CASE STUDY

Evaluating Wildlife Response to Coastal Dune Habitat Restoration in San Francisco, California

Will Russell, Jennifer Shulzitski and Asha Setty

ABSTRACT

The vast dune system that once dominated the entire western half of the San Francisco peninsula in California has been reduced to a few fragments that conserve locally threatened plant and animal species. We measured the effects of ongoing restoration efforts on wildlife abundance and diversity on one of the largest of these fragments, Fort Funston in the Golden Gate National Recreation Area. Efforts included removal of non-native species, active restoration of native dune vegetation, and restricted visitor use. We collected data regarding the composition and abundance of vegetation, birds, and ground-dwelling vertebrates on four treatments including an actively restored area with restricted visitor use, an unrestored area where visitor use had been restricted for ten years, an unrestored area where visitor use had been restricted for two years, and an unrestored area with unrestricted visitor use. Results indicated that the diversity and abundance of wildlife species, as well as the richness and cover of native plant species, were greater in the restored area than in all other sampled areas. Restricted visitor use alone had only modest positive effects on the abundance and diversity of wildlife and the richness and cover of native plant species.

Keywords: dune scrub, habitat restoration, iceplant (*Carpobrotus edulis*), native plants, wildlife response

Fragmented natural habitats that exist in urban areas provide a last refuge for locally threatened plant and animal species otherwise absent from the surrounding urban matrix (Bolger et al. 2008, Morrison et al. 1994). These areas improve connectivity between larger contiguous habitats in nearby parks and open-space reserves. Restoration of these small patches is critical to the conservation of native plant diversity in urban landscapes (Marzluff and Ewing 2001) and may improve conditions for wildlife as well (NPS 2009). In addition, the abundance of wildlife, including both vertebrates and invertebrates, can be used as a metric for evaluating the success of dune scrub restoration projects (Longcore 2003, Block et al. 2001).

Ecological Restoration Vol. 27, No. 4, 2009
ISSN 1522-4740 E-ISSN 1543-4079

Dune scrub communities are particularly susceptible to non-native plant introduction, especially in urban settings, as they are prone to human disturbance and characterized by openings in the vegetation (Bowler 2000, Pickart and Sawyer 1998, D'Antonio 1993). Non-native species introductions have had pronounced impacts on native vegetation and associated wildlife species by altering community composition and reducing diversity of native plants (Parker and Gilbert 2007).

Historically, the San Francisco dune system was species rich and contained a wide spectrum of dune forms and successional stages (Ramaley 1918, Brandegee 1892, Bolander 1863). Since the 1870s introductions of non-native, dune-stabilizing vegetation have modified the topography, stability, and soils of San Francisco dune remnants. European beachgrass (*Ammophila arenaria*) was first planted in the 1870s to stabilize otherwise mobile dunes. Iceplant (*Carpobrotus edulis*) was planted to stabilize both mobile and relatively stable dunes (D'Antonio 1993). Trees and shrubs such as Monterey cypress (*Cupressus macrocarpa*), bluegum (*Eucalyptus globulus*), and wattle (*Acacia longifolia*) were planted to act as baffles to dune-forming winds. Coastal dune communities were further modified by recreational use through trampling and destruction of vegetation.

Natural dune vegetation plays a role in trapping windblown sand and forming barriers that protect hind-dune areas from inundation, salt spray, and sand blast (Levin et al. 2008). Restricting visitor use for the purpose of precluding human and domestic animal impacts may help stabilize dune substrates and protect and enhance coastal dune species (Pratt et al. 2001, Lafferty 2000). Some evidence has also shown that restricting visitor use through fencing of dune habitats contributes to the protection

Figure 1. Location of Fort Funston, Golden Gate National Recreation Area, San Francisco, California.

Figure 2. View of a 9 ha restricted-use restored area in Fort Funston GGNRA. Fencing was installed to discourage trampling by visitors. A diversity of plants and growth forms is apparent. Photo by Will Russell

and recovery of state and federally listed wildlife species such as the California least tern (*Sterna antillarum* ssp. *browni*) and western snowy plover (*Charadrius alexandrinus* ssp. *nivosus*) by limiting the access of domestic animals to wildlife (Lafferty 2000, Saul 1982, Craig 1971).

In this study, we analyzed the effects of active restoration of native plant communities and restriction of visitor use on the diversity and abundance of plant and animal species on a remnant of the San Francisco Dune complex at Fort Funston, Golden Gate Recreation Area. We predicted that both active habitat restoration and visitor use restriction would have positive effects on the species richness and abundance of plants, birds, and ground-dwelling vertebrates.

Site Description

The 93 ha Fort Funston reserve (Figure 1) is the largest of several significant remnants of the historic San Francisco dune complex that once covered approximately 36 km² and was the fourth largest dune system in the state. Owing to urbanization and development, more than 95 percent of the original dune system has been drastically altered.

During the 1930s, the U.S. Army built a system of coastal defense batteries near the city of San Francisco that changed the dune topography east of the bluffs and removed much of the native plant community. Following construction, the Army planted non-native species including iceplant, European beachgrass, and wattle in an attempt to stabilize open sand dunes around the batteries. By the mid-1960s, extensive areas of the dunes, including Fort Funston, were covered with invasive non-native plants, both those that were planted and others such as ripgut brome (*Bromus diandrus*) and wild barley (*Hordeum murinum*) that colonized the area independently. In 1972, Fort Funston was closed as a military base and transferred to the National Park Service to become part of the Golden Gate National Recreation Area.

Approximately three-quarters of a million visitors visit Fort Funston annually, further impacting native plant and wildlife communities. While native dune vegetation is adapted to a harsh environment characterized by abrading winds, desiccating soils, and low nutrient conditions, it is not adapted to widespread and intensive foot traffic. The feet of 750,000 visitors a year have well-documented adverse impacts on vegetation (Potito and Beatty 2005, Lajeunesse et al. 1997).

Restoration Methods

In 1991, the National Park Service implemented a dune restoration project at Fort Funston to restore native dune vegetation, reduce human-induced impacts to the coastal bluffs and dunes, and protect critical habitat for the state-threatened bank swallow (*Riparia riparia*). The project was conducted in several stages that included the removal of non-native vegetation, propagation and planting of native plant species, and fencing of selected areas to restrict visitor impacts.

The removal of non-native vegetation that was dominated by iceplant commenced in 9 ha on the inland side of the site and progressed toward the bluff edge over the next three years. Removal of non-native vegetation was accomplished primarily by hand. Iceplant debris was piled upwind to act as a temporary barrier to sand movement across the site. Patches of wattle and tea tree (*Melaleuca alternifolia*) were left as additional wind barriers and as a refuge for birds while native dune species became established. Shrub species were removed with handsaws. Resulting debris was stacked on site in one-meter tall piles to provide cover for wildlife. All plant removal occurred between August 15 and March 15 beginning in 1991 to avoid disturbing birds nesting in the dunes and the bluff face.

Historical accounts documenting San Francisco's native dune species (Ramaley 1918, Brandegee 1892) were used to reconstruct the likely historic flora of Fort Funston. Surveys of Fort Funston confirm that the remnant flora was clearly allied with other dune systems (Howell et al. 1958). All plants used in the restoration (Table 1) were propagated in an on-site nursery. Seed was collected at Fort Funston for the majority of the species. Species that were not present on site but had been present historically were gathered from other remnant native dune sites within San Francisco. The hind-dune areas, where sand was relatively stable, were planted by hand 1 m on center.

Table 1. Plant species propagated and planted in the 9 ha restricted/restored area at Fort Funston, San Francisco.

Species	Scientific Name
Beach strawberry	*Fragaria chiloensis*
Broadleaf gumplant	*Grindelia stricta* var. *platyphylla*
California croton	*Croton californicus*
California goosefoot	*Chenopodium californicum*
Coast buckwheat	*Eriogonum latifolium*
Coast dudleya	*Dudleya farinosa*
Coyote brush	*Baccharis pilularis*
Deerweed	*Lotus scoparius*
Dune bluegrass	*Poa douglasii*
Dune knotweed	*Polygonum paronychia*
Dune sagewort	*Artemisia pycnocephala*
Dune tansy	*Tanacetum camphoratum*
False heather	*Ericameria ericoides*
Franciscan paintbrush	*Castilleja subinclusa* ssp. *franciscana*
Franciscan wallflower	*Erysimum franciscanum*
Goldenrod	*Solidago simplex* var. *spathulata*
Indian paintbrush	*Castilleja affinis*
Lizardtail	*Eriophyllum staechadifolium*
Maritime brome	*Bromus carinatus* var. *maritimus*
Nuttall's smooth milkvetch	*Astragalus nuttallii* var. *virgatus*
Pacific dunegrass	*Leymus mollis* ssp. *mollis*
Pacific wildrye	*L. pacificus*
Pink sand verbena	*Abronia umbellata* ssp. *umbellata*
Red fescue	*Festuca rubra*
California Sea pink	*Armeria maritima* var. *californica*
Silver beach bur	*Ambrosia chamissonis*
Silver beach lupine	*Lupinus chamissonis*
Small flowered melica	*Melica imperfecta*
Southern lotus	*Lotus heermannii* var. *orbicularis*
Sticky monkey-flower	*Diplacus aurantiacus* ssp. *aurantiacus*
Wight's paintbrush	*Castilleja affinis* ssp. *affinis*
Willow dock	*Rumex salicifolius*
Yarrow	*Achillea millefolium*
Yellow sand verbena	*Abronia latifolia*

The more dynamic fore-dune areas were cluster-planted 1.2 m on center. To sustain natural sand dune processes across the site, the areas that were dominated by open, moving sand were not planted but allowed to revegetate through natural colonization from adjacent planted areas. The restored areas were maintained with volunteers working approximately 10–15 hours/week on an ongoing basis. Maintenance activities included the removal of non-native species through hand weeding but did not include additional plantings (Cox and Allen 2008).

Use of the 9 ha restored area by visitors and their dogs was discouraged with a fence composed of wooden posts and cable (Figure 2). Signs were affixed to the fence to inform visitors that the site was closed to foot traffic. Though a small number of visitors and their pets continued to use the restricted areas, the measures were successful for the most part. Two adjacent areas were fenced as well: a 4 ha area closed to foot traffic in 1991 (Figure 3) and a 5 ha area closed to foot traffic in 1999. The purpose of these additional exclosures was to improve public safety around the cliff edge and eventually restore additional native dune vegetation. At the time of this study, no restoration had yet taken place within these 4 ha and 5 ha areas. The additional 68 ha of the

Figure 3. View of a 4 ha restricted use area in Fort Funston GGNRA. Fencing was installed to discourage trampling by visitors ten years prior. Iceplant (*Carpobrotus edulis*) is clearly dominant. Photo by Will Russell

park remained accessible to visitors and their pets.

Research Methods

We conducted surveys for birds, terrestrial vertebrates, and vegetation in each of the following treatments: 1) restricted/restored—9 ha restricted habitat protection exclosure with restored native dune vegetation; 2) ten-year restricted/unrestored—4 ha restricted habitat protection closure with non-native dune vegetation; 3) two-year restricted/unrestored—5 ha restricted habitat protection closure with non-native dune vegetation; and 4) unrestricted/unrestored—7 ha parcel without habitat protection closure and with non-native dune vegetation (Figure 4). An unrestricted/restored area was not included as a treatment, as no such plantings were conducted within the area of the park impacted by visitors and their pets.

Wildlife Sampling

We used a variety of survey techniques to detect birds, amphibians, reptiles, and mammals during the rainy season (November through April) and the dry season (May through October) of 2002–2003. The frequency of sampling varied depending on the techniques used.

Birds were sampled using a combination of the variable circular plot (VCP) method (Reynolds et al. 1980) and area searches. Variable circular plot locations were selected along a random line transect running through all four habitat areas. Plots were placed a minimum of 250 m apart and a minimum of 50 m from all habitat edges (Ralph et al. 1993), with two survey plots located in each treatment area. All birds detected by sight or sound, using the methods described above, were recorded during a five-minute period between sunrise and 10 A.M. Four point-count surveys were conducted at six variable plot locations in May, June, and July 2002 and May 2003. For area searches, the four habitat areas were divided into 2.5 ha sections to maximize the number of areas searched in each habitat, thereby increasing the power of the analysis (Ralph et al. 1993). All areas were located at least 25 m from all habitat edges. Each 2.5 ha area was searched for a ten-minute period between sunrise and 10 A.M. by a single researcher. Beginning in January 2003, area searches were conducted during the nonbreeding season for four days with a minimum of 20 days between visits. Data were collected in a manner consistent with regional protocols (Sauer et al. 2001).

We collected data on mammals, reptiles, and amphibians using pitfall arrays. Two pitfall trap arrays were randomly located in each of the four habitat areas. The arrays comprised seven pitfall traps (19 L plastic buckets) and three drift-fence arms extending 15 m from the center point (Bury and Raphael 1983, Corn and Bury 1990, Davis 1982). Traps were checked each morning during two 10-day trapping periods, one in May and one in October. In order to estimate relative abundance, all captured animals were marked by clipping in a unique combination of locations.

Poisson regression analysis was used to measure differences in wildlife species abundance and diversity in the four habitat types. Wildlife data, including species richness and numbers of individuals, were analyzed in two groups: birds and ground-dwelling vertebrates (amphibians, reptiles, and mammals). Since the vertebrate data consisted of relatively low counts with frequent counts of zero, the data were analyzed using a model that assumes an overdispersed Poisson distribution instead of a normal distribution (McCullagh and Nelder 1989). Treatment effects and differences between pairs of treatments were assessed using likelihood ratio chi-square tests.

Vegetation Sampling

Between April and June 2002, we sampled 30 vegetation plots (2 m × 3 m) located randomly within each of the four study areas. In each plot, we recorded the occurrence and total percent cover of all plant species and determined the species richness and total cover of all non-native and native plant species. Differences in vegetation variables between treatments were compared using one-way ANOVA with Bonferroni post-hoc analysis to test for differences between groups. In all cases, a *p*-value of less than 0.05 was considered significant.

Results

Significant differences were found in the number of bird species detected between treatments. A notably higher number of species was recorded in the restricted/restored area than the unrestricted/unrestored area (Figure 5). In contrast, the number of bird species detected in the ten-year and two-year restricted/unrestored areas were statistically equivalent to each other and to all other treatments. Two non-native species, rock dove (*Columba livia*) and barn swallow (*Hirundo rustica*), were detected only in the unrestricted/unrestored area, while the native species mourning dove (*Zenaida macroura*), Bewick's wren (*Thryomanes bewickii*), Cooper's hawk (*Accipiter cooperii*), and bushtit (*Psaltriparus minimus*) were detected only in the restricted/restored area (Table 2). The non-native brown-headed cowbird (*Molothrus ater*) and native American goldfinch (*Carduelis tristis*) were detected in the restricted/restored area but not in the unrestricted/unrestored area. Three other native species, house finch (*Carpodacus mexicanus*), white-crowned sparrow (*Zonotrichia leucophrys*), and American robin (*Turdus migratorius*) were ubiquitous in all habitat areas. No bank swallows were recorded.

Nine species of ground-dwelling vertebrates were detected in the treatment areas: two amphibians, two reptiles, and five mammals (Table 3). All ground-dwelling vertebrate species captured were native to the region with the exception of the northern alligator lizard (*Elgaria coerulea*), whose native range extends only to the most northern counties of California. The abundance of captured individuals was significantly different among the four treatments (Figure 6). The greatest number of individuals was detected in the restricted/restored treatment, with significantly fewer animals captured

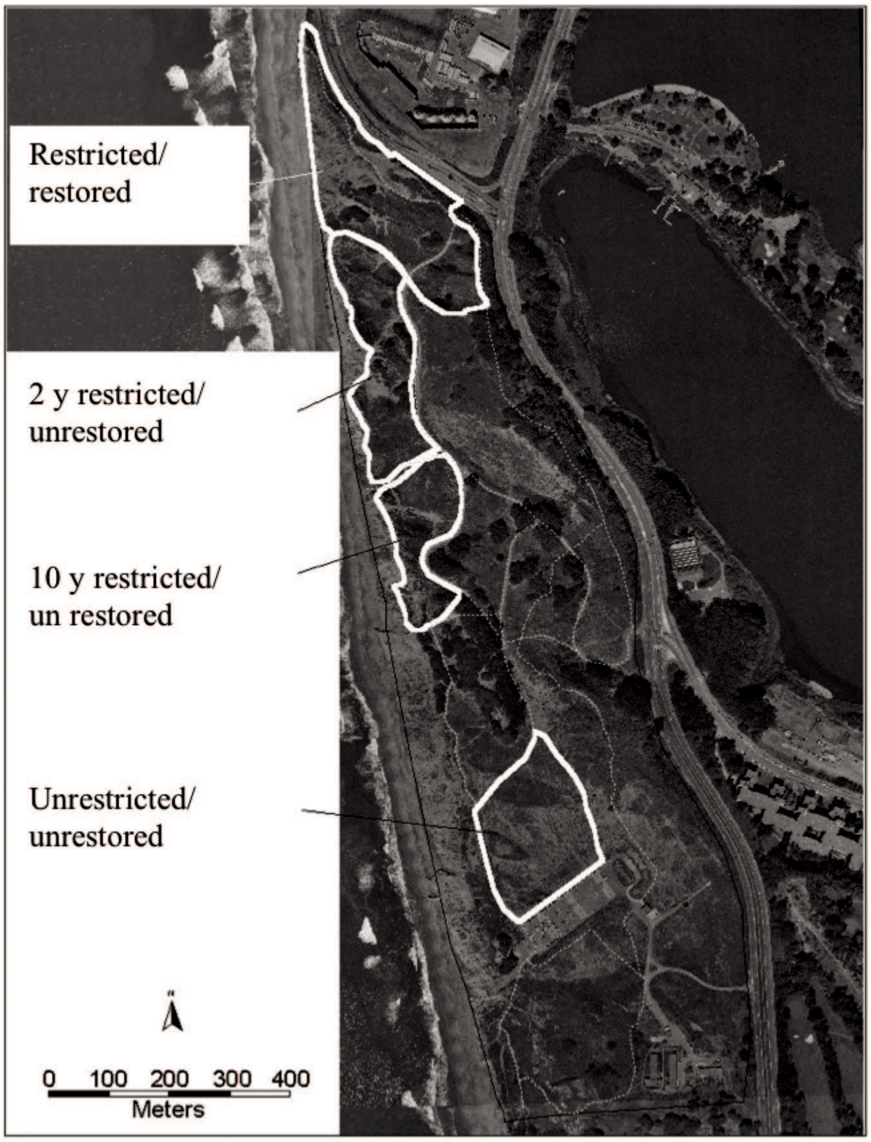

Figure 4. Location of four treatment areas within Fort Funston, Golden Gate National Recreation Area, San Francisco, California.

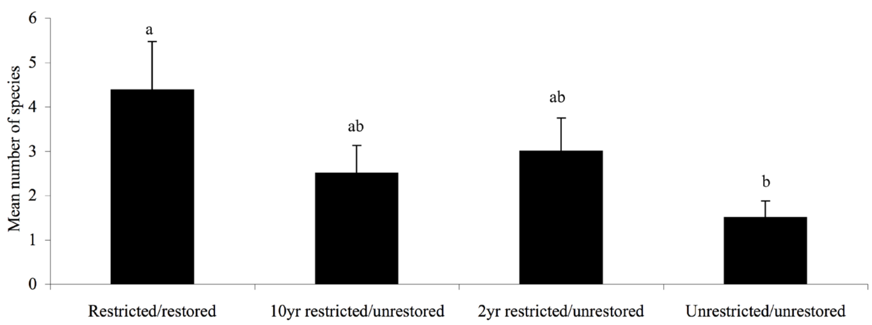

Figure 5. The mean (± SE) number of bird species detected in four habitat areas at Fort Funston, Golden Gate National Recreation Area, California, using variable circular plots and area searches. Poisson regression analysis indicated significant differences between groups, with the greatest difference found between the restricted/restored and unrestricted/unrestored treatments ($p = 0.0028$). Treatments sharing the same lowercase letter were not significantly different.

Table 2. Bird species detected (+) in four habitat areas using variable circular plots and area searches: RR = restricted/restored; 10-y = ten-year restricted/unrestored; 2-y = two-year restricted/unrestored; UU = unrestricted/unrestored.

Species	Scientific Name	RR	10-y	2-y	UU
American goldfinch	*Carduelis tristis*	+	+	-	-
American robin	*Turdus migratorius*	+	+	+	+
Anna's hummingbird	*Calypte anna*	+	-	+	+
Barn swallow	*Hirundo rustica*	-	-	-	+
Bewick's wren	*Thryomanes bewickii*	+	-	-	-
Black phoebe	*Sayornis nigricans*	+	-	+	-
Brewer's blackbird	*Euphagus cyanocephalus*	+	-	+	+
Brown-headed cowbird	*Molothrus ater*	+	+	+	-
Bushtit	*Psaltriparus minimus*	+	-	-	-
Common raven	*Corvus corax*	-	-	+	-
Cooper's hawk	*Accipiter cooperii*	+	-	-	-
European starling	*Sturnus vulgaris*	-	+	-	-
House finch	*Carpodacus mexicanus*	+	+	+	+
Mourning dove	*Zenaida macroura*	+	-	-	-
Rock dove	*Columba livia*	-	-	-	+
Song sparrow	*Melospiza melodia melodia*	+	-	+	-
White-crowned sparrow	*Zonotrichia leucophrys*	+	+	+	+

Table 3. Ground-dwelling vertebrates (mammals, reptiles, and amphibians) recorded (+) in four habitat areas using pitfall arrays: RR = restricted/restored; 10-y = ten-year restricted/unrestored; 2-y = two-year restricted/unrestored; UU = unrestricted/unrestored.

Common Name	Scientific Name	RR	10-y	2-y	UU
Botta's pocket gopher	*Thomomys bottae*	+	+	+	+
California newt	*Taricha torosa*	+	-	-	-
California slender salamander	*Batrachoseps attenuatus*	+	+	-	-
California vole	*Microtus californicus*	+	+	+	+
Deer mouse	*Peromyscus maniculatus*	+	+	-	+
Northern alligator lizard	*Elgaria coerulea*	+	+	-	-
Southern alligator lizard	*E. multicarinata*	+	+	-	+
Trowbridge shrew	*Sorex trowbridgii*	+	-	-	-
Vagrant shrew	*S. vagrans*	+	+	+	+

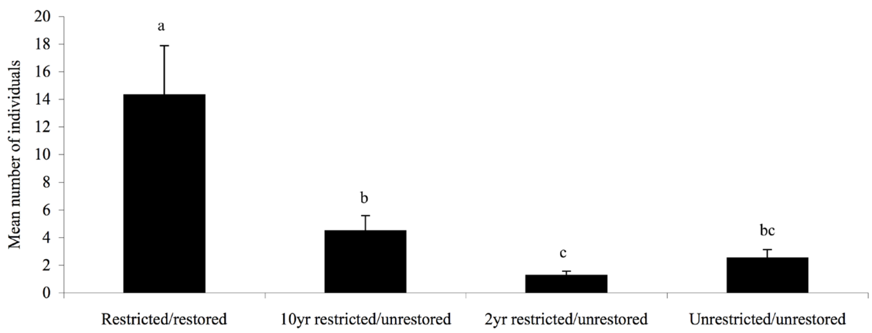

Figure 6. The mean (± SE) abundance of ground-dwelling vertebrates (mammals, reptiles, and amphibians) detected in four habitat areas at Fort Funston, Golden Gate National Recreation Area, California, using pitfall arrays. Poisson regression analysis indicated significant differences between groups ($p < 0.05$). Treatments sharing the same lowercase letter were not significantly different.

in the ten-year restricted/unrestored treatment. The two-year restricted/unrestored and unrestricted/unrestored treatments both had fewer captures than the restricted/restored and the ten-year restricted/restored treatments but were statistically equivalent to each other. The greater abundance of ground-dwelling vertebrates captured within the ten-year restricted/unrestored treatment compared to the two other unrestored treatments suggests a positive correlation between restricted visitor use and wildlife abundance, though this relationship was modest compared to the correlation between active restoration and wildlife abundance.

The richness of ground-dwelling vertebrate species captured was also significantly different in the four treatment areas (Figure 7). The highest number of species was captured in the restricted/restored and ten-year restricted/unrestored treatments. Species captures in the two-year restricted/unrestored and unrestricted/unrestored treatments were significantly lower than in the restricted/restored treatment but statistically equivalent to each other. Notably, a significantly higher number of species was captured in the ten-year restricted/unrestored treatment compared to two-year restricted/unrestored, but not compared to the unrestricted/unrestored area. These results suggest that visitor restriction over an extended period of time had a positive effect on the richness of ground-dwelling vertebrates. Over a shorter time, however, ground-dwelling vertebrates fared better in unrestricted areas than restricted areas.

Analysis of vegetation indicated significant differences in the average native species richness per sample plot among the four treatments (Figure 8, Table 4). The average native plant richness was significantly higher in the restricted/restored area than in the three other sites. The lowest average richness of non-native species was also found in the restricted/restored area compared to statistically equivalent average richness in the three other treatments (Table 5). Comparison between native and non-native species within treatments indicated significantly higher native richness in the restricted/restored treatment and statistically equivalent values in all other treatments.

Significant differences between treatments were also found in the total percent cover of native plants (Figure 9). The greatest total percent native plant cover was found in the restricted/restored treatment. Native plant cover in the ten-year restricted/unrestored treatment was significantly lower than in the restricted/restored treatment, yet was somewhat higher than in both the two-year restricted/unrestored and the unrestricted/unrestored areas. The cover of non-native species, however, was substantially lower in the restricted/restored than in all other treatments. Comparison between native and non-native cover within treatments indicated greater native than non-native plant cover within the restricted/restored treatment. The reverse was found for all other treatments: significantly greater non-native than native plant cover.

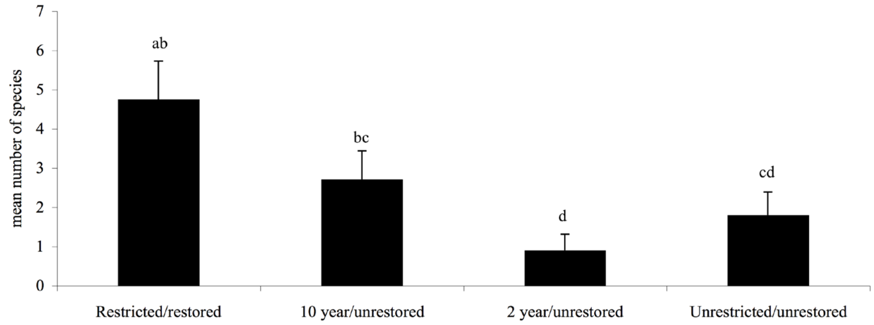

Figure 7. The mean (± SE) number of ground-dwelling vertebrate species (mammals, reptiles, and amphibians) detected in four habitat areas at Fort Funston, Golden Gate National Recreation Area, California, using pitfall arrays. Poisson regression analysis indicated significant differences between groups ($p < 0.05$). Treatments sharing the same lowercase letter were not significantly different.

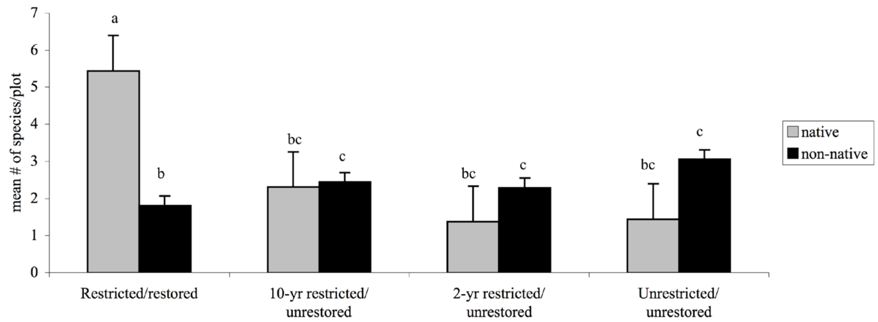

Figure 8. The mean (± SE) number of native and non-native plant species detected in four habitat areas at Fort Funston, Golden Gate National Recreation Area, California. One-way ANOVA with post-hoc Bonferroni analysis (adjusted $\alpha = 0.02$) indicated significant differences between groups ($F = 28.62$, df = 3,29, $p < 0.001$). Treatments sharing the same lowercase letter were not significantly different.

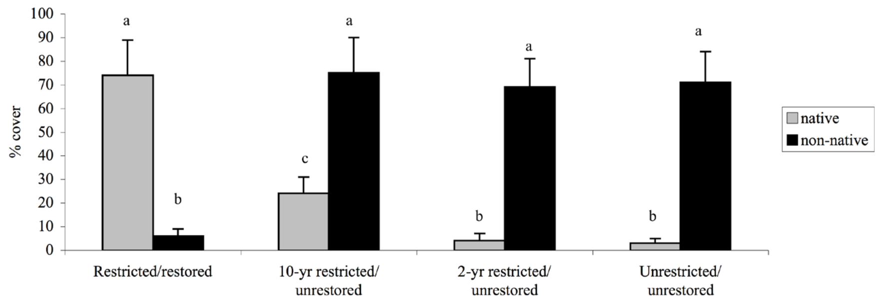

Figure 9. The mean (± SE) percent cover of native and non-native plant species estimated in four habitat areas at Fort Funston, Golden Gate National Recreation Area, California. One-way ANOVA with post-hoc Bonferroni analysis (adjusted $\alpha = 0.02$) indicated significant differences between groups ($F = 8.47$, df = 3,29, $p < 0.001$). Treatments sharing the same lowercase letter were not significantly different.

Discussion and Management Implications

The results of this study indicate that native plant restoration had a positive effect on the richness and abundance of plants, birds, and ground-dwelling vertebrate species in remnant dune habitats of the historic San Francisco dune sheet. The value of restricting visitor use for the purpose of improving plant and wildlife richness and abundance was positive but less pronounced, particularly for shorter time periods.

It has been well documented that fragments of native habitat conserve biodiversity, although it may be difficult to sustain viable populations in locations adjacent to urban areas (Schwartz and van Mantgem 1997), as these fragments are highly impacted by human disturbance, predators, and parasites (Robinson et al. 1995). However, these then serve as ecological sinks for native species (Pulliam 1988). In this study of one of these fragments (Fort Funston, Golden Gate National Recreation Area), we found that the variation in wildlife diversity and abundance between four treatments reflected differences in the richness and cover of native vegetation. The diversity of vegetation and the total percent cover of native plant species were greater in the restored area than in the unrestored areas. This was expected, as active restoration involved the introduction of a wide variety of native species. Surprisingly, though,

Table 4. Native plant species recorded in four habitat areas at Fort Funston, Golden Gate National Recreation Area: RR = restricted/restored; 10-y = ten-year restricted/unrestored; 2-y = two-year restricted/unrestored; UU = unrestricted/unrestored. Please note that the prostrate subspecies of *Baccharis pilularis* known as *B. pilularis* ssp. *pilularis* was recognized at the time that this data was collected and has therefore been included in this list.

Species	Scientific Name	RR	10-y	2-y	UU
Beach strawberry	*Fragaria chiloensis*	x	x	x	x
Bee plant	*Scrophularia californica* ssp. *californica*	x			
Blue blossom	*Ceanothus thyrsiflorus*	x			
Bracken fern	*Pteridium aquilinum* var. *pubescens*	x			
California acaena	*Acaena pinnatifida* var. *californica*	x			
California poppy	*Eschscholzia californica*	x			
Coast buckwheat	*Eriogonum latifolium*	x		x	x
Coast dandelion	*Agoseris apargioides*		x		x
Coast dudleya	*Dudleya farinosa*	x			
Coyote bush	*Baccharis pilularis*	x	x		x
Deerweed	*Lotus scoparius*	x			x
Dune bluegrass	*Poa douglasii*	x	x		
Dune knotweed	*Polygonum paronychia*				x
Dune sagewort	*Artemisia pycnocephala*	x	x		x
Dune tansy	*Tanacetum camphoratum*	x	x		
False heather	*Ericameria ericoides*	x			
Junegrass	*Koeleria macrantha*	x			
Lizardtail	*Eriophyllum staechadifolium*	x			
Maritime brome	*Bromus carinatus* var. *maritimus*	x	x	x	
Pacific dunegrass	*Leymus mollis* ssp. *mollis*	x			
Pacific wildrye	*L. pacificus*	x	x	x	
Pearly everlasting	*Anaphalis margaritacea*	x			
Prostrate coyote bush	*Baccharis pilularis* ssp. *pilularis**	x		x	x
Red fescue	*Festuca rubra*	x			
San Francisco spineflower	*Chorizanthe cuspidata* var. *cuspidata*	x			
Sandmat	*Cardionema ramosissimum*	x			
Seaside daisy	*Erigeron glaucus*	x		x	
Silver beach bur	*Ambrosia chamissonis*	x			
Silver beach lupine	*Lupinus chamissonis*	x			x
Sticky monkey-flower	*Mimulus aurantiacus*	x			
Suncup	*Camissonia cheiranthifolia*	x		x	x
Wavyleaf soap plant	*Chlorogalum pomeridianum* var. *divaricatum*	x			
Wight's paintbrush	*Castilleja wightii*	x			
Wild carrot	*Daucus pusillus*	x	x	x	x
Wild cucumber	*Marah fabaceus*	x			
Yellow bush lupine	*Lupinus arboreus*	x	x		
Yellow sand verbena	*Abronia latifolia*	x	x	x	

a difference in native plant cover was also found between treatments where visitor use had been restricted for different lengths of time (ten years, and two years). Significantly greater native plant cover was found on the site where visitor use had been restricted for ten years, indicating that use restriction may have facilitated an increase in native plant cover. However, no significant increase in native species richness accompanied the increase in native plant cover, suggesting that increased cover was based on expanding internal populations rather than recruitment from outside the treatment area. In addition, the cover of non-native plant species did not appear to vary as a result of visitor restriction. Though non-native plant cover was lowest in the actively restored area, no differences were detected among the unrestored areas. Therefore, the elevated cover of native species within the older restricted site does not appear to reflect a trend toward native vegetation eventually outcompeting non-native vegetation.

What was most interesting, however, was the apparent response of both birds and ground-dwelling vertebrates to the active restoration of plant species. The richness of birds and ground-dwelling vertebrates and the abundance of ground-dwelling vertebrates were both significantly greater on the restored site than on the three unrestored sites. This suggests that the restored area provided habitat value, including greater diversity of cover types (including open ground) and food sources, to highly mobile species such as Bewick's wren and Cooper's hawk, as well as less mobile species such as the northern alligator lizard and the California newt (*Taricha torosa*). Greater richness and abundance of ground-dwelling vertebrates were found on the unrestored site that had been restricted for ten years prior to this study than on the unrestored site that had been restricted for only two years. These differences were modest, however, and do not provide a persuasive argument for restricting visitor use alone without active restoration of native species.

When determining whether to employ active planting or restricted use techniques, the goals of each project must be considered. The value of active planting is that it not only reintroduces native plant species, but also provides a greater diversity of cover, growth forms, and food sources for species such as the bank swallow (Moffat et al. 2005), which was a stated goal of the Fort Funston Restoration Project. Restricting visitor use alone was less successful at Fort Funston because unrestored areas, including the restricted areas, were so highly dominated by one species, iceplant,

Table 5. Non-native plant species recorded in four habitat areas at Fort Funston, Golden Gate National Recreation Area: RR = restricted/restored; 10-y = ten-year restricted/unrestored; 2-y = two-year restricted/unrestored; UU = unrestricted/unrestored.

Species	Scientific Name	RR	10-y	2-y	UU
Chickweed	*Stellaria media*		x		x
Cottonweed	*Vulpia* sp.	x	x	x	x
European beachgrass	*Ammophila arenaria*	x		x	
European searocket	*Cakile maritima*	x	x	x	
Ice plant	*Carpobrotus edulis*	x	x	x	x
Knotweed	*Polygonum arenastrum*		x	x	
Mallow	*Malva* sp.				x
Milk thistle	*Silybum marianum*			x	x
Monterey cypress	*Cupressus macrocarpa*		x	x	
New Zealand spinach	*Tetragonia tetragonioides*			x	x
Ripgut brome	*Bromus diandrus*	x	x	x	x
Tea tree	*Leptospermum laevigatum*	x	x	x	
Wattle	*Acacia longifolia*	x		x	
Wild barley	*Hordeum murinum*	x	x	x	

that they were virtually homogenous in terms of cover and growth form and provided very little diversity of food sources for wildlife. In addition, the presence of iceplant has been shown to impede germination of native species for some time, even after it has been removed (Conser and Conner 2009), suggesting that ongoing restoration is necessary. Non-native trees such as wattle have also been shown to have long-term effects on soil conditions (Marchante et al. 2008) and need to be managed. For these reasons, we recommend active native plant restoration, including removal of species such as iceplant and wattle, as an essential part of the restoration of coastal dune habitat. Visitor restriction techniques alone, though attractive in terms of cost, yield limited results.

Though the results of this study are compelling, they are limited by the post-hoc nature of the treatments and by the fact that each treatment was represented by a single sample. Additional study of the questions addressed in this paper in the same habitat type using an experimental approach with multiple replicates of each treatment would improve the power of the analysis. The inclusion of a treatment area that had received active restoration without restricted visitor use would also add depth to the study. In addition, this study did not include an analysis of other active restoration techniques, such as topsoil replacement and selective weeding programs, that have been successful for coastal dune habitat on other sites (Buisson et al. 2006). That being said, the value of active restoration of native plant communities on the preservation and development of wildlife populations is illustrated convincingly by our results. In order to test these results further, we suggest that native dune scrub vegetation be restored over ever increasing areas. If this is done, the benefit to wildlife will become undeniable.

Acknowledgments

This research was supported by Golden Gate National Recreation Area and the USGS/BRD Western Ecological Research Station. Sayaka Eda, George Durgerian, Ingrid Cabada, and Bob Holloway provided invaluable support and expertise.

References

Block, W.M., A.B. Franklin, J.P. Ward Jr., J.L. Ganey and G.C. White. 2001. Design and implementation of monitoring studies to evaluate the success of ecological restoration on wildlife. *Restoration Ecology* 9:293–303.

Bolander, H.N. 1863. Enumeration of shrubs and trees growing in the vicinity of the mouth of San Francisco Bay. *California Academy of Sciences Proceedings* 2:78–84.

Bolger, D.T., K.H. Beard, A.V. Suarez and T.J. Case. 2008. Increased abundance of native and non-native spiders with habitat fragmentation. *Diversity and Distributions* 14:655–665.

Bowler, P.A. 2000. Ecological restoration of coastal sage scrub and its potential role in habitat conservation plants. *Environmental Management* 26 (Supplement):S85–S96.

Brandegee, K. 1892. Catalogue of the flowering plants and ferns growing spontaneously in the city of San Francisco. *Zoe* 2:334–383.

Buisson, E., K.D. Holl, S. Anderson, E. Corcket, G.F. Hayes and F. Torre. 2006. Effect of seed source, topsoil removal, and plant neighbor removal on restoring California coastal prairies. *Restoration Ecology* 14:569–577.

Bury, R.B. and M.G. Raphael. 1983. Inventory methods for amphibians and reptiles. Pages 416–419 *in* J.F. Bell and T. Attebury (eds), *Renewable Resource Inventories for Monitoring Changes and Trends, Proceedings of an International Conference, August 15–19, 1983*. Corvallis: Oregon State University.

Conser, C. and E.F. Connor. 2009. Assessing the residual effects of *Carpobrotus edulis* invasion, implications for restoration. *Biological Invasions* 11:349–358.

Corn, P.S. and R.B. Bury. 1990. Sampling methods for terrestrial amphibians and reptiles. USDA Forest Service General Technical Report PNW-GTR-256.

Cox, R.D., and E.B. Allen. 2008. Stability of exotic annual grasses following restoration efforts in southern California coastal sage scrub. *Journal of Applied Ecology* 45:495–504.

Craig, A. 1971. Survey of California least tern nesting sites. Final Report for Project W-54-R-4. Sacramento: California Department of Fish and Game.

D'Antonio, C. 1993. Mechanisms controlling invasion of coastal plant-communities by the alien succulent *Carpobrotus-edulis*. *Ecology* 53:237–245.

Davis, D. 1982. *Handbook of Census Methods for Terrestrial Vertebrates*. Boca Raton: CRC Press.

Howell, J.T., P.H. Raven and P. Rubtzoff. 1958. A flora of San Francisco, California. *Wasmann Journal of Biology* 16: 1–157.

Lafferty, K.D. 2000. Status, trends, and conservation of the western snowy plover with a focus on the Devereux Slough population at Coal Oil Point Reserve,

Santa Barbara County, California. Museum of Systematics and Ecology Environmental Report No. 15.
Lajeunesse, D., G. Domon, A. Cogliastro and A. Bouchard. 1997. Monitoring recreational use in urban natural areas. *Natural Areas Journal* 17:366–379.
Levin, N., G.J. Kidron and E. Ben-Dor. 2008. A field quantification of coastal dune perennial plants as indicators of surface stability, erosion or deposition. *Sedimentology* 55: 751–772.
Longcore, T. 2003. Terrestrial arthropods as indicators of ecological restoration success in coastal sage scrub (California, USA). *Restoration Ecology* 11:397–409.
Marchante, E., A. Kjoller, S. Struwe and H. Freitas. 2008. Short-and long-term impacts of *Acacia longifolia* invasion on the belowground processes of a Mediterranean coastal dune ecosystem. *Applied Soil Ecology* 40:210–217.
Marzluff, J.M. and K. Ewing. 2001. Restoration of fragmented landscapes for the conservation of birds: A general framework and specific recommendations for urbanizing landscapes. *Restoration Ecology* 9:280–292.
McCullagh, P. and J.A. Nelder. 1989. *Generalized Linear Models*, 2nd ed. London: Chapman & Hall.
Moffatt, K.C., E.E. Crone, K.D. Holl, R.W. Schlorff and B.A. Garrison. 2005. Importance of hydrologic and landscape heterogeneity for restoring bank swallow (*Riparia riparia*) colonies along the Sacramento River, California. *Restoration Ecology* 13:391–402.
Morrison, M.L., T.A. Scott and T. Tennant. 1994. Wildlife-habitat restoration in an urban park in southern California. *Restoration Ecology* 2:17–30.
National Park Service (NPS). 2009. Abbotts Lagoon area dune restoration plan environmental assessment. Point Reyes: USDI National Park Service. www.nps.gov/pore/parkmgmt/upload/planning_dunerestoration_ea_090209.pdf
Parker, I.M. and G.S. Gilbert. 2007. When there is no escape: The effects of natural enemies on native, invasive, and noninvasive plants. *Ecology* 88:1210–1284.
Pickart, A.J. and J.O. Sawyer. 1998. *Ecology and Restoration of Northern California Coastal Dunes*. Sacramento: California Native Plant Society.
Potito A.P. and S.W. Beatty. 2005. Impacts of recreation trails on exotic and ruderal species distribution in grassland areas along the Colorado Front Range. *Environmental Management* 36:230–236.
Pratt, R., K. Miller, D. Elam and I. Pisani. 2001. Western snowy plover (*Charadrius alexandrinus nivosus*) Pacific coast population draft recovery plan. Portland OR: U.S. Fish & Wildlife Service. ecos.fws.gov/docs/recovery_plans/2001/010501.pdf
Pulliam, H.R. 1988. Sources, sinks, and population regulation. *American Naturalist* 132:652–661.
Ralph, C.J., G.R. Geupel, P. Pyle, T.E. Martin and D.F. DeSante. 1993. Handbook of field methods for monitoring landbirds. USDA Forest Service General Technical Report. PSW-GTR-144.
Ramaley, F. 1918. Notes on dune vegetation at San Francisco. *Plant World* 21: 191–201.
Reynolds, R.T., J.M. Scott and R.A. Nussbaum 1980. A variable circular-plot method for estimating bird numbers. *Condor* 82:309–313.
Robinson, S.K., F.R. Thompson, T.M. Donovan, D.R. Whitehead, and J. Faaborg. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science 267:1987–1990.
Sauer, J.R., J.E. Hines and J. Fallon. 2001. The North American breeding bird survey, results and analysis 1966–2000, vers. 2001.2. Laurel MD: USGS Patuxent Wildlife Research Center. www.mbr-pwrc.usgs.gov/bbs/bbs00.html
Saul, S.M. 1982. Clam diggers and snowy plovers. *Washington Wildlife* 32:28–30.
Schwartz, M.W., ed. 1997. *Conservation in Highly Fragmented Landscapes*. New York: Chapman & Hall.

Will Russell, Department of Environmental Studies, 1 Washington Square, San Jose State University, San Jose, CA 95192-0115, russell_sjsu@yahoo.com

Jennifer Shulzitski, Golden Gate Field Station, USGS Western Ecological Research Center, Fort Cronkhite, Bldg 1063, Sausalito, CA 94965

Asha Setty, Golden Gate National Park Conservancy, Bldg 201, Fort Mason, San Francisco, CA 94123