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Historical Changes in the Physical and Vegetational Characteristics of Protection Island, Washington

Abstract

Protection Island National Wildlife Refuge, WA, is home to the majority of breeding seabirds and harbor seals found in the Puget Sound/San Juan Island area. The island consists of a high central plateau flanked by bluffs on the north and south and by low points on the southwest and east. We analyzed the physical and vegetational changes in Protection Island from the 1860s to 1999, an interval spanning an early period of agricultural use followed by intensive subdivision into building lots and then conversion to a refuge. During that time span Kanem Point on the southwest had shortened and Violet Point on the east had lengthened. The tall northwest bluffs, which experienced rapid erosion early last century, had steepened and stabilized. Little change had occurred on the northeast and southern bluffs or on the bluffs over the points where many seabirds nest. On the upper plateau, forested areas had shrunk sharply due to fires and lot development but were recovering. Dunes had migrated to the northeast and stabilized. Introduced species dominated the grasslands on the upper plateau. By contrast, native species continued to dominate Violet Point. Native dune grass, however, was expanding on Violet Point and tended to exclude most other species. Richness, percent cover, and diversity of introduced species on Violet Point were significantly lower than on the upper plateau, while richness and percent cover of native species were higher. Continued prevalence of native species on the point may be a result of a plant community adapted to the low, rocky substrate and frequent disturbance by nesting gulls.

Introduction

Protection Island National Wildlife Refuge, Washington State, contains one of the largest marine bird and mammal breeding sites in the Pacific Northwest. The island plays a crucial role in a coastal ecosystem experiencing intensifying human population pressures in one of the fastest growing regions of the United States. Despite its biological significance, little study has been given to Protection Island's topography or vegetation. Exceptions include a brief unpublished overview of the island's Pleistocene geological features (Carson 1983), unpublished results of an August 1983 vegetation survey (Washington Natural Heritage Program 1983), and memoirs by former residents.

Protection Island (Figure 1) is a 1.4 km² (136 ha) crescent-shaped landmass in the southeast corner of the Strait of Juan de Fuca. The island contains an undulating upland plateau surrounded by steep bluffs and is flanked on the east and west by two gravelly points. The upland plateau has

an area of 1.2 km² (115 ha) and varies in elevation from 35-62 m. About 75% of the plateau is covered by grassland and 25% by forest. Strong ocean currents run along the island's north edge and high tides sometimes rise to the base of the bluff, triggering slumping. Longshore currents carry the loose sediments to Violet Point (19 ha) on the east end and to Kanem Point (1.9 ha) on the southwest end. Except for a brackish marsh which was located at the west end of Violet Point before development (Figure 1A), the island has no stable freshwater supply, and Native Americans apparently never permanently inhabited the island (Power 1976).

We use data from historical records, aerial photos, GIS analysis, and vegetation transects to identify changes in Protection Island's topography over the past century and a half. We also discuss how human disturbance and natural processes have altered vegetation assemblages on the island.

Island History

When initially explored in the 1790s by Manuel Quimper and George Vancouver, the upper plateau was described as an extensive meadow with "a coppice of pine [sic] trees and shrubs" (Lamb

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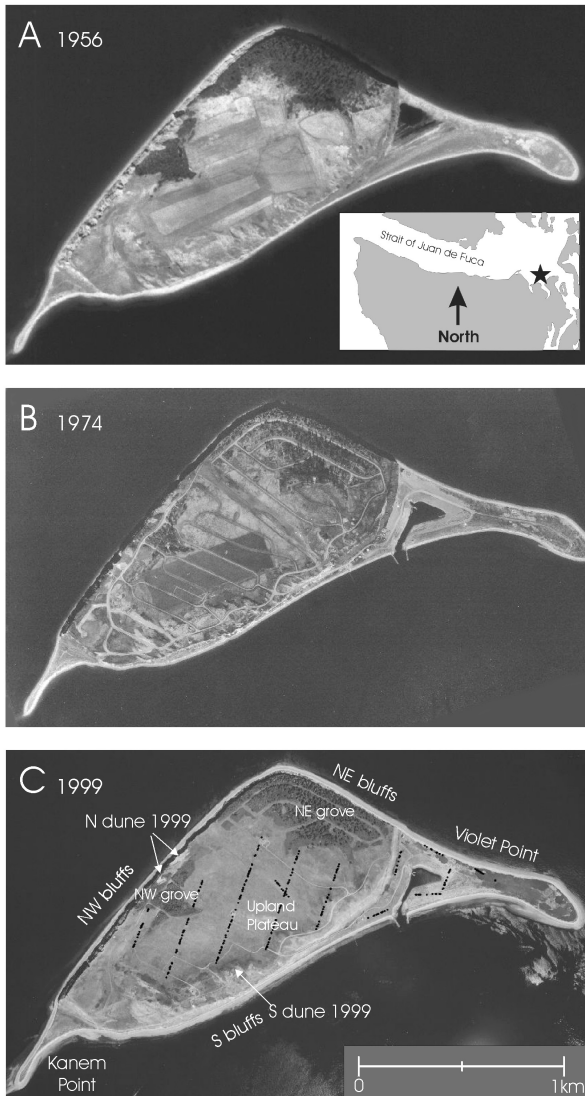


Figure 1. Aerial views of Protection Island in 1956 (A) with light farming, in 1974 (B) after development, and in 1999 (C) as a wildlife refuge. The 1999 locations of important island features are labeled on C and the positions of our vegetation quadrats are plotted in black. Inset in 1A shows the location and scale and 1C shows distances.

1984, Clark 1995). Europeans settled the island in 1857, and by 1867 a dock had been constructed near the end of Kanem Point, a road had been built up the bluff, and farm buildings and a well existed on the upper plateau. The island was farmed intermittently for the next several generations, raising livestock, poultry, grain, and potatoes. By 1912 overgrazing had reduced parts of the upland

plateau to hardpan. The end of Kanem Point had also washed away and pilings visible off the end of the point were all that were left from the earlier dock (Power 1976). By the 1920s blowing sand from erosion on the plateau had formed large dunes that smothered trees until marram grass (*Ammophila arenaria*) was planted to stabilize them, and other areas on the plateau were mulched with cut brush (Power 1976). Resident farming ceased in 1928, although several hundred sheep grazed the island in the 1950s and some crops were grown there by mainland farmers until at least 1956 (Figure 1A).

From 1937 to 1941 Arthur Einarsen studied the dynamics of introduced Mongolian ring-necked pheasants (*Phasianus colchicus*) on the island. During Einarsen's study the island contained 49 ha of tilled fields (wheat and barley), 33 ha of dense mixed coniferous forest, 19 ha of sandspits, 18 ha of barren sand dunes or gravel, and 40 ha of grass or pasture lands (Einarsen 1945). During World War II the island was used as an observation post. In August 1946, a fire burned most of the upper island and both points, including buildings and forested land, and a second fire a few years later burned Kanem Point (Power 1976). Subsequent photos of the woodland areas (Richardson 1961, Larsen 1982) show large numbers of snags mixed with shorter, healthy trees. Alcorn and Alcorn (1966) recorded the occurrence of another major fire on Violet Point in 1962.

In 1968 an investment company subdivided Protection Island into 1098 lots, which covered the entire island. Lot sales began in 1969. Developers built 15 km of roads and an airstrip, laid water pipes, and filled in the marsh and dug a marina near the base of Violet Point (Figure 1B, Figure 2). Lot owners built residences on 18 of the island lots (Larsen 1982). Controversy soon arose, however, over the lack of fresh water and disruption of seabird nesting. In 1974 Jefferson County put a moratorium on building permits. That same year the state of Washington purchased Kanem Point and the nearby western bluffs and created the Zella M. Schultz Seabird Sanctuary. Subsequently, the federal government purchased the remainder of the island, removed most of the buildings, and in 1988 established Protection Island National

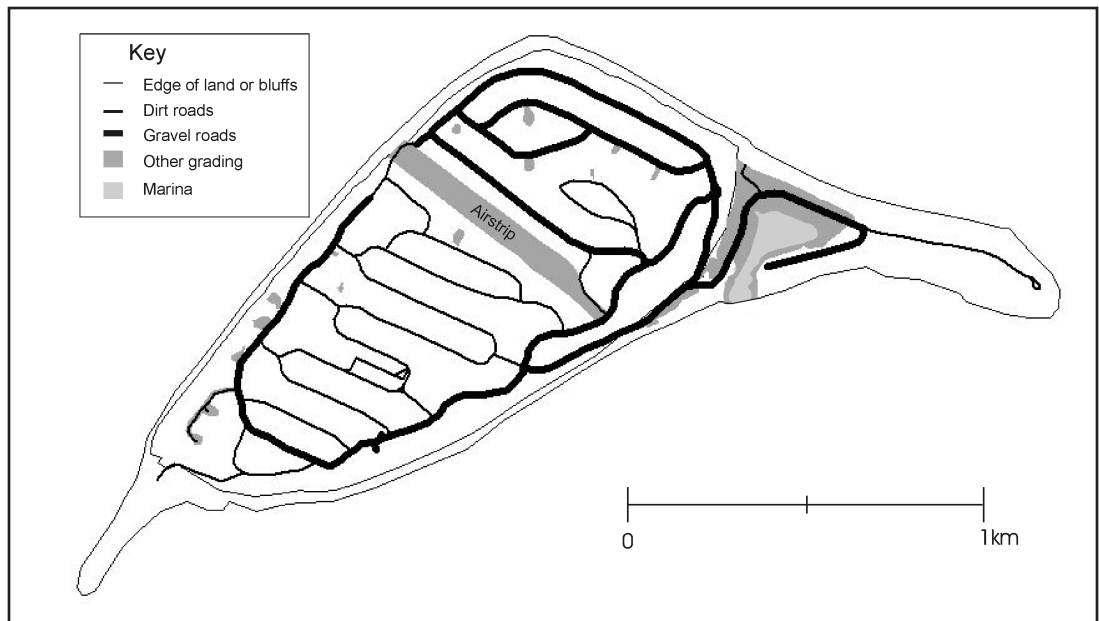


Figure 2. Land disturbances on Protection Island due to development of lots in the late 1960s. The outer fine line is the water's edge. The inner fine line is the base of the bluffs.

Wildlife Refuge. Since refuge establishment, Protection Island has remained relatively free of human disturbance. One permanent resident and a caretaker live on the island and scientists make intermittent visits. The grass along a few kilometers of roads is kept mowed while most of the island has reverted to a semi-natural state.

Island Fauna

Bird fauna include rhinoceros auklets (*Cerorhinca monocerata*), which were first noted in the 1850s (Suckley 1859). Despite damage to nesting burrows by trampling sheep in the 1950s (Richardson 1961), auklet numbers had increased to 17,000 pairs by 1977 (Wilson 1977, Wilson and Manuwal 1986). By 1981 Protection Island contained the largest rhinoceros auklet colony in the contiguous United States (Larsen 1982). Burrows were located on the slopes above both Kanem and Violet Points, with smaller numbers along the southern bluffs.

The first mention of glaucous-winged gulls (*Larus glaucescens*) nesting on the island is a report of nests on Violet Point in the 1940s (Power 1976). These birds were studied by Zella M. Schultz in the 1950s (Schultz 1951, 1952). By the early 1960s the gull colony was quite large (Richardson 1961). By 1975 gulls were also nesting on the upper plateau

(Power 1976) and the colony was the largest in the state (Wilson 1977). By 2002, approximately 10,000 gulls nested on Violet Point (Galusha and Hayward 2002) and many others nested on the south side of the upper plateau.

Bald eagles (*Haliaeetus leucocephalus*), which had nested on the island during the 1920s (Hufford, unpublished ms) re-established a nest in the northeast forested section of the plateau. By 1980 two eaglets were fledged (Larsen 1982) and non-resident eagles commonly used the island for foraging (Galusha and Hayward 2002). A pair of mule deer (*Odocoileus hemionus*) appeared on the island in the early 1990s and by 2006 the herd had increased to more than 50. The only rodents living on the island are Townsend's chipmunks (*Tamias townsendii*) and the only onshore predatory mammals are river otters (*Lutra canadensis*). Over 500 harbor seals (*Phoca vitulina*) haul out along the beaches.

Materials and Methods

Changes in island topography and land use were quantified by Geographical Information Systems (GIS, Arcview 3.1) using aerial photos dating from 1941 to 1999, a planimetric chart from the 1930s (Einarsen 1945), plot plans filed by the developers

in the 1960s, and a vegetation analysis chart of the island from the Washington Natural Heritage Program (1983). Selection criteria for aerial photos included high resolution and contrast and minimal parallax error. Key reference points on the island visible from the air were ground-truthed with a hand-held Global Positioning System (GPS) and were used to superimpose the aerial photographs from different years. Changes in physical features over the years, such as beach movement, were quantified by averaging position shifts at multiple equidistant points along the feature using GIS. Area determinations were made with the GIS area function. Time-of-day estimates for photos were made by examining the length and direction of shadows cast by tall trees.

Vegetative cover was assessed by transects (Figure 1C). Five magnetic N-S transects spaced 200 m apart and one E-W transect were established on the upland plateau. Five additional transects were established on Violet Point, each in a distinctive habitat type and oriented in various directions (Figure 1C). Individual transect lengths ranged from 100 to 650 m. All transects were made during the months of July and August 1999. No transects were made in the forest or on Kanem Point due to restricted access to those areas. Within each 100-m transect segment, 1 m² quadrat data were collected at 10 randomly chosen points for a total of 275 quadrats for all transects. Within each quadrat, each species was recorded and its percent cover estimated to the nearest 10%. Species present in very low numbers or which covered a very small area of the quadrat were recorded as having 1% cover. Percent cover could total more than 100% if the vegetation consisted of several layers. Species were identified using Hitchcock and Cronquist (1976), Natureserve (2007), and USDA (2007). Native or introduced status was determined using these same sources, as well as Pavlick (1995), Douglas et al. (1998), Turner and Gustafson (2006), and Barkworth et al. (2007).

Each quadrat was superimposed by GIS on the images of past land use and scored for past disturbance. All quadrats had experienced some level of disturbance. Quadrats which had been used for crops or as pasture in the past but which were not disturbed by the land development of the 1960s were rated as low disturbance. Quadrats which had been graded to bare earth or covered with fill or gravel during development were rated as high disturbance. Species richness and diversity,

based on percent cover, were calculated for each quadrat. Rarefaction was used as the diversity index because this method allows correction for different sample sizes (Krebs 1999, Gotelli 2001). All the more traditional diversity indices are affected by sample size so use of an index such as rarefaction is necessary to eliminate this bias. All diversity values were normalized to 40% cover so that the rarefaction diversity index answers the question: "In a random sample of this quadrat large enough to represent 0.4 square meters of cover, how many plant species could be expected to be found?" This approach allowed us to compare all the quadrats on the upland plateau and all but 10 of the quadrats on Violet Point without extrapolation or bias.

Changes in island topography and land use were measured from GIS projections. The effect of past disturbance on the distribution of individual plant species and community types was assessed by chi-square analysis. Percent cover, species richness, and diversity in low versus high disturbance areas were compared by ANOVA. Comparisons of native and introduced species on the same quadrats were made by paired t-tests. All statistical tests were carried out at the 0.05 significance level.

Results

Island Structure

Most of the shoreline showed little change between 1956 and 1999 beyond what could be accounted for by differences in tides (Figure 3). Exceptions include Kanem Point, which regressed 26 m in length over this 43-year period due to erosion at the tip and narrowed slightly at the base below the bluffs. Violet Point increased from 915 to 957 m in length and the wide beach that formerly spanned the region from the lagoon at the base of the Point north to the sea became vegetated due to filling and grading the area.

Physical changes in the bluffs that ring the plateau occurred mostly on the northwest margin. In 1956 the northwest bluffs showed considerable slumping and erosion channels (Figure 1A). The average horizontal distance between the top of the bluffs and the base at the beach below was 43 m ($n = 19$). By 1999, however, this distance had significantly decreased by half to no more than 23 m ($F = 53.5$, $P < 0.001$) (Figure 1C). The northeast bluffs, which were nearly vertical and

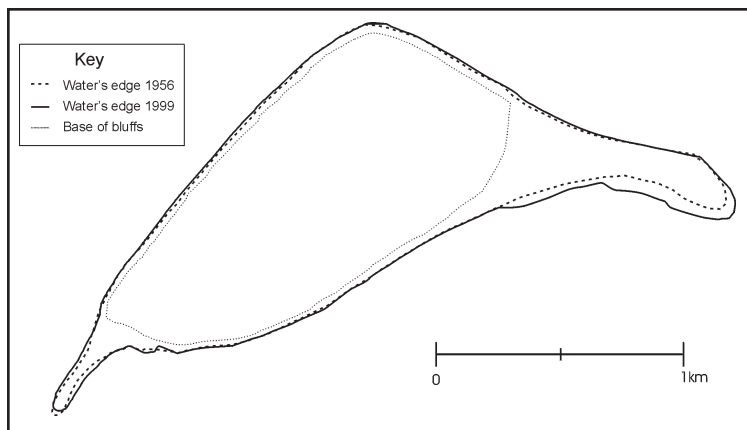


Figure 3. Outlines (land-water interface) of Protection Island made from GIS projections of aerial photos taken in 1956 (Figure 1A) and 1999 (Figure 1B). The base of the bluffs is plotted from the 1999 photo. These outlines are uncorrected for tidal change, and evidence suggests that the 1999 photo was taken at a lower tide than in the 1956 photo. The shortening of Kanem Point and the lengthening of Violet Point can also be seen.

mainly bordered above by forest, showed little change, nor did the less steep southern plateau margin.

The vegetated bluffs overlooking the points remained relatively unchanged as well. The bluff above Kanem Point was steepest at its southern end with a horizontal extent of about 25 m, while at the northern end it extended about 70 m. The road built up this bluff during the 1800s and used through the 1930s still could be seen in 1999, although it was highly eroded. In 1999, the bluff above Violet Point averaged 40-70 m in horizontal extent and a dirt road built at an angle up it during the 1960s was still visible, although it had eroded away by half or more. Erosion on the bluffs above the points was likely due to rhinoceros auklet burrowing.

The dunes on the plateau had moved northeast. Between the 1920s (Power 1976) and 1999 the southern dune migrated 350 m. The northern dune was 100 m northeast of its 1930s position (Einarsen 1945) and part of the dune had fallen over the bluff to the beach (Figure 1C). Both the northern and southern dunes were also more vegetated in 1999 than in former years.

Development during the late 1960s and early 1970s caused the greatest alteration of Protection Island since its discovery by Europeans. A 1974 aerial view shows 14.5 km of new roads including 7 km covered with gravel and 7.5 km of unimproved

dirt (Figure 1B, Figure 2). A 750-m airstrip covering 53 ha and house pads and turn-arounds totaling 22 ha had also been cleared and leveled. On Violet Point a 2.5 ha marina had been dug and 5.2 ha had been filled and graded where the marsh previously existed. The fill extended north of the marsh to the edge of the beach and probably accounted for the change in beach configuration that took place there. By 1999, however, only 3.2 km of these roads were still in regular use and another 1.8 km were lightly used and kept mowed. The remaining roads had been abandoned and become overgrown.

Vegetation

Although the general distribution of vegetation on the island in 1999 was similar to that described by Vancouver in 1792, significant alteration in cover and floristics had occurred. Changes in the grasslands included introduction of numerous exotic species, such that only 41% of the non-woody grassland species of sampled vascular plants were native (Table 1). The small groves of trees scattered through the grasslands mentioned by Vancouver no longer existed, although copses of snowberry (*Symphoricarpos albus*) and Nootka rose (*Rosa nutkana*) still could be found. The 1941 photo and Einarsen's (1945) account from the 1930s show the same two forested areas that existed in 1999. In Einarsen's diagram the northwest grove consisted primarily of conifers, whereas the northeast grove consisted of a mixture of conifers, deciduous trees, and shrubs (Table 2). Between the two groves a few forested patches totaling 500 m² were present. By 1956 the northwest grove had shrunk by 5% and the northeast grove by 10%, probably as a result of the fires of the 1940s, and the small patches of trees between the two groves were absent. By 1974 (Figure 1B) roads had subdivided the northwest grove into five sections and decreased its area by 24%. The northeast grove had been significantly thinned and also divided by roads into five sections. The western end of this grove had been cleared and leveled for the airstrip. By 1999, however, the

TABLE 1. Plant species occurring in grassland areas of Protection Island. N = native, I = introduced. An X indicates presence in quadrats whereas an * indicates presence in the habitat although not encountered in a quadrat.

Species	Common name	N/I	Found on	
			Upper Plateau	Violet Point
<i>Achillea millefolium</i>	yarrow	N	X	X
<i>Agrostis capillaris</i>	colonial bentgrass	I	X	
<i>Aira caryophylla</i>	silver hairgrass	I	X	
<i>Ambrosia chamissonis</i>	silver burweed	N		X
<i>Ammophila arenaria</i>	Marram grass	I	X	X
<i>Amsinckia menziesii</i>	rancher's tarweed	N		X
<i>Atriplex patula</i>	common orache	N		X
<i>Boschniakia hookeri</i>	Vancouver groundcone	N		X
<i>Bromus diandrus</i>	ripgut	I	X	X
<i>Bromus hordeaceus</i>	soft brome	I	X	X
<i>Bromus sitchensis</i>	Alaska brome	N	X	
<i>Bromus tectorum</i>	cheat grass	I	X	
<i>Castilleja hispida</i>	hairy Indian paintbrush	N		X
<i>Cirsium arvense</i>	Canada thistle	I	X	
<i>Convolvulus arvensis</i>	field bindweed	I	X	
<i>Crepis capillaris</i>	smooth hawksbeard	I	X	X
<i>Dactylis glomerata</i>	orchard grass	I	X	X
<i>Elymus glaucus</i>	blue wildrye	N	X	X
<i>Elymus repens</i>	quackgrass	I	X	X
<i>Equisetum hyemale</i>	scouring rush	N	X	
<i>Erodium cicutarium</i>	common storkbill	I		X
<i>Festuca idahoensis</i>	Idaho fescue	N	X	X
<i>Festuca rubra</i>	red fescue	N	X	X
	fruticose lichen	N	X	X
<i>Geranium molle</i>	dovefoot geranium	I	X	X
<i>Grindelia integrifolia</i>	gumweed	N	X	X
<i>Holcus lanatus</i>	common velvet grass	I	X	X
<i>Hordeum brachyantherum</i>	meadow barley	N		X
<i>Hypochaeris radicata</i>	false dandelion	I	X	X
<i>Leymus mollis</i>	dunegrass	N		X
<i>Lolium perenne</i>	ryegrass	I	X	
<i>Lupinus bicolor</i>	bicolored lupine	N	X	X
<i>Medicago lupulina</i>	black medic	I	X	X
<i>Medicago sativa</i>	alfalfa	I	X	X
	moss	N	*	X
<i>Plantago lanceolata</i>	buckhorn plantain	I	X	X
<i>Poa annua</i>	annual bluegrass	I		X
<i>Poa compressa</i>	Canadian bluegrass	I	X	X
<i>Poa pratensis</i>	Kentucky bluegrass	I	X	X
<i>Polygonum paronychia</i>	beach knotweed	N		X
<i>Rosa nutkana</i>	Nootka rose	N	X	
<i>Rumex acetosella</i>	sheep sorrel	I	X	X
<i>Rumex aquaticus</i>	western dock	N		X
<i>Sisymbrium officinale</i>	hedge mustard	I		X
<i>Sonchus oleraceus</i>	sow thistle	I		X
<i>Stellaria media</i>	chickweed	I		X
<i>Symphoricarpos albus</i>	snowberry	N	X	
<i>Taraxicum officinale</i>	common dandelion	I	X	
<i>Trifolium pratense</i>	red clover	I	X	
<i>Vicia cracca</i>	bird vetch	I	X	
<i>Vicia hirsuta</i>	hairy vetch	I	X	X
<i>Vicia sativa</i>	common vetch	I	X	X
<i>Vicia villosa</i>	woolly vetch	I	X	X
<i>Vulpia bromoides</i>	spiny grass	I	X	X

TABLE 2. Area (hectares) of Protection Island covered by forest and shrubs during different time periods, based on aerial photos. Con = conifers, Dec = deciduous trees and shrubs. "Other" is for trees and shrubs not in the two main groves.

Period	Northwest Grove			Northeast Grove			Other	Grand Total
	Con	Dec	Total	Con	Dec	Total		
1930s	4.85		4.85	17.90	2.00	19.90	0.05	24.80
1956			4.65			17.25		21.90
1974			3.55			13.55		17.00
1999	2.45	1.55	4.00	11.55	4.40	19.95		23.95

TABLE 3: Comparison of frequency of plant occurrence in low-disturbance areas with high-disturbance areas on the grassy portion of the upper plateau. All comparisons are to an expected chi-square ratio of 155:64 quadrats. Species without statistics listed were not abundant enough for chi-square analysis but were found in at least a 50% higher ratio than expected. (N) = native, (I) = introduced

Species	Chi-square	P
1. Species more common in the low disturbance areas of the Upper Plateau		
<i>Cirsium arvense</i> (I)	4.083	0.043
<i>Rosa nutkana</i> (N)		
2. Species more common in the high disturbance areas of the Upper Plateau		
<i>Agrostis capillaris</i> (I)	21.797	<0.001
<i>Aira caryophyllea</i> (I)	19.375	<0.0001
<i>Bromus hordaceus</i> (I)	11.682	0.001
<i>Festuca idahoensis</i> (N)	8.105	0.004
<i>Grindelia integrifolia</i> (N)	9.688	0.002
<i>Holcus lanatus</i> (I)	39.426	<0.001
<i>Hypochaeris radicata</i> (I)	47.633	<0.001
<i>Lupinus bicolor</i> (N)	6.233	0.013
<i>Medicago lupulina</i> (I)	7.266	0.007
<i>Plantago lanceolata</i> (I)	12.596	<0.001
<i>Poa compressa</i> (I)	9.051	0.003
<i>Rumex acetosella</i> (I)	31.484	<0.001
introduced grasses (I)	7.278	0.007
<i>Vulpia bromoides</i> (I)	19.284	<0.001
all grasses	4.529	0.033
all herbs	14.041	<0.001
fruticose lichens (N)	14.531	<0.001

northwest grove had recovered to 82% of its 1930s area and the northeast grove occupied 97% of its earlier extent (Figure 1C). Both groves contained a larger proportion of deciduous trees and shrubs in 1999 than in the 1930s (Table 2), reflecting an earlier stage of succession.

In 1999 on the upland plateau, many native plant species were more or less equally distributed among the disturbance classes. A number of introduced species, however, especially grasses, were concentrated in the more highly disturbed

areas (Table 3). Gumweed (*Grindelia integrifolia*) was found mainly close to roads, marram grass occurred near the bluffs over Violet Point, and lichens were most evident on ground graded for the airstrip where much mineral earth was exposed. Nootka roses occurred exclusively in areas of low disturbance.

More intensely disturbed upland plateau quadrats had significantly higher species richness and diversity than did other upland quadrats (Table 4). This higher richness was due to a significantly higher number of introduced species but not of native species found in the disturbed areas. Percent cover of introduced species (mean 118%) was much higher than that of native species (mean 16%) for quadrats on the upland plateau (Paired t-test, $t = 25.02$, $P < 0.001$). This difference was greatest in the most heavily disturbed land (8.7:1) and least in former pasture (5:1). There was no significant difference in percent cover for native or introduced plants between quadrats with low and high disturbance (Table 4).

Species richness was nearly 50% higher on land with greater disturbance than on land with less disturbance (Table 4). Land that had been previously plowed supported the lowest species richness (4.74) while highly disturbed land exhibited the highest richness (6.79). A similar result was found for diversity. Species richness for introduced species was much higher than that for native species in upland plateau quadrats (Paired t-test, $t = 12.41$, $P < 0.001$); moreover, the difference was significant at every disturbance level. Introduced species richness exceeded that of native species by the highest proportion in heavily disturbed land (2.4:1) and by the least proportion in former plowed fields (1.6:1). Introduced species, particularly grasses, had significantly higher occurrence and species richness on highly disturbed quadrats, however, native species did not (Table 4).

Despite some species overlap, Violet Point vegetation was distinct from that of the upland

TABLE 4. Comparisons between low disturbance and high disturbance quadrats from the upper plateau and from Violet Point. Comparisons are by ANOVA with df=1. Significant differences are in boldface.

Index	Low Disturbance (1-2)	High Disturbance (3-4)	ANOVA F	P
A. Upper plateau				
Percent cover	134	131	0.123	0.726
Native species % cover	16	15	0.043	0.835
Introduced species % cover	119	116	0.115	0.735
Species richness	4.92	6.47	26.794	<0.001
Native species richness	1.83	2.08	3.260	0.072
Introduced species richness	3.06	4.39	29.170	<0.001
Diversity	3.84	4.54	14.036	<0.001
B. Violet Point				
Percent cover	80	86	0.391	0.534
Native species % cover	54	37	3.819	0.055
Introduced species % cover	26	49	3.065	0.085
Species richness	3.51	5.79	6.522	0.014
Native species richness	2.05	2.81	4.329	0.042
Introduced species richness	1.38	2.48	3.594	0.063
Diversity	2.32	4.30	11.891	0.001

plateau. Dune grass (*Leymus mollis*), a native species, completely dominated some quadrats whereas other quadrats exhibited a mixture of plants. Quadrats with less than 50% dune grass had three times the diversity (3.8 vs 1.1) of those where dune grass dominated. When quadrats with 50% or more dune grass cover were disregarded, species assemblages were similar for all quadrats regardless of disturbance level, although there was some non-significant trend toward greater richness, diversity, and cover on the more highly disturbed quadrats. Violet Point had significantly higher native species richness and percent cover and significantly lower introduced species richness and cover than did the upland plateau (Table 5). Also in contrast to the upland plateau, on Violet Point native species richness and percent cover was greater than that of introduced species

(Paired t-test, for richness $t = 2.700$, $P = 0.009$; for percent cover $t = 1.45$, $P = 0.153$). This was due primarily to quadrats from low-impact sites since there was no difference between richness or percent cover of native vs. introduced species on sites with high disturbance. This trend persisted when quadrats dominated by dunegrass were disregarded, although the differences were no longer significant.

Discussion

In contrast to reports by early residents of rapid erosion on some parts of the island (Hufford undated, Power 1976), the topography of Protection Island was relatively stable during the 50 years covered by this study. The tip of Kanem Point shortened and the tip of Violet Point lengthened, each by about 0.2-0.5 m per year. The fact that

TABLE 5. Comparison of vegetation characteristics between the Upper Plateau and Violet Point. Comparisons are by ANOVA. Significant differences are in boldface.

Index	Plateau	Upper Point	Violet F	ANOVA P
Total percent cover	134	80.0	102.517	<0.001
Total cover of native species	15.5	48.2	73.094	<0.001
Total cover of introduced species	118.0	34.2	192.996	<0.001
Total species richness	5.36	4.08	13.137	<0.001
Native species richness	1.90	2.32	7.452	0.007
Introduced species richness	3.45	1.77	38.967	<0.001
Diversity	4.04	3.02	19.435	<0.001

the beach also narrowed near the base of Kanem Point, even though the tide was lower in the 1999 photo, suggests that the point also eroded in that area.

The most marked changes to the bluffs were along the northwest margin. Interestingly, most of the change seems to have come not from erosion and slumping of the bluffs themselves but from removal of previous slide debris from the foot and consequent steepening of the bluffs. Early residents (Hufford undated; Power 1976) mention running down these bluffs, a move that would have been suicidal in 1999. Einarsen (1945) stated that the steepness of the bluffs was about 45 degrees in the 1930s, whereas by 1999 they were at least twice that steep. Early residents and Larsen (1982) also mentioned rapid and extensive erosion by waves along the bluffs in that region during earlier years but waves seem to have had little effect on the bluffs themselves since the 1950s. Early settlers pastured large numbers of livestock on the island, resulting in overgrazing. This may have led to extensive slumping and wasting in that area followed by removal of the deposited material from the beach by the sea. The northeastern bluffs, stabilized by trees, and the southern bluffs, less steep and more protected from wave action, would have experienced less slumping. The rapid wasting and erosion noted in the early 20th century along the northwestern bluffs may thus have resulted from unsustainable land use, and the present slower erosion and steeper cliffs may represent a return to more normal conditions.

Vegetation experienced major anthropogenic impact but appeared to be on the way toward at least partial recovery by 1999. Due to fires, selective logging, and road building, the forest cover on the island declined sharply up through 1970. After that time the forested areas gradually increased by expanding in range and by closing over roads built through them. The 1999 forest likely represented an earlier state of succession than prior to 1940, however, as evidenced by the higher proportion of deciduous trees and shrubs. Several decades will likely be required before it regains its pre-1940 structure.

While grassland vegetation, both on the uplands and on Violet Point, had a very large contingent of introduced species in 1999, it also showed signs of partial recovery. Several presumed native species

such as red fescue (*Festuca rubra*), Idaho fescue (*Festuca idahoensis*), and blue wildrye (*Elymus glaucus*) were thriving in the least-disturbed areas of the uplands although some of these may have been varieties planted by residents for lawns or pasture. Aggressive invaders such as quackgrass (*Elymus repens*) in plowed areas, ripgut (*Bromus rigidus*) in former pastures, Canada thistle (*Cirsium arvense*), and orchard grass (*Dactylis glomerata*) continued to persist. Several introduced species of grass had established themselves in the most disturbed areas, along with some herbs such as false dandelion (*Hypochaeris radicata*), black medic (*Medicago lupulina*), and sheep sorrel (*Rumex acetosella*). Low diversity in former plowed fields seemed to be associated with introduced dominants, including field bindweed (*Convolvulus arvensis*), quackgrass, orchard grass, and Kentucky bluegrass; each of these species was represented in most sample quadrats where plowed fields had existed and covered 20% or more of each such quadrat. Blue wild rye, a native species, was also widespread and covered substantial areas of former pasture. In general, though, by 1999 the upland plateau was dominated by introduced species, especially in more highly disturbed areas.

By 1999, plant succession on Violet Point presented a different picture from that on the upland plateau, with different species and interactions. Overall plant cover was lower than on the upper plateau, perhaps due to the rocky soil, proximity to the sea, and presence of the gull colony. Native species continued to dominate even when associated with introduced species, although this dominance was less pronounced in highly disturbed sites. These native species may be adapted to the thin, rocky soil, salt spray, and seabird nesting activities. The most immediate threat to the diverse plant community on Violet Point seemed to come from dense stands of native dune grass, which was steadily expanding its cover and outcompeting most other species.

The 41% proportion of native versus non-native species encountered in the island transects was lower than reported for other nearby protected grasslands. For example, in Smith Prairie, 23 km NE of Protection Island on Whidbey Island and managed by the Au Sable Institute, 47% of the non-woody grassland species were native (Au Sable Institute of Environmental Studies 2004). On Colville Island, 33 km N of Protection Island and formerly the site of a large glaucous-winged

gull colony, 48% of the non-woody grassland species were native (based on specimens in the Burke Museum Herbarium, University of Washington, 2008). On Dungeness Spit, 17 km W of Protection Island and the site of a Caspian Tern colony, 62% of the non-woody grassland species were native (based on an unofficial list published by the Washington Native Plant Society, 1991). The latter two sites are part of the Washington Maritime National Wildlife Refuge Complex managed by the U.S. Fish and Wildlife Service. Two factors may account for the lower percentage of native species on Protection Island: 1) our sample contained only those species encountered along the transects and might have been somewhat higher if all grassland species were taken into account; and 2) the upland areas of PI were extensively disturbed by the grazing of domestic animals and the growth of agricultural crops when the area was farmed. By contrast, neither Colville Island nor Dungeness Spit were disturbed extensively by agriculture, although Smith Prairie was the site of a state game farm.

Now that agricultural and development activity on Protection Island has ceased, ecological structure is returning toward a state that resembles conditions two centuries earlier. Floristic composition, however, remains highly altered. Subjective observation suggests that blue wildrye, dunegrass, and Idaho and red fescue, all presumably native grass species, are doing well on the island. It is doubtful, however, that species composition will revert completely to pre-settlement conditions without intense intervention. Prescribed burns on the upper island, where invasive species predominate, might facilitate return of the prairie community toward to its original state although it may also run the risk of facilitating exotic species. Elsewhere, prescribed burns have been effective against a variety of invasive broadleaves,

perennial grasses, and woody species, although long-term changes to plant communities, impacts on invertebrate populations, and effects on soil characteristics after burns have been minimally evaluated. The effectiveness of prescribed burns on Protection Island might be enhanced if incorporated as part of an integrated management system, which also might include herbicide application, post-burn planting of native species, and use of biological control agents (Ditomaso et al. 2006, Robohm 1997). Special attention may need to be paid to problem species such as field bindweed (*Convolvulus arvensis*) and Kentucky bluegrass (*Poa pratensis*), both of which are persistent and aggressive in grasslands and may have lasting negative impacts on native species (NatureServe 2007). Integrated management of the island's flora, however, would need to occur with minimal disturbance to resident populations of birds and mammals, for which the island has been set aside and protected.

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