A Review of Human Disturbance Impacts on Waterbirds

Kathi L. Borgmann*
Audubon California, 376 Greenwood Beach Rd., Tiburon, California 94920

Abstract

The San Francisco Bay provides critical migratory, wintering, and breeding habitat to millions of waterbirds and provides many opportunities for human recreation along the shores and in the estuary. Due to the potential conflict between waterbirds and recreationists, I reviewed the impacts of human disturbance on waterbirds from the literature to provide management recommendations aimed at reducing potential negative impacts. I reviewed 50 unpublished and peer-reviewed published studies that examined the effects of human disturbance on waterfowl, diving duck, wading bird, and shorebird species that occur in the San Francisco Bay area, Eighty-six percent of these studies reported that human-caused disturbances impacted the study species. Human-caused disturbances such as boating and walking were shown to alter waterbird behavior, diverting time and energy away other essential behaviors such as feeding. Responses to disturbance varied significantly among species, types of disturbance, body condition, food availability, and frequency of disturbance. However 57% of the studies reviewed reported birds taking flight in response to a human caused disturbance. Although many studies reported an effect of disturbance very few studies reported population level consequences as a result of disturbance. Strategies, such as establishing set-back distances of 250 m from waterfowl, diving ducks, wading birds, and shorebirds may lessen the impacts to the most sensitive species.

Introduction

Millions of shorebirds, wading birds, diving ducks, and other waterfowl use the San Francisco Bay Estuary (the Bay) every year during migration, and throughout the breeding and wintering periods. In fact, the Western Hemisphere Shorebird Reserve Network recognizes the Bay as a site of hemispheric importance to shorebirds[1]. The Bay also provides wintering habitat to 44 - 50% of diving ducks species along the Pacific Flyway[2] and is considered a site of continental significance for waterfowl[3]. Coinciding with critical waterbird habitat are millions of people and numerous industries that are seeking recreational and business opportunities. Increased demand for recreational opportunities, shipping lanes, and ferry routes will also likely have an impact on the waterbirds that use the Bay. For example, human caused disturbances from boating or walking can cause birds to take flight, which may increase energy expenditure, or affect their ability to consume needed resources with potential population level consequences[4-6]. Disturbances can also affect habitat availability, leaving some areas no longer suitable for waterbirds[7].

Although millions of shorebirds, wading birds, diving ducks, and other waterfowl use the Bay, populations of many of these species are experiencing continental declines. Surf Scoters (*Melanitta perspicillata*), for example, have declined by 50-60% in the last 50 years[8-11] while Greater (*Aythya marila*) and Lesser Scaup (*Aythya affinis*) populations have declined by 15% from the long-term average population size[12]. Shorebird populations have also shown recent declines including Dunlin (*Calidris alpina*), Whimbrel (*Numenius phaeopus*), Snowy Plover (*Charadrius alexandrinus*), American Golden Plover (*Pluvialis dominica*), Solitary Sandpiper

* kborgmann@audubon.org

(*Tringa solitaria*), Long-billed Curlew (*Numenius americanus*), Marbled Godwit (*Limosa fedoa*), and Ruddy Turnstone (*Arenaria interpres*)[13-17]. The percentage of population declines for many of these shorebird species is unknown due to limited data and poor monitoring, however populations of these species are small and face severe threats that put them at risk[14]. Diving duck and shorebird population declines are hypothesized to stem from a variety of causes including habitat loss, contaminants, and reduced food availability, among others[9,14-16]. Human caused disturbance has also been suggested as a potential reason for population declines for Red Knot (*Calidris canutus*), Sanderling (*Calidris alba*), and Short-billed Dowitcher (*Limnodromus griseus*)[6].

Thus, with the increase in proposed water-based transportation and recreational activities along the shores and within the estuary of the San Francisco Bay[18-19] we need to better understand the impact of transportation and recreational activities on the millions of diving ducks and shorebirds that rely on the Bay area. To ensure adequate habitat within the Bay, we need to assess the potential impacts of human disturbance and recommend the most appropriate measures to reduce any potential disturbances and minimize related impacts. Here I review studies that have examined the effects of human caused disturbances on waterbirds to assess potential impacts, and compile the information to assist in making management recommendations.

Methods

I reviewed studies investigating the effects of human disturbance (boating, walking, running, driving, flying, hunting, fishing, and dog walking) on foraging, roosting, and breeding waterfowl, diving ducks wading birds, and shorebirds. I searched ISI Web of Knowledge for studies with disturbance, waterfowl, waterbird, diving duck, shorebird, and recreation as keywords. I also included studies that were referenced in published and unpublished reports. I reviewed 111 studies that examined the effects of human disturbance on waterbirds, waterfowl, and shorebirds throughout the North and South America and Europe. For this report, I limited the analysis to studies that examined the effects of disturbance on species that are likely to occur in California and specifically the Bay Area; 50 studies met these criteria. For each study I recorded: species, study location, type of disturbance, the response of each species to disturbance, the methods researchers used to record the effect of disturbance, and management recommendations.

Results and Discussion

I reviewed 50 unpublished and peer-reviewed published studies that examined the effects of human disturbance on diving duck, other waterfowl, wading bird, and shorebird species that occur in the Bay Area, to assess the impacts of human disturbance on birds and to provide management recommendations aimed at reducing potential negative impacts. Eighty-six percent of the 50 studies reviewed reported that human caused disturbances impacted the study species. Summaries describing the various effects of disturbance on waterbirds for each study reviewed are shown in Table 1. Flush distances by species are reported in Table 2. Summaries are provided for individual species where possible, however, many studies reported the effects of disturbance on entire groups (e.g., shorebirds) and thus summarizing species-specific effects was not possible.

Responses to Disturbance

A change in behavior in response to human disturbance was the most frequently cited impact to birds. Reported impacts included immediate effects on birds such as flushing, increased vigilance behavior, calling, and changes in daily activities (Table 1). Often individuals altered their current behavior from foraging or resting to flying or diving as the disturbing agent approached (Table 1). Fifty-seven percent of studies reported birds taking flight or flushing in response to a disturbance (Table 1 and 2). The distance at which individuals flushed when an anthropogenic disturbing agent approached varied considerably by species and by type of disturbance (Table 2). For example, 72% of dabbling ducks flew when pedestrians approached within 50m [20] but Scaup species flew when a ferry approached within 179 m[21]. Species also respond differently to the same disturbance. In an experimental study conducted in the San Francisco Bay, abundance of Greater and Lesser Scaup and Canvasback (*Aythya valisineria*) declined after hikers walked along trails adjacent to ponds, while abundance of Ruddy duck (*Oxyura jamaicensis*), Northern Shoveler (*Anas clypeata*), and Bufflehead (*Bucephala albeola*) did not change in response to hikers[22].

The distance at which species respond to disturbance is often thought to indicate their sensitivity to disturbance, such that individuals that flush when a disturbance is far are more sensitive than individuals that do not flush until the disturbance is near. In general, species that took flight when a disturbance was further away included Great Egret (*Ardea alba*), Great Blue Heron (*Ardea herodias*), Snowy Egret (*Egretta thula*), Clark's Grebe (*Aechmophorus clarkii*), Double-crested Cormorant (*Phalacrocorax auritus*), Common Loon (*Gavia immer*), Greater and Lesser Scaup, Surf Scoter, Red-breasted Merganser (*Mergus serrator*), and Ruddy Duck (Table 2). However, individuals that do not flush until the disturbing agent is very close may be, in fact, individuals most sensitive to disturbance, as they may be trading the risk of starvation against the risk of predation[23-24]. Individuals that flush sooner to disturbance may be in better condition and have the capability to respond to the disturbance, while birds in poorer condition may need to continue to forage until the last possible moment because the need to consume as many resources as possible [23-24].

The type of disturbance also affected when individuals were likely to respond. Overall, types of disturbances that appeared more likely to cause birds to flush sooner across all studies I reviewed included motorized boats at high speeds[25], all-terrain vehicle use [26], and activities with rapid movement such as running and unleashed dogs[27-28]. Although fast-moving and loud disturbances are generally thought to be more disturbing, non-motorized boat traffic can also cause birds to flush. For example, non-motorized boats caused several species of diving ducks and other waterfowl to flush when kayakers were on average 99 m away from a waterbird[29]. Only three studies compared the response of birds to different types of disturbance[20,30]. Pease et al[20] exposed seven species of dabbling ducks experimentally to walking, biking, a slow truck, a fast truck, or an electric tram[20]. Pedestrian and cyclists caused the highest proportion of dabbling ducks to flush relative to automobiles and trams[20]. Rodgers and Smith[30] measured the response of 16 species of waterbirds to four types of disturbance (walking, all-terrain vehicle, automobile, and boat), however, only one species was exposed to multiple types of disturbance. Brown Pelicans (*Pelecanus occidentalis*) flushed at greater distances to motor boats than to pedestrians[30]. Rodgers and Schwikert [31] measured flush distances in response to non-motorized watercraft and motorized boats. Three [Anhinga (*Anhinga anhinga*), Little Blue Heron (*Egretta Caerulea*), and Willet (*Catoptrophorus semipalmatus*)] out of the 15 species monitored flushed

at greater distances to motorized boats while one species Great Blue Heron flushed at greater distances to non-motorized watercraft[31].

Birds that flush in response to disturbance may or may not return to the original site or may take several minutes to return. In general breeding birds tend to return to their nest site relatively quickly following a disturbance because they need to care for their young. Breeding Western Snowy Plovers (*Charadrius alexandrinus nivosus*) for example, returned to their nests on average within four minutes following a disturbance by a pedestrian[32]. Non-breeding birds may be less likely to return to the original location following disturbance, however, time to return is likely dependent on activity engaged in (e.g., foraging or nesting), food availability, and body condition. When food abundance is low shorebirds may take longer to return following a disturbance[33]. Whether birds return to the original site can also depend on the proportion of suitable habitat in the region[34] as well as frequency of the disturbance.

Shorebirds may avoid areas with extensive disturbance all together and choose roosting or foraging sites with fewer disturbances[7,21]. In fact, another common response reported was the reduction in the number of birds present after a disturbance or in heavily disturbed areas[21-22,28,35-36] (Table 1). For example, the average number of birds along a tidal creek decreased after an experimental boat disturbance[36] and the number of diving ducks (Scaup species and Canvasbacks) decreased after hikers repeatedly walked along trails adjacent to ponds[22]. Whether disturbance caused long-term abandonment of the sites is not clear from the data presented as many of these studies did not perform long-term monitoring of the population.

Other behavioral changes reported included changes in the amount of time spent resting or foraging. A number of studies documented a change in the proportion of time birds spent foraging as disturbance increased[4,37-39]. For example, as an all-terrain vehicle repeatedly passed through a section of beach, observers recorded instantaneous behavior of Sanderlings and found the amount of time Sanderlings spent resting decreased while the amount of time spent being active (e.g., locomotion, antagonistic behavior, and maintenance) increased relative to Sanderling activity at control sites[35].

Factors Affecting Response to Disturbance. —Numerous factors affected how species responded to disturbance. Response to disturbance varied by species[22,40-42], flock size[38,43-44], body condition[45-46], food availability[47], frequency and quantity of disturbance[48-49], body size[31,41], distance to other suitable foraging areas[50], speed of disturbance[25,28,38], and type of disturbance[20] (Table 1). Migrants, for example were less tolerant of disturbance than resident birds[40], suggesting that disturbance on wintering grounds could have larger consequences for migratory birds. Thus, care should be taken to reduce potential impacts of human disturbance on wintering grounds. Larger species tended to flush when the disturbing agent was further away, likely due to their need for more space to take off compared to a smaller bird[31,41]. Waterbirds may also be more susceptible to disturbance during periods of inclement weather, during molting, and during periods when food availability is reduced[47].

Speed of disturbance can also affect flush responses. Although fast moving disturbances are generally thought to cause birds to flush[28], slow moving vehicles that made frequent stops were more likely to flush Great Egrets and Snowy Egrets compared to a vehicle passing at constant speeds[37]. Even a slow moving disturbance such as a kayak can cause waterbirds to flush; a single kayak that approached within 30 m caused 600 cormorants to flush[51].

Flock size can also affect when individuals respond to a disturbance. Rafting ducks in large flocks tended to flush sooner than smaller flocks at the approach of a non-motorized boat[52]. However, flock size did not affect how Sanderlings responded to disturbance[53]. Birds that tend to

aggregate in groups may respond sooner to a disturbance because a flight response by one individual will often cause the entire group to take flight. Thus establishing larger set-back distances in areas with large rafts of diving ducks may prevent large numbers of birds from taking flight.

Costs of Disturbance

Although 86% of the studies I reviewed documented a change in behavior as a result of disturbance, the effects reported were immediate behavioral responses (e.g., taking flight or "flushing") and very few studies reported population level consequences of disturbance. Only seven studies assessed impacts to reproduction, and another eight studies reported changes in time spent foraging (Table 1). Disturbance may have notable impacts to populations of waterbirds; yet very few studies in the United States or Europe have documented specific costs of disturbance.

Energetic costs.—Eight studies reported changes in the amount of time individuals spent foraging, and only three of these studies reported the energetic consequences of increased flight or lost feeding time due to disturbance. The few studies that did report energetic costs found that disturbance increased energetic expenditure[4,46,54] and reduced the amount of time spent foraging[27,37-39,55]. Five boating disturbances a day increased energy expenditure of Canvasbacks, suggesting that Canvasbacks would need to consume an additional 75 kcal/day to compensate for energy lost due to disturbance[54]. For American Coots (*Fulica americana*) a disturbance of 4 boats/hour increased energy expenditure by 10.5 kcal/day above the 111.40 kcal/day for normal activities [4]. Mallards (*Anas platyrhynchos*) that were experimentally disturbed lost a significant amount of body mass compared to the undisturbed group due to increased flights in response to disturbance[46].

In addition to the three studies on waterbird species that occur in the Bay Area, two additional studies examined energy expenditure on species that typically do not occur in the Bay Area but they are related to Bay Area species. For example, for a 30 minute increase in alarm flights, total energy expenditure for a lean Great Knot (*Calidris tenuirostris*) increased by 13.3% [56]. Snow Goose (*Chen caerulescens*) hourly energy expenditure increased 2.7 kj/hour for every 0.5/hour of disturbance, and time spent foraging decreased between 4 and 51% depending on disturbance level [57]. Although very few studies have been conducted on birds that occur in California and specifically the Bay Area, these additional studies suggest that lost foraging time due to human disturbance can increase energy expenditure and potentially decrease fitness. Birds that cannot compensate for lost foraging time are likely to be in poorer physical condition, which could translate to poor reproductive success on the breeding grounds. Moreover, because flying is energetically expensive, birds that flush in response to disturbance will need to acquire additional resources to compensate both for increased energy expenditure due to flight and lost foraging time. Thus, disturbance, especially if frequent, could have large energetic consequences for waterbirds and potentially impact populations.

Reproductive Costs.—Very few studies (n = 7) reported effects of disturbance on reproductive success. Disturbances during the breeding season also have the potential to reduce reproductive success either through nest abandonment or increased risk of nest predation due to exposure[58]. For example, researcher disturbance at Brown Pelican and Double-crested Cormorant nest sites caused incubating females to flush from the nest, leaving the nests vulnerable to predators[59]. Egg loss and hatching failure of Western Gulls (*Larus occidentalis*)

was also positively correlated with frequency of disturbance[48] and Western Snowy Plover chick loss was greater on weekends than weekdays when a greater number of people used the beach[60].

Management Recommendations

Flush distances are often used to set buffer zones, or set-back distances to lessen the impacts of human-caused disturbance on wildlife. Yet, individuals that wait until the disturbance is nearer may in fact be those individuals most sensitive to disturbance[23-24]. Thus, individuals that flush sooner to disturbance may have the capability to respond because they are in better condition relative to birds in poorer condition that may need continue to forage until the last possible moment[23-24]. Regardless, establishing conservative buffer zones or set-back distances should help lessen potential negative impacts that could occur as a result of disturbance and will protect a larger proportion of species (Table 2).

Potentially adverse impacts of human disturbance could be lessened by:

- Routing trails and access around sensitive breeding and roosting sites,
- Establishing and enforcing set-back distances or buffer zones of 250 m (Table 2),
- Designing public access features to reduce disturbance (e.g., blinds),
- Establishing and enforcing seasonal or temporary closures of high priority diving duck and shorebird sites,
- Enforcing leash requirements for pets, and
- Educating the public.

Although responses to disturbance are quite variable, establishing set-back distances of 250 m from groups of diving ducks, other waterfowl, wading birds, and shorebirds will likely lessen the impacts to the most sensitive species. Establishing fencing to keep people away from sensitive breeding areas can also help improve reproductive success[61]. Enforcement of leash laws can also reduce the number of birds disturbed[61].

Additional Research Needs

Additional research focusing on population level consequences of disturbance is needed to more accurately assess the impacts and devise appropriate response strategies. Research priorities include (1) determining energetic costs of disturbance, (2) evaluating the effects of disturbance on marked individuals, and (3) assessing the relationship between food availability and sensitivity to disturbance. The use of individual-based models that link behavioral responses to disturbance with population level consequences can also help managers make more informed decisions about the predicted effects of disturbance[62-63].

Table 1. Summary of the effects of human disturbance on diving ducks, other waterfowl, wading birds, and shorebirds and suggested management recommendations. Summaries are provided for individual species were possible, however, many studies reported the effects of disturbance on entire groups (e.g., shorebirds) and thus summarizing species-specific effects was not possible.

Species	Study Location	Type of Disturbance	Effect of disturbance	Management recommendations	Ref.
Brown Pelican	Baja, Mexico	Walking	Disturbances reduced productivity in ground-nesting Brown Pelicans. Human disturbance can cause Heerman's gulls to attack neighboring gulls reducing productivity.	Controlling access. Isolation of critical areas. Warden patrols to enforce restrictions.	59
Double-crested Cormorant	Quebec Canada	Walking	Frequent researcher visits caused nest abandonment, gull predation, and discouraged settling in disturbed colonies by late-nesting Cormorants. Nest predation was greater at only one of the disturbed island sites and only in one year.	Restrict access to later in the nesting cycle.	64
Brandt's Cormorant	California	Air traffic	20 Brandt's cormorants flushed when a hang glider passed by. A passing jet flushed 4 of 10 roosting birds	Use a visual screen. Limit activities to the non-breeding season.	65
Brandt's Cormorant	California	Boating (motorized and non), air traffic, fireworks	26% of the major disturbance events were due to kayaks or other non-motorized watercraft. Small motorized boats caused 22% of major disturbances. A single kayak within 100 feet caused 600 cormorants to flush.	Use a visual screen. Limit activities to the non-breeding season.	51
Brandt's Cormorant	California	Boating (motorized and non), air traffic	21% of disturbances were minor, 67% were major. Non-motorized watercraft caused 23% of the major disturbances and motorized watercraft caused 19% of the major disturbances. 2 canoes flushed 450 cormorants, 1 kayak flushed 100 more cormorants causing the birds to abandon and lose nesting material.	Use a visual screen. Limit activities to the non-breeding season.	66
Brandt's Cormorant	California	Boating (motorized and non), air traffic	49% of disturbances were major, 7% moderate, and 44% minor. Motorized and non-motorized boats and air traffic caused most disturbances.	Use a visual screen. Limit activities to the non-breeding season.	67
Brandt's Cormorant, Pelagic Cormorant, Western Gull	California	Human activity	39% of the birds responded to event (human activity) related activities. Most disturbances were due to sudden noises. Cormorant numbers decreased from 1900 to 13 individuals during the event.157 birds occupied the island prior to disturbance in attempts to breed, but nearly all abandoned the breeding attempt and only 8 pairs remained after the disturbance.	Use a visual screen. Limit activities to the non-breeding season.	68

Species	Study Location	Type of Disturbance	Effect of disturbance	Management recommendations	Ref.
Great Blue Heron and Double-crested Cormorant	Colorado	Recreation	Distribution of Great Blue Heron nests shifted further away from the viewing area once installed. Heron nesting success was lower for nests closer to the viewing area. Distribution and nesting success of Cormorants did not change.		69
Great Egret and Snowy Egret	Florida	Vehicle	47.5% of birds did not respond to a passing vehicle. 19% of birds flushed (moved 100 m or greater) in response to experimental disturbance. Odds of disturbance increased by a factor of 2.8 when a vehicle slowed near foraging birds and increased by 2.3 times when a vehicle stopped compared to vehicles passing by at a steady speed. Foraging wading birds were more likely to be disturbed by vehicles when vehicles stopped. Snowy Egrets experienced reduced foraging rates when experimentally disturbed by a vehicle.	Concentrate ecotourist activities or provide areas that are free of ecotourist activities.	37
Great Blue Heron, Great Egret, Snowy Egret, Brown Pelican, Double-crested Cormorant, Black-crowned Night Heron, and Least Tern	Florida	Walkers and boating (motorized and non-motorized)	Response to disturbance was species specific. Colonial waterbirds exhibited greater flush distances in response to walking disturbance compared to motorboat disturbance. All birds initially exhibited an alert and agonistic behavior and then left the nest. Great Blue Herons and Great Egrets were two of the species most sensitive to human and boat disturbances. Brown Pelicans showed the least response. Double Crested Cormorants, Great Blue Herons, and Brown Pelicans exhibited smaller flush distances in response to boats as compared to walkers.	The most sensitive species, the one with the greatest flushing distance, should be used to establish set back distances.	42
38 waterbird species	Florida	Driving and walking	Response to disturbance was species specific and varied throughout the season. In general, resident species (19) were less bothered by disturbance than migratory species. See Table 2for list of species and species specific flush distances.	Enact entrance fees to parks, close certain areas, provide guided tours, education, periodic closings of entire refuge, permits, and limit number of visitors.	40
Shorebirds and wading birds (Great Egret, Snowy Egret, Great Blue Heron, and Green Heron)	South Carolina	Boating	Half of all individuals of all species except Snowy Egrets abandoned the tidal creek after experimental boat intrusion. The average number of birds detected decreased after the first pass of a boat.	Suggests that disturbance impacts be assessed on a species by species basis.	36

Species	Study Location	Type of Disturbance	Effect of disturbance	Management recommendations	Ref.
Great Egret, Snowy Egret, Black-crowned Night Heron, and Least Tern	Virginia and North Carolina	Walking	Birds flushed at varying distances to approaching people. Wading birds flushed when people were 53 m away. Least Terns flushed when people were 70 m away. Phase of the nesting cycle and colony size had little effect on the response to disturbance.	100 m buffer for Least and Royal Terns and wading birds and 200 m for Common Terns and Skimmers.	70
Mallard	Colorado	Hunting, Walking	Mallards exposed to shooting had a greater flight distance after disturbance than Mallards disturbed by hunters walking.		71
Mallard	France	Vehicle	Body mass was significantly lower in both experimentally disturbed groups, those disturbed twice daily and those disturbed four times daily. Females lost more body mass than males in the experimentally disturbed groups. Loss of body mass likely due to increased number of flights in response to disturbance.		46
Dabbling ducks (Gadwall, Mallard, Northern Pintail, American Wigeon , Green-winged Teal)	Virginia	Vehicles, walking	Most ducks flew when disturbance was between 0-50 (72.2% flew) and 51-100 m (41% flew) away. Higher proportion of birds flew in response to pedestrians and cyclists compared to slow trucks, trams, and fast trucks	Use trams or buses to reduce the rate of disturbance. Continue seasonal closures.	20
Canvasback, Mallard, American Wigeon, Mallard, Blue-winged Teal, and other diving ducks	Minnesota	Boating	Boats resulted in 5.2 disturbances per day. Minimum flight time per disturbance of Canvasback flocks was 4.43 minutes. Minimum flight time for all diving ducks was 3.4 minutes. Suggests that Canvasbacks would need to consume an additional 75 kcal/day to compensate for 1 hour per day of disturbance.		54
Diving ducks (Scaup species, Surf Scoter, and Grebe species)	California	Ferry	The total number of Scaup and Grebe species detected decreased significantly after ferry passage. Surf Scoters also showed non-significant declines after ferry passage. Ferry routes affected approximately 3% of the foraging area in the bay for these species. See Table 2 for flush distances		21

Species	Study Location	Type of Disturbance	Effect of disturbance	Management recommendations	Ref.
Diving ducks (Bufflehead, Ruddy Duck, Scaup species, Canvasback)	California	Walking	Number of ducks detected decreased after disturbance. Most notable differences in duck numbers occurred 80 m from the levee trail where the disturbance occurred. Scaup and Canvasback showed significant effect of trail disturbance, but Ruddy ducks, Northern Shovelers, and Buffleheads did not. Scaup appeared more sensitive, fewer were detected after disturbance 120 m from levee trail. See Table 2 for species specific flush distances.	Locate trails 144 m away from ponds.	22
Diving ducks (Scaup species, Goldeneye, Merganser, Scoter, Ruddy Duck)	Ontario, Canada	Boating	Diving ducks flew 746 m away from the disturbance in the spring and 939 m in the fall. Flight time in response to disturbance was 33 seconds in the spring and 51 seconds in the fall.	Provide refuges with restricted or banned boat traffic during peak migration	72
Diving ducks (See Table 1 for list of species)	California	Boating (non-motorized)	Birds flew, dove, or swam in response to disturbance. Larger flocks responded at a greater distance. See Table 2 for species specific flush distances.	Suggests a buffer zone of 250 m to minimize effects of non-motorized small boats based on the recommended distance for the most sensitive species plus 40 m. See Table 1 for species specific flush distances	52
Diving ducks (See Table 1 for list of species)	California	Boating	See Table 2 for species specific flush distances.		73
American Coot	Oklahoma	Boating, fishing	Boat fishing decreased feeding and increased swimming, flight, and alertness. Fishing from the shore also increased flight and alertness. Energy expenditure was greater during boat fishing disturbance. Energy expenditure during undisturbed periods = 111.40 kcal/bird/day and disturbed periods = 112.32 kcal/bird/day. Maximum disturbance of 4 boats/hour increased energy expenditure by 10.5 kcal/day above the 111.40 kcal/day for normal activities.	Manages should consider individual foraging strategies, habitat requirements, and migration chronologies of waterbirds when establishing management recommendations.	4
Black Oystercatcher	Alaska	Recreation	Annual productivity was not strongly affected by recreational disturbance.	Suggests preventative management to minimize disturbance during critical breeding periods. Move camp sites away from nest sites.	74

Species	Study Location	Type of Disturbance	Effect of disturbance	Management recommendations	Ref.
Semipalmated Plover and Least Sandpiper	British Columbia, Canada	Walking	Feeding rates of Semipalmated Plovers decreased with increasing human density and was not influenced by flock size or worm availability. Feeding rates of Least Sandpipers were not affected solely by number of people or amphipod density, but feeding rates decreased with increasing flock size and number of people.		38
Western Snowy Plover	California	Recreation	On weekends and holidays, chick loss was 73% greater than expected in 1999 and 69% greater than expected in 2000.		60
Western Snowy Plover	California	Recreation	Wintering Snowy Plovers were disturbed at a rate of 4.3 per hour. Dogs, horses, and crows were the main disturbing agent. Feeding rates declined with increasing human activity.	Prohibit dogs and create a 30 m buffer zone surrounding 400 m stretch of beach	39
Western Snowy Plover	California	Recreation	The Beach barrier reduced disturbance by half. Snowy plovers moved inside the protected area as humans began using the beach. Percentage of successful nests also increased following protection.	Create small protected areas for breeding snowy plovers.	61
Western Snowy Plover	California	Walking	Birds flushed off their nests 80% of the time to trail walkers and 82% of the time to research walkers. Birds flushed 20% of the time at the control sites. Plovers returned after flushing within 4 minutes on average. Control plovers returned within 1 minute. Average flush distance was 146 m.	Locate trails at leas 150 m from Plover nesting habitat.	32
Western Snowy Plover	California	Walking	Birds flushed off the nest when person was 175 m from the nest (Range 55-296)	245 m buffer	75
Sanderling	California	Recreation	Number of people in a group, type of activity, and dogs reduced the amount of time spent foraging, affected distance moved by Sanderlings, and affected the response by Sanderlings (running or flying). 96% of Sanderlings responded to humans at 30 m or less. Average minimum approach distance for all activities was 14 m	30 m buffer in areas where shorebirds concentrate and enforce leash laws.	49
Sanderling	Florida	Recreation	Number of people within 100 m was the most important factor affecting variation in feeding time.		43
Sanderling	England	Walking	Average flush distance was 12 m. Flock size did not affect flush response distance.		53

Species	Study Location	Type of Disturbance	Effect of disturbance	Management recommendations	Ref.
Ruddy Turnstone	Scotland	Walking	Experimentally food supplemented group stopped feeding sooner, flushed at a greater distance, and flew further away than control (unfed group) birds in response to disturbance.	Suggest that reserve managers not rely solely on flush distance to determine which birds are at higher risk.	45
Shorebird species	Delaware	Recreation	Birds flew in response to disturbance and often did not return. Study suggests that due to conservation efforts in the region birds have other disturbance free beaches available.	They encourage management of beaches/birdwatchers and closures during migration season, education, dog leash laws, bird viewing platforms, enforcement, etc. Enactment and enforcement of regulations decreased birder disruptions from 53 minutes/hr in 1992 to 3.6 minutes in 2002.	34
Shorebird species	California	Recreation	The proportion of birds disturbed increased with human activity. The proportion of birds feeding did not decline with increased disturbance for most species. Black-bellied Plovers and Willets showed a stronger association between feeding rates and disturbance. Leashing dogs reduced the number of birds disturbed.	Concentrate activity away from preferred shorebird habitats. Enforce leash laws.	27
Shorebird species	California	Recreation	Number of people on the beach appeared to have little effect on shorebird abundance.		76
Shorebird species	South Carolina	Boating	Selection of annual roost sites was affected by environmental conditions and boats within 1000 m for Red Knots,Whimbrel, Ruddy Turnstone, and Dowitchers. Red knots, in particular, tended to avoid annual roost sites with increased boat activity within 1000 m of the roost. Dowitcher daily roost site selection appeared to avoid areas with heavy boat traffic within 100 m.	Ensure that an adequate number of functional and diverse roost sites are available.	7
Shorebird species	California	Walking	There was no relationship between number of trail users and proportion of birds foraging, however 25% fewer birds were detected at trail sites during high use days relative to non-trail sites.	Place trails where humans do not directly approach shorebirds. Managers should provide high quality areas for shorebirds that are not adjacent to trails.	77
Shorebird species	British Columbia, Canada	Walking	Time to resume feeding following disturbance was greater in the morning and in areas with low food availability.		33

Species	Study Location	Type of Disturbance	Effect of disturbance	Management recommendations	Ref.
Shorebirds: Black-bellied Plover, Semipalmated Plover, Ruddy Turnstone, Sanderling, Semipalmated Sandpiper, Red Knot, Short-billed Dowitcher	Massachusetts	Vehicles	Four of seven species showed one or more types of movement in response to disturbance. Species that preferred the front area of the beach changed locations in relation to vehicle numbers (Sanderlings, Semipalmated Plovers, and Ruddy Turnstones). Sanderlings moved to the back beach when disturbance was high, but preferred the front beach when disturbance was low. Red knot, Short-billed Dowitcher, and Sanderling abundance were negatively correlated with vehicle abundance.	Reduce or eliminate activity at small portions of the front beach	6
Shorebirds: Sanderlings, Black-bellied Plover, Willet	North Carolina	ATV	Vehicle disturbance reduced the number of shorebirds present and reduced the use of swash zone by shorebirds, in particular numbers of Black-bellied Plovers. Vehicle disturbance decreased the amount of time Sanderlings spent resting and increased the proportion of time they spent being active. Willet and Sanderling numbers did not change with disturbance but disturbance did affect distribution of Willets and Sanderlings	Reduce disturbance especially at sites used for roosting.	35
Shorebird species	New Jersey	Recreation	Number of birds using shore was lower when people were present. Activities with rapid movements such as jogging at close proximity often caused birds to flush. Birds were less likely to flush in response to slower activities such as bird watching.	Protect areas from close and fast-moving human activities such as jogging. Human activities should be restricted to certain distance around shorebird roosting areas.	28
Shorebird and Gull species	New Jersey	Beach clean-up activities and construction	Beach clean-up and demolition work shifted birds further out on to the mudflat. Foraging efficiency of gulls was reduced after disturbance. Gull numbers decreased when workers arrived and increased when workers left.	Restrict access to 100 m stretches of beach.	55
Waterbirds and Shorebirds	Florida	Recreation	Flush distances in response to disturbance were species specific. Shorebirds had the smallest flush distance (i.e., allowed a closer approach). See Table 2 for species specific flush distances.	100 m buffer for foraging and roosting waterbirds.	30
Waterbirds and Shorebirds	Florida	Boating (both)	Larger species flushed at greater distances. Found variation within and among species in response to the approach of both Jet Ski and outboard boats. 11 of 16 species did not show a difference in flush distance between boat types. See Table 2 for species specific flush distances.	Establish set back distances. See Table 1 for species specific flush distances.	31

Species	Study Location	Type of Disturbance	Effect of disturbance	Management recommendations	Ref.
Waterbirds and Shorebirds	Florida	Boating	Larger species had greater flush distances. See Table 2 for species specific flush distances.	Species with the largest flush distances should be used to calculated set back distances	41
Western Gull	California	Walking	Egg loss and hatching failure was positively correlated with frequency of disturbance, but chick mortality was highest on the least disturbed plots.		48
Common Murre	Scotland	Walking	Common Murre nest failure was not associated with visitor numbers and was instead affected by timing; Common Murre nest failures occurred more at the beginning of the season.	Concludes that capping numbers alone will not do much unless it is done in conjunction with other restrictions, such as managing visitors so birds have longer periods of undisturbed time.	24
Marbled Murrelet	British Columbia, Canada	Boating	25% of birds flushed when boats were 40 m away at speeds >29 kmh but flushed when boats were 28 m away at speeds <12 kph. More juveniles flushed than adults. More birds dove in response to boats that flew. Of the birds that flew 83% left the feeding area. Age of individual, boat speed, and boat density affected response.	29 m on either side of the boat is required to reduce disturbance, such that 75% of the population would be minimally affected. 1) limiting boat speed, 2) limiting density of boats in an area, 3) concentrate boat use in areas with low densities of murrelets, 4) exclude boats in areas with high densities of murrelets, 5) exclude boats in areas that have historic high densities of murrelets, 6) seasonal closures when murrelets are actively foraging	25

Table 2. Average flush distance (m) and recommended set-back distance (m) based on type of disturbance for waterfowl, wading birds, and shorebirds during breeding and non-breeding seasons.

Species	Flush distance (m)	Recommended set-back distance (m)	Type of disturbance	Season	Additional comments	Ref.
Common Loon	51	218	Boating (non-motorized)	Non-breeding		52
Horned Grebe	24	126	Boating (non-motorized)	Non-breeding		52
Western Grebe	40	156	Boating (non-motorized)	Non-breeding		52
Clark's Grebe	41	202	Boating (non-motorized)	Non-breeding	Depends on flock size; highest reported.	52
Grebe species (Western and Clarks)	103	Not provided	Ferry	Non-breeding	As a ferry approached individuals flew at 103 m, dove at 96 m, swam at 176 m and were alter at 171 m	21
Brown Pelican	10	65	Boating	Breeding	No information provided on the effects of disturbance on nesting success	42
Brown Pelican	19	76	Walking	Breeding	No information provided on the effects of disturbance on nesting success	42
Brown Pelican	27	107	Walking	Non-breeding		30
Brown Pelican	34	126	Boating	Non-breeding		30
Brown Pelican	47	183	Jet ski	Non-breeding		31
Brown Pelican	53	147	Boating	Non-breeding		31
Double-crested Cormorant	30	96	Walking	Breeding	No information provided on the effects of disturbance on nesting success	42
Double-crested Cormorant	21	71	Boating	Breeding	No information provided on the effects of disturbance on nesting success	42
Double-crested Cormorant	47		Boating (non-motorized)	Breeding	No information provided on the effects of disturbance on nesting success	42
Double-crested Cormorant	31	102	Walking	Non-breeding		30
Double-crested Cormorant	49	156	Jet ski	Non-breeding		31
Double-crested Cormorant	43	132	Boating	Non-breeding		31
Double-crested Cormorant	152	284	Boating	Non-breeding	Airboat disturbance. Responded at greater distance to airboat compared to outboard motor boat.	41
Double-crested Cormorant	61	213	Boating (non-motorized)	Non-breeding		52
Great Blue Heron	32	100	Walking	Breeding	No information provided on the effects of disturbance on nesting success	42
Great Blue Heron	27	82	Boating	Breeding	No information provided on the effects of disturbance on nesting success	42

Species	Flush distance (m)	Recommended set-back distance (m)	Type of disturbance	Season	Additional comments	Ref.
Great Blue Heron	31	100	Walking	Non-breeding		30
Great Blue Heron	50	145	Jet ski	Non-breeding		31
Great Blue Heron	42	133	Boating	Non-breeding		31
Great Blue Heron	99	247	Boating	Non-breeding	Airboat disturbance. Responded at greater distance to airboat compared to outboard motor boat.	41
Great Egret	28	91	Walking	Breeding	No information provided on the effects of disturbance on nesting success	42
Great Egret	27	89	Boating	Breeding	No information provided on the effects of disturbance on nesting success	42
Great Egret	31	91	Walking	Non-breeding		30
Great Egret	36	107	Boating	Non-breeding		30
Great Egret	46	130	Jet ski	Non-breeding		31
Great Egret	51	146	Boating	Non-breeding		31
Great Egret	113	251	Boating	Non-breeding	Airboat disturbance. Responded at greater distance to airboat compared to outboard motor boat.	41
Snowy Egret	27	87	Walking	Non-breeding		30
Snowy Egret	32	118	Jet ski	Non-breeding		31
Snowy Egret	32	110	Boating	Non-breeding		31
Snowy Egret	81	192	Boating	Non-breeding	Airboat disturbance. Responded at greater distance to airboat compared to outboard motor boat.	41
Great Egret & Snowy Egret	40	Not provided	Vehicle[1]	Non-breeding	Probability of flushing increased at 40 m. Birds more likely to flush at slowing or stopping vehicle than a passing vehicle.	37
Black-crowned Night Heron	31	97	Walking	Breeding	No information provided on the effects of disturbance on nesting success	42
Wading birds	36	110	Boating	Non-breeding		73
Canada Goose	54	186	Boating (non-motorized)	Non-breeding		52
Mallard	18	83	Boating (non-motorized)	Non-breeding		52
Gadwall	65	Not provided	Boating	Non-breeding	Flush distance depended on single species (65 m) versus multi species flocks (107 m)	78
Canvasback	160	144	Walking	Non-breeding	Number present on ponds decreased after disturbance	22

Species	Flush distance (m)	Recommended set-back distance (m)	Type of disturbance	Season	Additional comments	Ref.
Dabbling ducks	100	Not provided	Vehicles & walking	Non-breeding	Most ducks flew when disturbance was between 0-50 (72.2% flew) and 51-100 m (41% flew). Pedestrians and bicyclists caused the most disturbance.	20
Dabbling ducks	31	108	Boating	Non-breeding		73
Greater Scaup	99	246	Boating (non-motorized)	Non-breeding	Depends on flock size; highest reported.	52
Lesser Scaup	51	252	Boating (non-motorized)	Non-breeding	Depends on flock size; highest reported.	52
Scaup species	149	144	Walking	Non-breeding	Number present on ponds decreased after disturbance	22
Scaup species	179	Not provided	Ferry	Non-breeding	As a ferry approached individuals flew at 179 m, swam at 184 m, were alert at 337 m	21
Surf Scoter	61	153	Boating (non-motorized)	Non-breeding	Depends on flock size; highest reported.	52
Surf Scoter	104	Not provided	Ferry	Non-breeding	As a ferry approached individuals flew at 104 m, dove at 87 m, swam at 245 m, were alert at 232 m	21
Common Goldeneye	37	163	Boating (non-motorized)	Non-breeding		52
Bufflehead	151	144	Walking	Non-breeding		22
Bufflehead	58	174	Boating (non-motorized)	Non-breeding	Depends on flock size; highest reported.	52
Red-breasted Merganser	28	219	Boating (non-motorized)	Non-breeding		52
Ruddy Duck	116	144	Walking	Non-breeding		22
Ruddy Duck	60	209	Boating (non-motorized)	Non-breeding		52
Diving ducks	189-174	Not provided	Boating	Non-breeding	Diving ducks includes Scaup species. Depends on season 189 m in spring and 174 m in fall	72
Diving ducks	35	103	Boating	Non-breeding		73
Common Moorhen	50	Not provided	Boating (non-motorized)	Non-breeding	Birds took little notice of boats until boats were 50 m away	44
American Coot	24	107	Boating (non-motorized)	Non-breeding		52
Black-bellied Plover	24	88	Jet ski	Non-breeding		31
Black-bellied Plover	23	84	Boating	Non-breeding		31
Semipalmated Plover	20	76	Vehicle	Non-breeding		30
Snowy Plover	30	30	Recreation	Non-breeding	Includes dog activity. Plover feeding activity declined with an increase in beach users. Unleashed dogs was the primary source of disturbance	39
Snowy Plover	146	150	Walking	Breeding	No information provided on the effects of disturbance on nesting success	32

Species	Flush distance (m)	Recommended set-back distance (m)	Type of disturbance	Season	Additional comments	Ref.
Snowy Plover	175	245	Walking	Breeding	No information provided on the effects of disturbance on nesting success	75
Willet	21	74	Walking	Non-breeding		30
Willet	24	77	Vehicle	Non-breeding	Flush distance for automobile listed. Flush distance for all-terrain vehicle = 19, recommended distance = 73	30
Willet	24	91	Jet ski	Non-breeding		31
Willet	31	94	Boating	Non-breeding		31
Ruddy Turnstone	12	Not provided	Walking	Non-breeding		45
Ruddy Turnstone	15	72	Vehicle	Non-breeding		30
Ruddy Turnstone	47	Not provided	Walking	Non-breeding		79
Sanderling	12	Not provided	Walking	Non-breeding	Birds further away were more likely to flush in response to birds that flushed close to the disturbance	53
Sanderling	14	67	Walking	Non-breeding		30
Sanderling	15	69	Vehicle	Non-breeding		30
Sanderling	14	30	Walking	Non-breeding	Includes dog activity. Number of people in the group affected flush distance.	49
Dunlin	71	Not provided	Walking	Non-breeding	Depended on location; 71 m in the Delta area and 163 m in the Wadden sea	79
Western Sandpiper	19	68	Vehicle	Non-breeding		30
Short-billed Dowitcher	21	82	Jet ski	Non-breeding		31
Shorebirds	20	Not provided	Recreation	Non-breeding	Includes dog activity. Leashing dogs reduced the number of disturbed birds	27
Ring-billed Gull	34	91	Walking	Non-breeding		30
Ring-billed Gull	32	101	Vehicle	Non-breeding	Flush distance for All-terrain vehicle listed. Flush distance for automobile = 22 m, recommended distance = 84 m	30
Ring-billed Gull	22	84	Vehicle	Non-breeding		30
Ring-billed Gull	42	137	Jet ski	Non-breeding		31
Gulls	13	65	Boating	Non-breeding		73
Least Tern	28	154	Walking	Breeding	No information provided on the effects of disturbance on nesting success	42
Least Tern	20	86	Jet ski	Non-breeding		31
Forster's Tern	24	87	Jet ski	Non-breeding		31

Species	Flush distance (m)	Recommended set-back distance (m)	Type of disturbance	Season	Additional comments	Ref.
Forster's Tern	23	83	Boating	Non-breeding		31
Caspian Tern	31	98	Jet ski	Non-breeding		31
Marbled Murrelet	40	Not provided	Boating	Non-breeding	Depends on boat speed; flushed at 40 m when speeds > 29 kph, flushed at 28 m when speeds <12 kph	25

[1]Vehicles include All-Terrain Vehicles, cars, and trucks.

References

1 Western Hemisphere Shorebird Reserve Network. *Western Hemisphere Shorebird Reserve Network List of Sites* http://www.whsrn.org/site-profile/san-francisco-bay, 2009).

2 Takekawa, J. Y. *et al.* Environmental threats to tidal-marsh vertebrates of the San Francisco Bay estuary. *Studies in Avian Biology* **32**, 176-197 (2007).

3 North American Waterfowl Management Plan Committee. North American waterfowl management plan 2004 strategic guidance: strengthening the biological foundation. (Canadian Wildlife Service, U.S. Fish and Wildlife Service, Secretaria de Medio Ambiente y Recursos Naturales, 2004).

4 Schummer, M. L. & Eddleman, W. R. Effects of disturbance on activity and energy budgets of migrating waterbirds in south-central Oklahoma. *Journal of Wildlife Management* **67**, 789-795 (2003).

5 Hockin, D. *et al.* Examination of the effects of disturbance on birds with reference to its importance in ecological assessments. *Journal of Environmental Management* **36**, 253-286 (1992).

6 Pfister, C., Harrington, B. A. & Lavine, M. The impact of human disturbance on shorebirds at a migration staging area. *Biological Conservation* **60**, 115-126 (1992).

7 Peters, K. A. & Otis, D. L. Shorebird roost-site selection at two temporal scales: is human disturbance a factor? *Journal of Applied Ecology* **44**, 196-209, doi:10.1111/j.1365-2664.2006.01248.x (2007).

8 Accurso, L. M. *Distribution and abundance of wintering waterfowl on San Francisco Bay 1988-1990* M.S. Thesis thesis, Humboldt State University, (1992).

9 Savard, J. P. L., Bordage, D. & Reed, A. in *The Birds of North America* Vol. 363 (eds A. Poole & F. Gill) (The Birds of North America, Inc., Philadelphia, PA, 1998).

10 Nysewander, D. R., Evenson, J. R., Murphie, B. L. & Cyra, T. A. in *Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference: Vancouver, B.C. , 21 March-3 April 2003.* eds T. Droscher & D. A. Fraser) (2003).

11 Trost, R. E. Pacific Flyway 2001-2002 Fall and Winter Waterfowl Survey Report. (Portland, Oregon, 2002).

12 Afton, A. D. & Anderson, M. G. Declining scaup populations: a retrospective analysis of long-term population and harvest survey data. *Journal of Wildlife Management* **65**, 781-796 (2001).

13 Andres, B., Clay, R. & Duncan, C. Shorebird species of conservation concern in the Western Hemisphere. (2006). <Availalbe online at www.whsrn.org/shorebird/status.html>.

14 Brown, S., Hickey, C., Harrington, B. & Gill, R. (Manomet Center for Conservation Sciences, Manomet, MA, 2001).

15 Clay, R. P., Lesterhuis, A. J. & Johnson, O. Conservation plan for the American Golden Plover (*Pluvialis dominica*). Version 1.0. (Manomet Center for Conservation Sciences, Manomet, massachusetts, 2009).

16 Melcher, C. P., Farmer, A. & Fernandez, G. Version 1.1 Conservation plan for the Marbled Godwit. Manomet Center for Conservation Science. (Manomet, Massachusetts, 2006).

17 Fernandez, G., Buchanan, J. B., R. E. Gill, J., Lancot, R. & Warnock, N. Conservation plan for Dunlin with breeding populations in North America (*Calidris alpina articola, C. a. pacifica,* and *C. a. hundsonia*). (Manomet, Massachusetts, 2010).

18 GAIA Consulting Inc. San Francisco Bay Area Water Trail Plan Draft Revised EIR. (2010).

19 Bay Conservation and Development Commission. Public access and wildlife compatibility. (BCDC, San Francisco, CA, 2001).

20 Pease, M. L., Rose, R. K. & Butler, M. J. Effects of human disturbances on the behavior of wintering ducks. *Wildlife Society Bulletin* **33**, 103-112 (2005).

21 Takekawa, J., Wilson, N. R., Cruz, S. E. W. D. L., Anfinson, J. O. & Namgail, T. Effects of ferry traffic on the distribution, abundance and behavior of migratory waterbirds in the San Francisco Bay. *U. S. Geological Survey, Western Ecological Research Center, San Francisco Bay Estuary Field Station, 505 Azuar Drive, Vallejo, California USA 94592* (In review).

22 White, H. R. *Wintering duck response to trail use at former San Francisco Bay salt ponds* Master's Thesis thesis, San Jose State University, (2009).

23 Stillman, R. A. & Goss-Custard, J. D. Seasonal changes in response of oystercatchers *Haematopus ostralegus* to human disturbance. *Journal of Avian Biology* **33**, 358-365 (2001).

24 Beale, C. M. & Monaghan, P. Modeling the effects of limiting the number of visitors on failure rates of seabird nests. *Conservation Biology* **19**, 2015-2019, doi:10.1111/j.1523-1739.2005.00256.x (2005).

25 Bellefleur, D., Lee, P. & Ronconi, R. A. The impact of recreational boat traffic on Marbled Murrelets (Brachyramphus mamoratus). *Journal of Environmental Management* **90**, 531-538, doi:10.1016/j.jenvman.2007.12.002 (2009).
26 McGowan, C. P. & Simons, T. R. Effects of human recreation on the incubation behavior of American Oystercatchers. *Wilson Journal of Ornithology* **118**, 485-493 (2006).
27 Lafferty, K. D. Birds at a Southern California beach: seasonality, habitat use and disturbance by human activity. *Biodiversity and Conservation* **10**, 1949-1962 (2001).
28 Burger, J. The effect of human activity on birds at a coastal bay. *Biological Conservation* **21**, 231-241 (1981).
29 Evans, J. *North Basin waterbird study* (Avocet Research Associates, Point Reyes Station, CA, 2007).
30 Rodgers, J. A. & Smith, H. T. Buffer zone distances to protect foraging and loafing waterbirds from human disturbance in Florida. *Wildlife Society Bulletin* **25**, 139-145 (1997).
31 Rodgers, J. A. & Schwikert, S. T. Buffer-zone distances to protect foraging and loafing waterbirds from disturbance by personal watercraft and outboard-powered boats. *Conservation Biology* **16**, 216-224 (2002).
32 Trulio, L. A., Robinson-Nilsen, C., Sokale, J. & Lafferty, K. D. Report on nesting snowy plover response to new trail use in the South Bay Salt Pond Restoration Project. (2011).
33 Yasue, M. Environmental factors and spatial scale influence shorebirds' responses to human disturbance. *Biological Conservation* **128**, 47-54, doi:10.1016/j.biocon.2005.09.015 (2006).
34 Burger, J., Jeitner, C., Clark, K. & Niles, L. J. The effect of human activities on migrant shorebirds: successful adaptive management. *Environmental Conservation* **31**, 283-288 (2004).
35 Tarr, N. M., Simons, T. R. & Pollock, K. H. An Experimental Assessment of Vehicle Disturbance Effects on Migratory Shorebirds. *Journal of Wildlife Management* **74**, 1776-1783, doi:10.2193/2009-105 (2010).
36 Peters, K. A. & Otis, D. L. Wading bird response to recreational boat traffic: Does flushing translate into avoidance? *Wildlife Society Bulletin* **34**, 1383-1391 (2006).
37 Stolen, E. D. The effects of vehicle passage on foraging behavior of wading birds. *Waterbirds* **26**, 429-436 (2003).
38 Yasue, M. The effects of human presence, flock size and prey density on shorebird foraging rates. *Journal of Ethology* **23**, 199-204 (2005).
39 Lafferty, K. D. Disturbance to wintering western snowy plovers. *Biological Conservation* **101**, 315-325 (2001).
40 Klein, M. L., Humphrey, S. R. & Percival, H. F. Effects of ecotourism on distribution of waterbirds in a wildlife refuge. *Conservation Biology* **9**, 1454-1465 (1995).
41 Rodgers, J. A. & Schwikert, S. T. Buffer zone distances to protect foraging and loafing waterbirds from disturbance by airboats in Florida. *Waterbirds* **26**, 437-443 (2003).
42 Rodgers, J. A. & Smith, H. T. Set-back distances to protect nesting bird colonies from human disturbance in Florida. *Conservation Biology* **9**, 89-99 (1995).
43 Burger, J. & Gochfeld, M. Human activity influence and diurnal and nocturnal foraging of sanderlings (*Calidris alba*). *Condor* **93**, 259-265 (1991).
44 Batten, L. A. Sailing on reservoirs and its effects on water birds. *Biological Conservation* **11**, 49-58 (1977).
45 Beale, C. M. & Monaghan, P. Behavioural responses to human disturbance: a matter of choice? *Animal Behaviour* **68**, 1065-1069 (2004).
46 Zimmer, C., Boos, M., Petit, O. & Robin, J. P. Body mass variations in disturbed mallards *Anas platyrhynchos* fit to the mass-dependent starvation-predation risk trade-off. *Journal of Avian Biology* **41**, 637-644, doi:10.1111/j.1600-048X.2010.05110.x (2010).
47 Goss-Custard, J. D., Triplet, P., Sueur, F. & West, A. D. Critical thresholds of disturbance by people and raptors in foraging wading birds. *Biological Conservation* **127**, 88-97, doi:10.1016/j.biocon.2005.07.015 (2006).
48 Robert, H. C. & Ralph, C. J. Effects of human disturbance on the breeding success of gulls. 495-499 (1975).
49 Thomas, K., Kvitek, R. G. & Bretz, C. Effects of human activity on the foraging behavior of sanderlings *Calidris alba*. *Biological Conservation* **109**, 67-71 (2003).
50 Dias, M. P., Granadeiro, J. P., Lecoq, M., Santos, C. D. & Palmeirim, J. M. Distance to high-tide roosts constrains the use of foraging areas by dunlins: implications for the management of estuarine wetlands. *Biological Conservation* **131**, 446-452 (2006).

51 Acosta, S., Thayer, J., Merkle, W. & Bishop, S. Ecological studies of seabirds on Alcatraz Island, 2008. Final report to the Golden Gate National Recreation Area National Park Service. (PRBO Conservation Science, Petaluma, CA, 2008).
52 Evans, J. *North Basin waterbird study, Eastshore State Park Berkeley, California 2004-2007* (Avocet Research Associates, Point Reyes Station, CA, 2009).
53 Roberts, G. & Evans, P. R. Responses of foraging sanderlings to human approaches. *Behaviour* **126**, 29-43 (1993).
54 Korschgen, C. E., George, L. S. & Green, W. L. DISTURBANCE OF DIVING DUCKS BY BOATERS ON A MIGRATIONAL STAGING AREA. *Wildlife Society Bulletin* **13**, 290-296 (1985).
55 Burger, J. Effects of demolition and beach clean-up operations on birds on a coastal mudflat in New Jersey. *Estuarine, Coastal, and Shelf Science* **27**, 95-108 (1988).
56 Rogers, D. I., Piersma, T. & Hassell, C. J. Roost availability may constrain shorebird distribution: Exploring the energetic costs of roosting and disturbance around a tropical bay. *Biological Conservation* **133**, 225-235, doi:10.1016/j.biocon.2006.06.007 (2006).
57 Belanger, L. & Bedard, J. Energetic cost of man-induced disturbance to staging Snow Geese *Journal of Wildlife Management* **54**, 36-41 (1990).
58 Carney, K. M. & Sydeman, W. J. A review of human disturbance effects on nesting colonial waterbirds. *Waterbirds* **22**, 68-79 (1999).
59 Anderson, D. W. & Keith, J. O. The human influence on seabird nesting success: conservation implications. *Biological Conservation* **18**, 65-80 (1980).
60 Ruhlen, T. D., Abbott, S., Stenzel, L. E. & Page, G. W. Evidence that human disturbance reduces Snowy Plover chick survival. *Journal of Field Ornithology* **74**, 300-304 (2003).
61 Lafferty, K. D., Goodman, D. & Sandoval, C. P. Restoration of breeding by snowy plovers following protection from disturbance. *Biodiversity and Conservation* **15**, 2217-2230 (2006).
62 Stillman, R. A. & Goss-Custard, J. D. Individual-based ecology of coastal birds. *Biological Reviews* **85**, 413-434, doi:10.1111/j.1469-185X.2009.00106.x (2010).
63 Stillman, R. A., West, A. D., Caldow, R. W. G. & Durell, S. Predicting the effect of disturbance on coastal birds. *Ibis* **149**, 73-81 (2007).
64 Ellison, L. N. & Cleary, L. Effects of human disturbance on breeding of double-creasted cormorants. *Auk* **95**, 510-517 (1978).
65 Acosta, S., Jahncke, J., Pitkin, M., Merkle, W. & Rachowicz, L. Ecological studies and interpretation of seabirds on Alcatraz Island, 2009. Final report to the Golden Gate National Recreaton Area National Park Service. (PRBO Conservation Science, Petaluma, CA, 2009).
66 Acosta, S., Thayer, J., Merkle, W. & Hellwig, C. Ecological studies of seabirds on Alcatraz Island, 2007. Final report to Golden Gate National Recreation Area National Park Service. (PRBO Conservation Science, Petaluma, CA, 2007).
67 Gardner, D., Thayer, J. & Merkle, W. Population studies of seabirds on Alcatraz Island, 2004. Final report to Golden Gate National Recreation Area National Park Service. (PRBO Conservation Science, Petaluma, CA, 2004).
68 Acosta, S., Thayer, J., Merkle, W. & Hellwig, C. Alcatraz Island Special Event Seabird Disturbance Monitoroing Report 2007. Final report to the Golden Gate National Recreation Area National Park Service. (PRBO Conservation Science, Petaluma, CA, 2007).
69 Skagen, S. K., Melcher, C. P. & Muths, E. The interplay of habitat change, human disturbance and species interactions in a waterbird colony. *American Midland Naturalist* **145**, 18-28 (2001).
70 Erwin, R. M. Responses to human intruders by birds nesting in colonies: experimental results and management guidelines. *Colonial Waterbirds* **12**, 104-108 (1989).
71 Dooley, J. L., Sanders, T. A. & Doherty, P. F. Mallard Response to Experimental Walk-In and Shooting Disturbance. *Journal of Wildlife Management* **74**, 1815-1824, doi:10.2193/2009-284 (2010).
72 Knapton, R. W., Petrie, S. A. & Herring, G. Human disturbance of diving ducks on Long Point Bay, Lake Erie. *Wildlife Society Bulletin* **28**, 923-930 (2000).
73 Evans, J. *Aquatic Park Berkeley, California: Waterbird population and disturbance response study* (Avocet Research Associates, Point Reyes Station, CA, 2005).
74 Morse, J. A., Powell, A. N. & Tetreau, M. D. Productivity of Black Oystercatchers: Effects of recreational disturbance in a national park. *Condor* **108**, 623-633 (2006).
75 Robinson, C. *Western snowy plover use of managed salt ponds at Eden Landing, Hayward, CA* Master of Science thesis, San Jose State University, (2008).

76 Neuman, K. K., Henkel, L. A. & Page, G. W. Shorebird use of sandy beaches in central California. *Waterbirds* **31**, 115-121 (2008).
77 Trulio, L. A. & Sokale, J. Foraging shorebird response to trail use around San Francisco Bay. *Journal of Wildlife Management* **72**, 1775-1780 (2008).
78 Mori, Y., Sodhi, N. S., Kawanishi, S. & Yamagishi, S. The effect of human disturbance and flock composition on the flight distances of waterfowl species. *Journal of Ethology* **19**, 115-119 (2001).
79 Smit, C. J. & Visser, G. J. M. Effects of disturbance on shorebirds: a summary of existing knowledge from the Dutch Wadden Sea and Delta area. *Wader Study Group Bulletin* **68**, 6-19 (1993).