during these winter months, in the form of stored lipids and nutrients, directly impacts migration, survival, and reproductive success (Ankney and MacInnes, 1978).

Energy reserve size has been identified as a limiting factor in clutch size for multiple waterfowl species, including ross's goose (*Chen rossii*) (Ryder, 1970), lesser scaup (*Aythya affinis*) (Afton and Ankney, 1991), canvasback (*Aythya valisineria*) (Barzen and Serie, 1990), mallard (*Anas platyrhynchos*) (Krapu, 1981), and lesser snow goose (*Chen caerulescens caerulescens*) (Ankney and MacInnes, 1978). For canvasback females, lack of sufficient nutrients may not only result in smaller clutch size, but also in nest abandonment or a shorter nesting period (Barzen and Serie, 1990). Lack of sufficient nutrients may even lead to starvation during incubation in female lesser snow geese (Ankney and MacInnes, 1978).

Since the wintering months are so crucial to ducks' survival and reproduction and since the salt ponds of the South Bay provide essential wintering habitat, it is essential to assess the potential ramifications of human

trail use near these salt ponds before it begins. According to Frid and Dill (2002), if repeated exposure to disturbance, such as trail use, reduces body condition and reproductive rates, it can contribute to population decline over time.

While there is a real potential for negative impacts from disturbance, this is not to say that public access should be prohibited near wintering duck habitat. Current recreation trends indicate that California will experience an increase in trail-based recreation in the future, making restrictions on public access, at the very least, unpopular, particularly in highly populated areas such as the San Francisco Bay area. California State Parks (2005) points out that trail-based recreation activities such as day-hiking, bicycling, running, and wildlife viewing are quickly growing in popularity and are expected to be among the most popular outdoor activities in the near future, and as California's population grows, so too will the demand for high-quality outdoor recreation opportunities.

As the demand for public access increases, so too does the need to examine the interaction between trail users and wildlife in key habitat areas. Once wildlife response to trail use is evaluated, methods for mitigation can be explored. Researchers have proposed many methods for the mitigation of human recreational disturbance to wildlife. Knight and Temple (1995, p. 328) refer to these methods as "restrictions that promote coexistence" and discuss four broad categories: spatial, temporal, behavioral, and visual. Of these four categories, the one most often considered in waterbird studies is the spatial method of buffer zone designation (DeLong, 2002; Rodgers and Smith, 1995; Rodgers and Smith, 1997).

To use the buffer zone method, researchers determine the minimum distance at which human activities fail to elicit a behavioral response from waterbirds (the “buffer distance”). Human activities are then restricted to at least that distance away from nesting, foraging, or roosting sites (Rodgers and Smith, 1997). Buffer zones can be a very powerful management tool when designing recreational trails in sensitive habitat. They provide a means for accommodating recreational trail usage without interfering with the daily habits of wildlife, thereby allowing wildlife to “function in a normal state” (Knight and Temple, 1995).

In this study, I delineated buffer zones based on the trail’s “zone of influence” which is defined as the zone in which trail use disturbance resulted in significantly fewer birds compared to the pre-disturbance condition. With this concept in mind, my objective was to assess the impacts of trail use on wintering ducks’ behavior and distribution and then to use my analysis to calculate the trails’ zones of influence in the Project area. Once zones of influence were determined, I performed spatial analysis using GIS on the entire SBSRP area, examining all proposed trails and their associated zones of influence, with the goal of understanding the percentage of waterfowl habitat that would fall within the zones of influence if all proposed Phase 1 trails were put into use. I then used this information to examine how the planned actions of Phase 1 could impact potential duck habitat within the Project area. Project managers need to know how much habitat is in the zone of influence if they are to provide wildlife-oriented public access in the SBSRP area, as is their goal. The results of this

research should also prove useful to managers anywhere trail use is located adjacent to waterfowl habitat.

Related Research

Conceptual Framework

Boyle and Samson (1985) were among the first researchers to compile a review of the effects of recreation on wildlife. Their review focused on nonconsumptive recreation (activities such as wildlife viewing, hiking, biking, and boating that generally do not directly result in wildlife mortality) rather than consumptive recreation (activities such as hunting and fishing). They found that of the 166 studies reviewed, most nonconsumptive activity types resulted in a negative effect for birds, mammals, and herpetofauna most of the time.

This review of human-wildlife interactions was further clarified by Knight and Cole (1995). They developed a conceptual model that categorizes the different levels of human disturbance and the various types of wildlife response to this disturbance. They divide human disturbance activities into four categories: harvest, habitat modification, pollution, and disturbance. They divide wildlife responses to disturbance into two main categories: immediate response (behavior change or death) and long-term effects. The long-term effects include effects on individuals (altered behavior, altered vigor, altered productivity, or death), effects on populations (impacts to abundance, distribution, and demographics), and effects on communities (species composition and community interactions). This model provides a helpful understanding of the overall issue of wildlife-recreationist interaction.

To deepen the understanding of wildlife response to human activity, Frid and Dill (2002), based on the work of Gill et al. (1996), developed the risk-

disturbance hypothesis, which states that an animal's response to a disturbance should follow the same economic principles and cost-benefit analysis associated with predator interaction. Prey species have evolved anti-predator responses to generalized threats such as rapidly approaching objects and will respond in the same manner whether the threat comes from a non-lethal human source or from a potentially lethal predator (Frid and Dill, 2002).

Anytime an animal experiences a human-caused or predator-caused disturbance, it has a decision to make: the individual must weigh the cost of staying and dealing with the "predator" versus the cost of leaving the area. The latter choice results in the energetic costs of fleeing and lost foraging time (Yasue, 2006; Goss-Custard et al., 2006). In the case of long-term repetitive human disturbance, individuals may increase their anti-predator strategies, ultimately reducing their overall fitness and potentially impacting the species on a population level (Figure 1).

Frid and Dill (2002) further hypothesize that, as a perceived "predator" gets nearer, the "prey" animal will choose the behavior (fleeing or remaining) with the lowest cost. Therefore, "flight distance should increase with increasing cost of remaining (i.e. risk of capture) and decrease with increasing cost of flight" (Ydenburg and Dill, 1986, p. 233). This decision is impacted by many factors including availability of alternative habitat(s), food resources in the current and alternative habitat(s), proximity to nesting sites, availability of cover, proximity to roosting sites, and flock size (Gill et al., 1996; Gill et al., 2001; Roberts and Evans, 1993; Yasue, 2006). Additionally, the decision seems to be impacted by

animal size (Burger and Gochfeld, 1991), habituation (Ikuta and Blumstein, 2003), migratory status (Burger, 1981), and approach style of the disturber (Burger and Gochfeld, 1991), among other factors (Figure 2).

Some experts postulate that migratory species are more susceptible to trail use disturbance than resident species. In her study of waterbirds in a New York Bay, Burger (1981) found that migratory birds showed a greater response to human disturbance than resident species. She suggests this may be explained by the fact that in a particular location, migratory birds are less habituated to human uses of the landscape.

It is also important to note that type of approach, i.e., direct approach (walking directly toward the animal) or tangential approach (walking a straight line near, but not directly toward, the animal), exerts an influence on wildlife response to trail use (Burger and Gochfeld, 1991). Many studies have observed the impact of direct approach (Beale and Monaghan, 2004; Blumstein et al., 2003; Roberts and Evans, 1993; Thomas et al., 2003). This is most likely due to the fact that earlier works in this field used such an approach (Fraser et al., 1985; Burger and Gochfeld, 1991), as do some of the more recent works on the use of buffer zones to mitigate recreation disturbance to birds (Rodgers and Smith, 1995; Rodgers and Smith, 1997).

However, some recent studies have assessed the effect of tangential approach (Trulio and Sokale, 2008; Miller et al., 2001). Taylor and Knight (2003) suggest that a study should utilize a tangential approach for the study design if

the results of the study will be used to analyze impacts of a trail system, since this is the most likely approach taken by trail users.

Related Studies

Disturbance responses can have very negative implications for wildlife; however, research on this topic as it applies to waterfowl is limited. A substantial gap exists in the knowledge of waterfowl responses to on-shore, non-consumptive human recreational activities such as walking. Many studies of waterfowl (order Anseriformes) response to human recreation specifically examine water-based activities such as boating, hunting, or fishing. Additionally, many studies of on-shore recreation impacts to waterbirds focus on shorebird species (order Charadriiformes). Following is a summary of some of the major studies in these areas.

Waterfowl response to hunting and boating. Hunting can have a significant effect on waterfowl individuals and populations. Knight and Cole (1995) point out that hunting can impact “behavior, population structure, and distribution patterns of wildlife.” Madsen (1998a), in a study of various forms of disturbance to migratory waterfowl in Denmark, found that hunting caused longer disruptions to waterfowl than fishing, sailing, or windsurfing. Of the three species included in this study [mute swan (*Cygnus olor*), eurasian coot (*Fulica atra*), and eurasian wigeon (*Anas penelope*)], the one most affected by shooting was eurasian wigeon, the only duck species; wigeon generally flew when approached. Further, Madsen (1998b) showed that hunted species tend to vacate hunted areas in favor of non-hunted refuges, regardless of habitat value

differences between the two locations. These types of responses to hunting disturbance are thought to have negative consequences for birds' energetic budgets. Bélanger and Bédard (1995), studying greater snow geese in Canada, found that even if the birds foraged at night or at low-disturbance times, this would not compensate for their energy deficit caused by responding to hunting disturbances.

Boating has also been shown to impact waterfowl, as shown by Havera et al. (1992) who found that boating closer than 450 m to diving ducks (mainly lesser scaup and canvasback) made them take flight. Similarly, a study by Knapton et al. (2000) showed that mixed-species flocks of scaup and canvasback were the waterfowl group most frequently disturbed on a bay in Lake Erie. Havera et al. (1992) further postulate that the high level of boating disturbance experienced by diving ducks in their region (Keokuk Pool, Mississippi River) has contributed to recent population declines there.

Shorebird response to on-shore activities. Some studies that examine shorebird response to on-shore human activities indicate a considerable response, while others do not. In her study of a wildlife refuge in New York, Burger (1981) found that human activity usually caused shorebird species to completely vacate the area. Similarly, a study by Thomas et al. (2003) found that foraging sanderlings (*Calidris alba*), when directly approached by humans, always responded when people were within 30 m, and that the number and activity level of trail users significantly reduced the amount of foraging time spent by sanderlings. Similarly, shorebirds were found to completely avoid the

area close to a drive / footpath at times of high visitation by trail users and automobiles in a refuge in Florida (Klein et al., 1995). However, Yasue (2006), studying flocks made up mostly of sandpipers (*Scolopacidae*), noted that the birds returned quickly after being disturbed and went on to suggest that this type of quick recovery meant that the disturbance would not result in a significant long-term impact to the birds. This conclusion is similar to that reached by Roberts and Evans (1993) who noted that sanderlings (*Calidris alba*) only flew when humans approached directly to within 12 m and then quickly relanded and resumed foraging. This conclusion is also supported by the research of Trulio and Sokale (2008), who studied shorebirds along a system of trails in the San Francisco Bay area, and the research of Gill et al. (2001), who studied black-tailed godwit (*Limosa limosa*) response to trail-use in England. Both of these studies showed that human trail use did not affect the number of shorebirds foraging at trail sites.

Waterfowl response to on-shore activities. While there are few studies that focus on waterfowl and trail-based recreation specifically, those that do tend to show that ducks and other waterfowl are impacted by trail use. Purdy et al. (1987) interviewed wildlife refuge managers who cited hiking, bicycling, and jogging as reasons for reduced waterfowl use of refuges 50% of the time. In a study at Ding Darling National Wildlife Refuge in Florida, Klein et al. (1995, p. 1462) found that of the 38 waterbird species studied, “migratory dabbling ducks were the group most uniformly sensitive to human visitors.” Specifically, they noted that northern shovelers (*Anas clypeata*) and American wigeon (*Anas*

americana) exhibited a strong response to visitation levels when they first arrived in the early winter and that northern pintails (*Anas acuta*) continued to show strong responses into the later winter months. Additionally, American wigeon and greater scaup (*Aythya marila*) frequently responded to human activity by flying to the middle of the pond during a study by Burger (1981) in New York. All ducks responded to trail use treatments in a study of wintering ducks in Virginia by Pease et al. (2005), with American wigeon, northern shoveler, and gadwall (*Anas strepera*) among the group that exhibited “high proportions of flight responses.”

These studies found that trail use does have an impact on waterfowl species; however, it is imperative to collect data “specific to the location, time of year, species, and individuals” in question before one can confidently state anything about a particular population’s response to trail use (Trulio 2005, p. 9). The studies cited above all took place in the eastern United States and studied, primarily, the response of dabbling ducks to trail use. Many ducks found in the salt ponds of the Project area, however, are diving ducks, due to the relatively deep nature of the ponds. Therefore, data are necessary on the response of diving duck species specifically found in these South Bay ponds before conclusive statements can be made about their response to trail use. It is also important to note that the observed response of one species cannot be extrapolated to another; in fact, there is evidence to suggest that behavioral response to human activity is a species-specific trait (Blumstein et al., 2003). There can even be significant disparities in response to the same disturbance in

different populations of the same species (Knight and Temple, 1995). Therefore, the results of these distant studies of waterfowl response to trail use cannot be reliably applied to the San Francisco Bay population of waterfowl. A study examining these ducks, specifically, is necessary.

Figure 1. Conceptual model of how human disturbance can impact population size (adapted from Frid and Dill 2002)

Figure 2. Some of the inputs to the decision to stay or flee

Research Objectives and Hypotheses

The purpose of this study was to examine the response of wintering ducks to trail users in a previously undisturbed area and to use this information in examining proposed trails in the SBSPRP area. Specifically, I tested the following hypotheses and research questions at ponds that have experienced no trail use:

Hypotheses

- Ho1. a) The abundance of ducks located at various distances from a trail does not change significantly before, versus after, trail use.
- b) Response to trail use by distance is not affected by pond, tide level, time of day, year, or by presence of hunting in nearby ponds.
- Ho2. As trail users walk along the trail, ducks encountered at the end of the trail are not located at a significantly greater or lesser distance from the trail than ducks encountered at the beginning of the trail.

Research Questions

1. How far away from the disturbance do different species move during the disturbance? What is the “zone of influence” of a trail near waterfowl habitat?
2. What percentage of potential wintering duck habitat would be affected should all proposed SBSPRP Phase 1 trails adjacent to waterfowl habitat be put into use?

Methods

Study Site

This study took place in Santa Clara County, California, which is characterized by a mild Mediterranean climate, with hot dry summers (average summer temperature is 70 degrees F) and cool, wet winters (average winter temperature is 50 degrees F and average annual rainfall is 14.4 inches). The study site is located in the southern portion of San Francisco Bay, on former salt ponds that are part of the South Bay Salt Pond Restoration Project (SBSRP). These ponds ring the southern portion of San Francisco Bay (Figure 3), and the entire area surrounding the salt ponds is highly urbanized, such that the system of ponds functions as habitat islands within an urban matrix. These salt ponds have a unique plant community, dominated mainly by microalgae and photosynthetic bacteria, with vascular plants found along levee edges (Baye, 2000).

The salt ponds included in this study were purchased from Cargill Company in 2003, are now owned by the United States Fish and Wildlife Service (USFWS), and comprise a portion of the Don Edwards San Francisco Bay National Wildlife Refuge.

Disturbance trials were conducted on levees bordering ponds A9, A10, and A11 in the Alviso Complex of the Project (Figure 4). I chose these levees and ponds based on multiple characteristics. In an attempt to decrease chances of encountering habituated ducks, I chose levees that are not part of a trail system. To minimize differences in environmental conditions as much as possible, the

ponds chosen were similar to each other in depth and surrounding habitat types. No hunting was allowed on any of the ponds; however, hunting was allowed at some nearby ponds three days per week during the winter months (mid-October through late-January).

Field Methods

I used plastic poles at each pond that extended outward at 40 m intervals from the base of each target levee, to create a total of five distance bands (Figure 5). These poles allowed measurement of ducks' distances from each target levee, while observing from a distance to avoid disturbing the ducks. I used a Nikon Spotter XL 16-47X60 scope, Bushnell 10X50 WA binoculars, and a Bushnell Elite 1500-7X26 rangefinder, accurate to ± 1 yard.

Data were collected during times of zero to light precipitation, when visibility was high, and during daylight hours. On any given day, levee choice for trials was determined based on road conditions and presence of ducks; I did not use the same levee twice in one day. I collected data up to four days per week, allowing for some recovery time between visits to the study site. Samples that were interrupted by an external disturbance, regardless of source, were eliminated. Two pedestrians who functioned as both observers and trail users caused all trail use disturbance. I used two different data collection methods to address my study questions: before-/after-disturbance counts and point counts, described below.

Before- /After-disturbance Counts. The before-/after-disturbance count method was based on measuring the distribution of ducks from a levee before

and after a trail use disturbance along that levee. To begin, two observers used a scope at highest magnification to get a measure of the before-disturbance species abundance at the opposite end of the pond (greater than 400m from the observation point), within each of five 40 m distance bands (Figure 5). The observers took a sample of duck abundance in each distance band by counting the number of ducks, identified to species when possible, in one scope field of view. If ducks could not be identified to species, they were identified to guild if possible, or categorized as unknown duck species. For ease of data collection, greater scaup and lesser scaup were combined into one category, referred to as scaup species.

To maintain consistency, the scope field of view was defined each time by positioning the top-most portion of the scope's field of view in the center of the distance band being sampled along the far-distant levee. Once the before-disturbance sample was completed, the two trail users/ observers walked the entire length of the levee, taking point counts (see below). Then the two trail users returned to the starting location and repeated the above steps to get a measure of the number of ducks by species in each band after disturbance.

Point Counts. For point counts, trail users stopped at six pre-determined points to collect data along the levee they were walking. The first point count was taken halfway down the length of the levee (approximately 500-600 m from the start location). Each subsequent data collection point was approximately 90 m from the preceding point (Figure 5). At each point count location, the observers turned and used binoculars to count and identify all ducks in the

binoculars' field of view following a straight line perpendicular to the levee. The observers used a laser rangefinder to measure the distance to each of the ducks, up to the rangefinder's capabilities (approximately 200 m on water).

Analytical Methods

All statistical analyses were completed using SYSTAT 12® (SYSTAT Software, Inc., Richmond, CA). All Geographic Information Systems analyses were completed using ArcGIS 9.3® (ESRI, Redlands, CA).

Before-/After-disturbance Count Data. For analysis of before-/after-disturbance count data, I dropped one trial at pond A11 that occurred during high tide, which caused the ducks' numbers in the bands to differ greatly from the other trials. This trial was not dropped for analysis of point count data, as tide level did not affect the distribution of ducks from one point to the next.

To determine if the abundance of ducks located at various distances from a levee changed before versus after trail users walked along the levee (before-/after-disturbance counts), I used a General Linear Model. The independent variable in this test was band, and the dependent variables were the difference in abundance of all ducks combined, abundance of individual species, and species richness in each band before trail use disturbance versus after.

I log-transformed $[\log(x+1)]$ each of the difference variables after performing a Shapiro-Wilk test that showed non-normality in the raw data. An $F_{\max}$ test indicated homogeneity of variances. When examining the abundance response of each species, I removed all trials that had an abundance of zero for that species in both before-disturbance and after-disturbance counts. In cases

where response to band was significant, I employed Tukey's Honestly-Significant-Difference Test as a posthoc test to examine differences in response to bands.

To examine whether response to trail use by distance band was affected by pond, year, presence of hunting in nearby ponds, time of day, or tide level, I used those factors as independent variables in the General Linear Model, along with band. The pond variable had three levels (A9, A10, A11), year had two levels (2006-2007 field season and 2007-2008 field season), and hunting had two levels (present or absent). Time of day had two levels (AM and PM) with all trials beginning before noon in the AM category and all trials beginning after noon in the PM category. Tide had four levels (high, low, in-coming, out-going). High and low tides were defined as the actual time of the tide with a 30 minute buffer added to both sides, resulting in a one hour high-tide range and a one hour low-tide range. If greater than half of the trial occurred in one of those ranges, the trial was categorized as a high or low-tide trial. All other trials were categorized as incoming or outgoing, depending on the direction of tidal movement during the trial.

Point Count Data. To determine whether ducks encountered at the end of the trail were located at a different distance from the trail than ducks encountered at the beginning of the trail, I used a Repeated Measures Linear Mixed Model with the distance data gathered in the point counts. All species data showed homogeneity of variances; only data for canvasback and bufflehead were non-normally distributed and were, therefore, log-transformed.

I used the distance data collected with the point count method to investigate how far away from the disturbance different species moved during the disturbance. Only the data for the closest individual of each species at each point were used. Data were grouped by point and the mean distance and standard error were calculated for each species at each point that had a sample size larger than five. Then the points were each averaged to arrive at a single mean distance and standard error for each species. This value for each species (mean + 1 SE) is that species' response zone.

To determine the trails' zone of influence, I averaged the response zones of the four most frequently seen species in point counts and added one standard error. I then input this zone of influence value into the buffer tool within ArcMap to generate a buffer around each existing trail and proposed Phase 1 trail in the Project area. To calculate the existing affected habitat area, I used the clip tool within ArcMap to find areas where the existing trails' zone of influence buffer overlapped with ponds in the Project area, and calculated the area of this overlap region. To calculate the post-Phase 1 affected habitat area, I used the clip tool to find the areas where all existing and Phase 1 trails' zone of influence buffer overlapped with ponds and calculated the area of this overlap region. I then calculated unaffected habitat to see how it will change under the Phase 1 trail conditions and I assessed how Phase 1 actions, in total, will affect the amount of potential wintering duck habitat in the SBSRP. For the first three of these analyses, I excluded all ponds that will be converted to salt marsh as part of

the Project's Phase 1 actions. GIS data were provided by San Francisco Bay Bird Observatory, EDAW Environmental Consulting and U.S. Geological Survey.

Figure 3. View of entire SBSPRP area with study site circled.

Figure 4. View of study site.
Levees encircle all ponds; hatch marks indicate levees used for data collection.

Results

I performed 32 trials from December 2006-March 2007 and October-December 2007. Trials took an average of 89 minutes from beginning to end, with the shortest trial lasting 67 minutes and the longest lasting 120 minutes. The portion of the trials when I walked the levees was the longest portion, lasting an average of 48 minutes. Two trials were interrupted by an unknown disturbance and were not completed. A before-/ after-disturbance count from pond A11 was dropped because of a tidal issue; thus, a total of 29 trials were analyzed for the before-/ after-disturbance data analysis and 30 trials for the point count data analysis. Of these 30 trials, 11 of them took place at pond A9, 13 trials at pond A10, and 6 trials at pond A11.

The guild composition of all ponds aggregated together was dominated by divers (54%), with dabblers making up 10% of ducks counted; 36% of ducks were at too great a distance to be identified. Of the diving ducks, ruddy ducks (RUDU) made up the greatest percentage at 35%, with scaup species (SCAU), canvasback (CANV), bufflehead (BUFF), and red-breasted merganser (RBME) making up smaller percentages of the total counted. Of the dabbling ducks observed, northern shoveler (NSHO) was the only species present in any significant number (Figure 6).

When considering guild and species composition of ducks counted at pond A9 only, the majority of ducks identified were diving ducks, with ruddy ducks and canvasback making up the largest portion of the diving duck total. Northern shoveler was the only identifiable dabbling species to be observed in

any large numbers. At pond A9, 50% of ducks observed were at too great a distance to be identified (Figure 7).

Ducks observed in pond A10 were predominantly diving ducks (73%), with a more even division of species present in this guild. Ruddy duck was, again, the diving duck species seen the most, but other species such as scaup species, canvasback, bufflehead, and red-breasted merganser were observed regularly. Once again, northern shoveler was the only common dabbling duck species (11% of ducks observed) (Figure 8).

Pond A11 showed less inter-guild diversity than the other two ponds, with only divers identified in numbers large enough to assess. Five northern pintails were observed once in pond A11, but that number was too small to evaluate. The majority of diving ducks observed here were ruddy ducks (39% of all ducks observed), with scaup species also showing up in large numbers (20% of all ducks observed), and a measurable number of bufflehead as well (4% of all ducks observed) (Figure 9).

ALL PONDS, GUILD COMPOSITION **ALL PONDS, SPECIES COMPOSITION**

Figure 6. Guild composition and species composition of all ponds
 N = 11,242 (number of ducks counted in all before and after observations)

POND A9, GUILD COMPOSITION **POND A9, SPECIES COMPOSITION**

Figure 7. Guild composition and species composition of pond A9
 N = 11,242 (number of ducks seen in all before and after observations)

UNKN=unknown, DABB= dabbler, DIVE= diver, RUDU= ruddy duck, SCAU= scaup species, CANV= canvasback, BUFF= bufflehead, NSHO= northern shoveler, RBME= red-breasted merganser

POND A10, GUILD COMPOSITION **POND A10, SPECIES COMPOSITION**

Figure 8. Guild composition and species composition of pond A10

N = 11,242 (number of ducks seen in all before and after observations)

POND A11, GUILD COMPOSITION **POND A11, SPECIES COMPOSITION**

Figure 9. Guild composition and species composition of pond A11

N = 11,242 (number of ducks seen in all before and after observations)

UNKN=unknown, DABB= dabbler, DIVE= diver, RUDU= ruddy duck, SCAU= scaup species, CANV= canvasback, BUFF= bufflehead, NSHO= northern shoveler, RBME= red-breasted merganser

Response to Trail Use by Distance Band

Overall Abundance. The response of bird abundance to trail use differed greatly by band ($F_{(4,145)} = 5.596$, $p < 0.001$) (Table 1). Within all distance bands, except band 5, there were more ducks present before trail use than after; however, the before and after numbers became more similar as the distance from the trail increased (Figure 10). A posthoc test showed that response in band 1 was significantly different from response in band 3 ($p = 0.024$), band 4 ($p = 0.009$), and band 5 ($p < 0.001$); also, response in band 2 varied significantly from response in band 5 ($p = 0.029$) (Table 2).

In particular, in band 1 (0-40m from the levee) the actual number of ducks present before trail use was a mean of 57 (SE=12) and after was 20 (SE=6) and in band 2, (40-80m from the levee) the average number of ducks present before trail use was 39 (SE=6) while after was 14 (SE=2) (Table 3). Numbers in bands 3, 4 and 5 (80-200m from the levee), were not significantly different from each other before versus after disturbance, as supported by the results of the post-hoc test (Table 2). In band 3 (80-120m from the levee), the average number of ducks present before trail use was 37 (SE=5) and after was 27 (SE=5). Moving further from the levee, there were 49 (SE=8) ducks before and 34 (SE=5) ducks after in band 4 (120-160m from the levee) and a mean of 52 (SE=12) ducks before trail use and 42 (SE=6) ducks after in band 5 (160-200m from the levee) (Figure 11).

Table 1. GLM results, difference in duck abundance by band.
Statistically significant results marked with an asterisk (*).

Dependent Variable	Response by Band
Overall abundance	$F_{(4,145)}=5.596, p<0.001^*$
Species richness	$F_{(4,145)}=2.235, p=0.068$
Canvasback abundance	$F_{(4,72)}=5.354, p=0.001^*$
Scaup abundance	$F_{(4,54)}=3.379, p=0.016^*$
Ruddy duck abundance	$F_{(4,138)}=1.298, p=0.274$
Northern shoveler abundance	$F_{(4,35)}=.278, p=0.890$
Bufflehead abundance	$F_{(4,57)}=0.509, p=0.730$

Table 2. Posthoc test results, overall abundance by band.
Statistically significant results marked with an asterisk (*).

Band Comparisons	Difference	p-value
1-2	0.349	0.778
1-3	0.903	0.024*
1-4	0.996	0.009*
1-5	1.234	<0.001*
2-3	0.554	0.357
2-4	0.647	0.205
2-5	0.885	0.029*
3-4	0.093	0.998
3-5	0.331	0.811
4-5	0.238	0.935

Table 3. Mean number of individuals present in bands before and after disturbance.

Dependent Variable	Before or After Disturbance	Band				
		1	2	3	4	5
Overall abundance (mean $\pm$ SE)	Before	57 $\pm$ 12	39 $\pm$ 6	37 $\pm$ 5	49 $\pm$ 8	52 $\pm$ 12
	After	20 $\pm$ 6	14 $\pm$ 2	27 $\pm$ 5	34 $\pm$ 5	42 $\pm$ 6
CANV abundance (mean $\pm$ SE)	Before	13 $\pm$ 5	7 $\pm$ 3	6 $\pm$ 3	5 $\pm$ 1	5 $\pm$ 2
	After	2 $\pm$ 1	1 $\pm$ 1	7 $\pm$ 2	8 $\pm$ 2	12 $\pm$ 3
SCAU abundance (mean $\pm$ SE)	Before	12 $\pm$ 5	14 $\pm$ 4	9 $\pm$ 3	9 $\pm$ 3	11 $\pm$ 4
	After	1 $\pm$ 1	2 $\pm$ 1	2 $\pm$ 1	7 $\pm$ 2	11 $\pm$ 4
RUDU abundance (mean $\pm$ SE)	Before	22 $\pm$ 5	11 $\pm$ 2	12 $\pm$ 2	17 $\pm$ 3	20 $\pm$ 5
	After	10 $\pm$ 3	7 $\pm$ 1	12 $\pm$ 3	13 $\pm$ 2	15 $\pm$ 2

Figure 10. GLM results, all species response by band
 Band 1= 0-40 m, Band 2= 40-80 m, Band 3= 80-120 m, Band 4= 120-160 m, Band 5= 160-200 m

Figure 11. All species, mean abundance response by band
 Band 1= 0-40 m, Band 2= 40-80 m, Band 3= 80-120 m, Band 4= 120-160 m, Band 5= 160-200 m

Species Richness. Species richness did not vary significantly by band in response to trail use ($F_{(4,29)} = 2.235$, $p = 0.068$).

Abundance by Species. Abundance of ruddy duck, northern shoveler, and bufflehead in distance bands did not vary significantly in response to trail use (Table 1). However, the abundance of canvasback by distance band did vary significantly in response to trail use ($F_{(4,72)} = 5.354$, $p = 0.001$). In bands 1 and 2, there were more canvasback present before trail use than after but in bands 3, 4, and 5, there were more canvasback present after trail use than before (Figure 12). The mean number of canvasback present in band 1 (0-40m) before trail use was 13 (SE=5) and after was 2 (SE=1); in band 2, (40-80m) the average number of canvasback present before trail use was 7 (SE=3) while after was 1 (SE=1) (Table 3). However, by bands 3, 4 and 5 (80-200m), there were more canvasback after trail use than before. In band 3 (80-120m), the average number of canvasback present before trail use was 6 (SE=3) and after was 7 (SE=2). Moving further into the pond from the levee, there were 5 (SE=1) canvasback before and 8 (SE=2) after in band 4 (120-160m) and a mean of 5 (SE=2) canvasback before trail use and 12 (SE=3) canvasback after in band 5 (160-200m) (Figure 13).

Also, the abundance of scaup species by distance band varied significantly in response to trail use ($F_{(4,54)} = 3.379$, $p = 0.016$). There were more scaup before than after disturbance in bands 1, 2, and 3, with the before- and after-disturbance numbers becoming more similar in bands 4 and 5 (Figure 14). The mean number of scaup seen in band 1 before trail use was 12 (SE=5) while 1 (SE=1) was seen after trail use (Table 3). This trend of more ducks seen before trail use than after

continues in bands 2 and 3. The average before trail use in band 2 was 14 (SE=4) and after at 2 (SE=1), while in band 3 there were a mean of 9 (SE=3) scaup before trail use and 2 (SE=1) after. Moving out to band 4, I found a mean of 9 (SE=3) scaup before and 7 (SE=2) after trail use; band 5 averaged 11 (SE= 4) birds seen both before and after trail use (Figure 15).

There was no significant change in abundance of ruddy duck by distance band ($F_{(4,138)} = 1.298$, $p = 0.274$) (Table1). In band 1, there were slightly more ducks before trail use than after, but this was not enough to support a statistically significant difference (Figure 16). In fact, in band 1, there was a mean of 22 (SE=5) ruddy duck before trail use and 10 (SE=3) after trail use (Table 3). In band 2, there was a mean of 11 (SE=2) ruddy duck present before trail use and 7 (SE=1) present after trail use. In band 3, there was an average of 12 (SE=2) observed before trail use and 12 (SE=3) observed after trail use. Band 4 showed a similar trend for ruddy duck with 17 (SE=3) present before trail use and 13 (SE=2) present after trail use. Band 5 averaged 20 (SE=5) ruddy duck before trail use with 15 (SE=2) present after trail use (Figure 17).

Figure 12. GLM results, canvasback response by band

Band 1= 0-40 m, Band 2= 40-80 m, Band 3= 80-120 m, Band 4= 120-160 m, Band 5= 160-200 m

Figure 13. Canvasback, mean abundance response by band

Band 1= 0-40 m, Band 2= 40-80 m, Band 3= 80-120 m, Band 4= 120-160 m, Band 5= 160-200 m

Figure 14. GLM results, scaup species response by band
 Band 1= 0-40 m, Band 2= 40-80 m, Band 3= 80-120 m, Band 4= 120-160 m, Band 5= 160-200 m

Figure 15. Scaup species, mean abundance response by band
 Band 1= 0-40 m, Band 2= 40-80 m, Band 3= 80-120 m, Band 4= 120-160 m, Band 5= 160-200 m

Figure 16. GLM results, ruddy duck response by band
 Band 1= 0-40 m, Band 2= 40-80 m, Band 3= 80-120 m, Band 4= 120-160 m, Band 5= 160-200 m

Figure 17. Ruddy duck, mean abundance response by band
 Band 1= 0-40 m, Band 2= 40-80 m, Band 3= 80-120 m, Band 4= 120-160 m, Band 5= 160-200 m

Effect of Factors on Band Response

Overall Abundance. There was no interaction between band and any of the following factors: pond, tide, time of day, year, and hunting. These results indicate that these factors did not impact ducks' response to trail use by band.

Species richness. There was no interaction between band and tide, time of day, year, or presence of hunting. Therefore, these factors did not significantly affect species richness by band. However, there was an interaction effect between band and pond ($F_{(8,145)} = 2.254$, $p = 0.027$). Species richness in response to distance bands differed significantly among the three ponds. Pond A9 consistently had more species in bands before trail use than after, but this before-disturbance number was only slightly larger for all bands. Overall, pond A10 showed a consistently lower species number when moving outward from the levee and in before-disturbance numbers minus after-disturbance numbers. This pond contained more species before trail use than after in bands 1, 2, and 3. However, the before- and after-disturbance species numbers were very similar in band 4, and in band 5 there were more ducks after trail use than before. There is no clear pattern in species richness numbers in pond A11. There were more duck species before trail use than after in bands 1, 3, and 5, but the before- and after-disturbance numbers were very similar in bands 2 and 4 (Figure 18).

Abundance by species. When examining abundance of each individual species, none of these factors (pond, tide, time of day, year, and hunting) interacted with any species' response to trail use by band.

Figure 18. Band and pond interaction for species richness

Band 1= 0-40 m, Band 2= 40-80 m, Band 3= 80-120 m, Band 4= 120-160 m, Band 5= 160-200 m

Cumulative Distance Change During Disturbance

Only ruddy duck ($F_{(5,132)} = 0.226$, $p = 0.951$) and scaup species ($F_{(5,47)} = 0.275$, $p = 0.924$) had large enough sample sizes for this analysis. Neither of these species showed a significant difference between responses at points during trail use, when comparing distances of ducks at the beginning of the trail to distances seen as trail users traversed the levee.

Distance Moved During Disturbance

The sample sizes for four species were large enough for this analysis of duck distances at each of the six point count locations during disturbance; these were ruddy duck, canvasback, scaup species, and bufflehead. The mean distance of the closest ruddy duck for all point count data averaged was 106.5 (SE=9.6) m. The sample size for each point ranged between 19 and 25 for this species. For canvasback, the mean distance was 142.2 (SE=16.6) m, with the sample size for each point ranging between 5 and 9. For scaup species, the mean distance of the closest individual for all points was 132.3 (SE=16.2) m, with the sample size for each point ranging between 6 and 10. Finally, the mean distance of the closest bufflehead at points was 138.5 (SE=12.8) m, with the points' sample sizes ranging between 7 and 12 (Figure 19). These distances were greater than before the disturbance, as ducks were evenly distributed in close bands before any trail use disturbance (Figure 20).

Figure 19. Point counts, average distance of closest individuals by species

Figure 20. Distribution of ducks before disturbance
 Band 1= 0-40 m, Band 2= 40-80 m, Band 3= 80-120 m, Band 4= 120-160 m, Band 5= 160-200 m

Species' Response Zones and Trail's Zone of Influence

The response zone (mean + 1 SE) for each of the four species mentioned above was as follows: canvasback = 160 m, ruddy duck = 116 m, scaup species = 149 m, and bufflehead = 151 m. The mean of the four species response zones (the trails' zone of influence) was 144 m (Figure 21).

Trail Affected Habitat

Using the trails' zone of influence, and considering the area contained within this zone to be affected habitat, the affected habitat area under current trail conditions in all of the Project area comes to 476 ha. Under Phase 1 trail conditions, this affected habitat area will become 929 ha, an increase of 95% over current conditions (Figure 22). The current amount of ponded habitat in the Project area, outside the zone of influence of any trails is 5389 ha; this amount will decrease by 8.5% to 4932 ha with the implementation of Phase 1 trails (Figure 23).

Phase 1 Changes to Duck Habitat

Phase 1 actions include a 95% increase in trail access and the conversion of four ponds to tidal marsh habitat. The total project area, as it exists now in the form of salt ponds, is 6470 ha. Approximately 605 ha of this area will be converted to tidal marsh and will not be suitable habitat for wintering ducks. Of the resulting 5,856 ha, 476 ha are within the zone of influence of existing trails and are currently affected habitat and 457 ha are within the zone of influence of the planned Phase 1 trails. The remaining 4932 ha are unaffected ponded habitat,

suitable for the use of wintering ducks, a 24% decrease in suitable habitat, project-wide (Table 4).

Figure 21. Trails' 144m zone of influence throughout Project area

Figure 23. Unaffected habitat (denoted with stippled gray in the maps) will decrease 8.5% with Phase 1 trail actions.

Table 4. Impact of Phase 1 actions on suitable duck habitat Project-wide

Total Project Area	6470 ha
Phase 1 Tidal Marsh Conversion	- 605 ha
Current Trail-affected Habitat	- 476 ha
Phase 1 Trail-affected Habitat	- 457 ha
Remaining Unaffected Ponded Habitat	4932 ha
24% Decrease in suitable duck habitat project-wide	

Discussion

Wintering ducks at this study site in the SBSPRP area responded measurably to trail use disturbance along a levee adjacent to their pond. When considering all duck species combined, this response extends to 80 m from the levee. Additionally, the average distance moved during disturbance extended beyond 106 m for all species, a distance that is considerably farther than the distances at which many ducks were found before trail use. For example, during disturbance, the average distance of the nearest ruddy duck was 106.5 (SE=9.6) m. This distance is within band 3 (80-120 m from the trail); if this is the preferred distance of this species, one would expect to see ducks no closer than band 3 in any before-disturbance observations. However, there were as many ruddy ducks located in bands 1 (0-40 m from the trail) and 2 (40-80 m) as in further bands before disturbance. This point holds true for scaup species, canvasback, and bufflehead. In fact, canvasback appeared in larger numbers in band 1 than in the other four bands in the before disturbance observations.

This result is consistent with that of many other studies that also indicate ducks respond behaviorally to human disturbance. For example, in their study of dabbling ducks' response to pedestrians, bicyclists, and vehicles, Pease et al. (2005) found 90% of birds showed a response by raising their head, swimming away, or flying away. Burger's (1981) study of general on-shore human activity around a bay (including walking, jogging, horseback riding, clamming, and grass-mowing) also indicated that ducks generally flew away from disturbance to the center of the pond. Additionally, in a study by Klein et al. (1995), dabbling

ducks always tended to stay away from a road being used by pedestrians and vehicles. Additionally, they found that, of the two types of disturbance studied, pedestrians were more disruptive than vehicles. Guillemain et al. (2007) found that dabbling ducks responded to groups of visitors located in an observation blind by moving away from the blind and then increasing their feeding behavior.

The high level of response by waterfowl to trail use seen in the current study is in keeping with Frid and Dill's (2002) risk-disturbance hypothesis. The ducks observed in this study responded to human-caused disturbance stimuli by fleeing. Therefore, it seems they considered the approaching disturbance to be equal to a predator and determined that the benefits of moving outweighed the costs. According to Frid and Dill (2002), repeated response to human disturbance could impact survival by reducing the amount of energy available for feeding, migration, and reproduction. It is important to note that, as a hunted class of species, waterfowl do often experience a real threat to survival from humans. For hunted wildlife such as waterfowl, "disturbance stimuli and true predatory stimuli may be indistinguishable from the animal's perspective" (Frid and Dill, 2002).

Response to trail use varied by species. Canvasback and scaup species showed a more significant response to trail use than other species studied. In fact, canvasbacks responded by moving from closer bands to outer bands and then remained in the outer bands in relatively large numbers; they did not recover and move back into the closer bands in the time it took to complete a trial—an average of 58 minutes from the end of the before-disturbance count to

the end of the after-disturbance count. For scaup species, the response measure of more ducks present before trail use than after extended to band 3 (80-120m from the trail). This response is further than that of all species combined or canvasback, both of which responded this way in the first two bands only. Of the species tested in this analysis, scaup species were thus the most sensitive to trail use. Scaup sensitivity is partially supported by the results of the distance moved during disturbance analysis, in which the distance moved by scaup species was second only to that of bufflehead.

The response of ruddy duck to trail use by distance was not statistically significant when comparing before-disturbance to after-disturbance numbers. This species was by far the most plentiful species in trials (Figure 6) and seems to occur in the South Bay salt ponds in large numbers. In fact, according to Johnsgard (1975), North American wintering duck surveys in the 1960s showed that more than 60% of the wintering ruddy duck population is located along the Pacific Flyway, of which the San Francisco Bay is an important part. The quality of habitat in the South Bay is particularly important for ruddy duck.

Although ruddy duck showed no significant response to trail use by distance band in the before-disturbance versus after-disturbance data, an examination of the point count results indicates that this species did respond to trail use as it was happening. The average distance of the closest individual ruddy duck to the disturbance was 106.5 (SE=9.6) m. This distance is further from the trail than ruddy duck tended to be located either before or after trail use, indicating that individuals of this species responded to trail use while it

occurred, but recovered to their pre-disturbance locations very quickly. This response is different from canvasback and scaup, which responded to trail use and did not recover in the time (58 minutes on average) it took the two observers to complete their trail walk and then collect after-disturbance data.

Even though they did respond to trail use, ruddy ducks recovered to before-disturbance conditions more quickly than the other species studied. There are many possible reasons for this disparity in response between different species. For example, it has been postulated that wildlife tend to be less responsive when in a large group of conspecifics. Ydenberg and Dill (1986) suggest 4 reasons for why this trend may be observed: (1) Presence within a group dilutes the risk for any one particular individual in the group since, in many instances, a predator only captures one individual from the group. (2) It is frequent that groups form where there is a high density of food; this presence of an ample food supply may reduce an individual's likelihood of fleeing. (3) Groups may form specifically at times or places where danger is highest. (4) Individuals tend to increase feeding and decrease vigilance as group size increases. Ruddy duck were the most numerous species seen in each trial and across all ponds; this abundance may help explain their lower response level.

Results from the three ponds were very different with respect to species richness by band. No pattern by band, consistent over the three ponds, emerged in response to trail use. Rather, the presence of different species at various distances in each pond is most likely due to differences in habitat conditions in the three ponds. Species have different habitat requirements for food resources,

pond depth, and salinity; therefore, differences between salt ponds will result in a different variety of species across various ponds (Warnock, 2005). This study did not quantify habitat quality or appeal to different species of the three ponds.

This research estimates a 144 m zone of influence of trails; the concept of a zone of influence most closely resembles the idea of a minimum approaching distance (MAD) found in the disturbance literature (Fernandez-Juricic et al., 2005). While there are many different ways to calculate buffer zones based on disturbance distance, the MAD method fits well for a study with a distribution focus, such as this one. The MAD represents the closest distance humans should be allowed to approach wildlife and is often used to determine recommended buffer zones (Fernandez-Juricic et al., 2005). A buffer zone is a management tool used to mitigate human recreation impact to wildlife and is defined by Knight and Temple (1995, p. 328) as a “spatial area within which managers temporarily isolate wildlife from factors that would disrupt normal life-history processes,” such as disturbance from recreationists.

The 144 m zone of influence found in this study is consistent with the distances at which Pease et al. (2005) observed a response behavior from a large proportion of wintering ducks. Specifically, they observed that in the range of 0-50m from the trail, 84.7% of birds responded, in the range of 51-100m 78.9% of ducks responded, and 69.8% responded in the 101-150m range, in which this study's 144 m zone of influence would fall. Pease et al. (2005) saw a continuing response further from the trail as 74.2% of ducks responded in the 151-200m range, and 59.0% responded in the 201-300m range. This result is also consistent

with those of Klein et al. (1995) who reported that wintering migratory dabbling ducks generally stayed more than 80m from a levee on which cars were driving, even at relatively low levels of visitation. Klein et al. (1995) studied waterfowl response to automobiles and pedestrians combined, which may confound results.

Rodgers and Smith (1997), studying foraging and loafing shorebirds (*Charadriiformes*), wading birds (*Ciconiiformes*), and pelicans (*Pelecaniformes*) in Florida, suggest a buffer distance of 100m to minimize disturbance from pedestrians, ATVs, automobiles, and boats. A study by Rodgers and Schwikert (2002) of boat disturbance to waterbirds in Florida suggests buffer zones as follows: 180m for wading birds, 140m for terns and gulls, 100 m for plovers and sandpipers, and 150 m for ospreys. These studies provide buffer zone guidance but neither specifically examined waterfowl response to pedestrian trail use.

The zone of influence found in the current study along with the actions of Phase 1 activities are predicted to affect 24% of current wintering duck habitat in the project area, resulting in 4932 ha of unaffected habitat. However, there are still many unknowns included in this estimate of habitat impact.

First, not all of the resulting 4932 ha of ponded habitat will be managed for ducks. This is one of the challenges of a large-scale project that seeks to manage a mix of habitat types for the use of multiple species of wildlife. Some species that need ponded habitat, such as shorebirds, require that ponds be drained or kept rather shallow for foraging, which would render the habitat

unusable for diving ducks. At this point, it is not clear what proportion of the 4932 ha will be managed for ducks.

Also, there are a number of factors that influence how waterfowl respond to disturbance in any given situation. One such factor is the timing of disturbance. Waterfowl are only found in the San Francisco Bay area in large numbers in the winter months; therefore, trail use disturbance to waterfowl is less of a concern in the other seasons of the year. Another important factor is the existence of high-quality habitat nearby to which birds can escape if disturbed by recreationists. This study dealt with waterfowl utilizing very large salt ponds; A9 at 372 acres, A10 at 258 acres, and A11 at 270 acres; within an extensive network of ponds providing many acres of habitat to which birds could escape in response to disturbance. Ydenberg and Dill (1986) point out that an animal's likelihood of fleeing a predator is dependent upon the existence and nearness of other high-quality sites. Gill et al. (2001) further suggest that, in the absence of other places of refuge, a bird might choose not to leave a heavily disturbed area. In these situations, the individuals that are forced to stay in a heavily disturbed area may suffer reduced fitness, reproduction and survival (Gill et al., 2001).

A third critical factor is the frequency of disturbance. This study examined birds in circumstances with very little human disturbance—only two pedestrians at a time—on a site that has never before accommodated recreation. However, at a site with regular, frequent disturbance, birds may become accustomed to the disturbance, thereby altering their behavior through habituation. Habituation is the concept that wildlife acclimate to disturbance

and, with repeated disturbance, the level of behavioral response will decrease in intensity and may even disappear altogether (Gabrielsen and Smith, 1995).

Avocet Research Associates (2005) examined waterfowl response to boat disturbance at a very small, 56-acre pond that was continuously and heavily used both by boaters and by on-shore recreationists such as joggers, bikers, and dog walkers. This site also experienced extensive disturbance from a nearby railroad, heavily used highway, and airport. Avocet Research Associates suggest a minimum buffer zone of 30-50 m for waterbirds at this site. This buffer zone recommendation is based on the birds' flush distance, the distance from disturbance at which an individual or flock moves away from the disturbance. The mean flush distance exhibited by diving ducks in the Avocet Research Associates study was 34.74 m and for dabbling ducks was 31.00 m. These numbers are much lower than the 144m zone of influence I found in the current study. The large difference in response distances suggested by our two studies may be indicative of the fact that, at my study site, birds were naive to recreational disturbance and had a very large area to which they could retreat in the presence of disturbance, while at the Avocet Research Associates' site, birds may have become habituated to high levels of human activity.

Recommendations

Management Recommendations

In this study, waterfowl showed a response to new trail use at previously undisturbed ponds, suggesting that managers should seek to lessen the disturbance effect caused by trails. Management recommendations based on the results of this research include:

1. When possible, locate a trail at least 144 m from ponded wintering duck habitat. This will ensure that trail use activity along the trail will be less likely to elicit a disturbance response from ducks.
2. If the location of the trail cannot be manipulated, explore other options to create a buffer between the trail and the pond. With many of the ponds in the SBSRP, trails are placed atop levees that divide two ponds from one another, leaving few options for location of a trail relative to the pond. Other options aside from a spatial buffer include visual buffers such as high vegetation, shielding the ducks from view of the trail users, or temporal buffers, such as closing certain trails during times of large waterfowl use of those ponds (Knight and Temple, 1995).
3. Enhance non-trail ponds to compensate for habitat that is affected by trails. Since the SBSRP covers such a vast area, it would be reasonable to expect that certain areas could be set aside and managed as prime wintering duck habitat, away from trail use and other disturbances. These ponds would function not only as primary habitat for ducks but also as refugia for ducks

that have left an area experiencing a high level of trail use and/or other disturbance.

Research Recommendations

A study such as this raises many new questions that have yet to be examined, including these suggestions for further research:

1. How much winter trail use occurs presently on the existing trails in the Project area and how will this change with the establishment of Phase 1 trails? At this point, no one has conducted a study of the use levels experienced by the trails located in the Project area. It would be particularly valuable to measure the use levels in winter, when weather conditions may not be ideal for outdoor recreation. This type of study would help us to understand how frequently wintering ducks are disturbed and if, given that disturbance rate, mitigations are appropriate.
2. If wintering ducks using the SBSRP area respond significantly to two people walking along a trail, how would they respond to larger groups using the trail? Previous studies show that number of disturbers could have a significant impact on response from wildlife. Burger and Gochfeld (1991) found that “number of people approaching” was a significant factor in determining flush distance in bird species in India. Even a small shift in number of approachers can elicit a change in response; in a Monterey, California study by Thomas et al. (2003), the number of times an individual took flight increased as did the number of human disturbers. This is an issue that has not been studied for the population of wintering ducks that use the

salt ponds of the South Bay; a study of this issue would provide valuable information to land managers here.

3. If trail use increases near wintering waterfowl habitat, would habituation play a role in the ducks' response to trail use? There is the possibility that if the trails in the Project area experience relatively high levels of use, ducks may exhibit less of a response to disturbance. This would have the two-fold result of reducing the trails' zone of influence and reducing the amount of energy spent by ducks moving away from disturbance. It is important to note, however, that according to Gabrielsen and Smith (1995), birds may tend to habituate less quickly to human disturbance than to disturbance from non-human sources, such as mechanical noises. No one has, of yet, conducted a study directed specifically at the presence or absence of habituation in the waterfowl population of the South Bay; a study such as this would provide important information to land managers.
4. Will the Project's Phase 1 actions have a population-level impact on the South Bay's wintering ducks? This study shows, on an individual and group-level basis, ducks do respond to trail use, and, based on trail increases and habitat conversion, Phase 1 of the SBSRP will decrease potential duck habitat. However, the larger, long-term repercussions of these actions are unknown at this point and need additional research. This is an issue that is difficult to research since there are many factors that tie into survivorship and population trends, such as predation, food availability, and competition. As pointed out by Nisbet (2000), it is difficult to measure the effects of factors

such as these while simultaneously controlling variation in the others. Also, long-term trends cannot be extrapolated from a study showing short-term behavioral impact to wildlife, particularly migratory species for which disturbance and reproductive success may occur thousands of kilometers apart (Guillemain et al., 2007). However, the SBSPRP provides much-needed habitat to ducks in a very urban area; therefore, any information regarding the long-term effects of the Project's actions on ducks would prove very useful to project managers.

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