Global Climate Change and Sea Level Rise: Potential Losses of Intertidal Habitat for Shorebirds

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Abstract

Global warming is expected to result in an acceleration of current rates of sea level rise, inundating many low-lying coastal and intertidal areas. This could have important implications for organisms that depend on these sites, including shorebirds that rely on them for foraging habitat during their migrations and in winter. We modeled the potential changes in the extent of intertidal foraging habitat for shorebirds at five sites in the United States that currently support internationally important numbers of migrating and wintering shorebirds. Even assuming a conservative global warming scenario of 2°C within the next century (the most recent projections ranging between 1.4°C and 5.8°C), we project major intertidal habitat losses at four of the sites. These losses typically range between 20 percent and 70 percent of current intertidal habitat. The projected habitat losses would jeopardize the ability of these sites to continue to support their current shorebird numbers. The most severe losses are likely to occur in sites where the current coastline is unable to move inland because of steep topography or coastal defense structures such as sea walls.

Key words: climate change, global warming, sea level rise, shorebirds, WHSRN sites.

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Introduction

During their energetically demanding migrations, most shorebirds depend for foraging habitat on tidal sand and mud flats. The ability of a site to support large numbers of shorebirds is determined by the extent of these habitats, and by the density of invertebrate prey (Evans and Dugan 1984, Goss-Custard 1996). However, unlimited numbers of birds cannot simultaneously exploit a site, since the availability of feeding habitat will impose a limit on its carrying capacity. As the area of feeding habitat is reduced, densities of shorebirds increase, and density-dependent interactions may be triggered, resulting in the exclusion of individuals from the site, increased mortality rates among the excluded birds, and, ultimately, in limitation of numbers (Goss-Custard 1980).

During the 20th Century, tidal sand and mud flats came under considerable anthropogenic pressure, particularly from agricultural or industrial development. More recently, a new threat has been recognized — sea level rise due to global climate change. Increasing global temperatures will result in rises in sea level due to thermal expansion of the oceanic water and to melting of glaciers and ice sheets. The most widely accepted projection is that over the next 100 years, sea level will rise globally by between 10 and 90 cm (IPCC 2001). However, local sea level rise may be much greater or smaller due to the confounding effects of crustal subsidence or uplift, respectively (U.S. EPA 1995). Inundation due to sea level rise could result in the conversion of tidal to subtidal habitat and reductions in the availability of shorebird foraging habitats.

In this study, we modeled the potential consequences of future sea level rise for shorebird tidal foraging habitat at five important migration sites in the US, and the ability of these sites to continue supporting important numbers of shorebirds.

Methods

Study sites that are classified as at least of International Importance for wintering or migratory shorebirds were selected: Willapa Bay (Washington), Humboldt and San Francisco Bays (California), Bolivar Flats (Texas), and Delaware Bay (New Jersey and Delaware).

At each site we:

1. Quantified the current areas of tidal feeding habitats (sand beaches or mudflats) from the U.S. Fish and Wildlife Service's National Wetland Inventory maps.

2. Identified probabilistic sea level change scenarios from U.S. EPA (1995). The data in U.S. EPA (1995) allow the estimation of probabilistic sea level changes for specific sites and are based on historical rates of sea level change (obtained from tide gauges) superimposed on projected 50 percent and 5 percent probability global sea level changes by 2100 of 34 cm and 77 cm, respectively. The 50 percent and 5 percent probability sea level change projections in U.S. EPA (1995) assume global temperature increases of 2°C (50 percent probability) and 4.7° C (5 percent probability), respectively.

3. Modeled changes in the extents of intertidal feeding habitats in response to sea level change using the Sea Level Affecting Marshes Model (SLAMM 4). SLAMM 4 converts the habitat type occurring in a 30 m cell to another for given changes in the inundation regime. The variables that are included in this process included elevation, habitat type, slope, sedimentation and accretion and erosion rates, and the extent to which the affected area is protected by sea walls. Additional details regarding SLAMM in general have been presented in Lee et al. (1992) and Park et al. (1993).

Results

All of the study sites are projected to lose tidal flat habitat (*Tables 1-3*). However, the extent of loss is site-specific. Habitat loss will be greatest at southern San Francisco Bay, Humboldt Bay, and Delaware Bay. Substantial areas of tidal flats are lost at these sites even under the 50 percent scenario and as soon as 2050. In southern San Francisco Bay more than half of the current tidal flats may be lost by 2100 at the current rate of sea- level rise, without factoring in any future acceleration due to climate change. At Bolivar Flats, the tidal flat habitat loss is predicted to be almost complete (though temporary) by 2100 at the historical rate of sea level rise.

The scale of these losses is likely to result in major reductions in shorebird numbers at these sites. Indeed, if our 50 percent probability predictions for southern San Francisco Bay and Delaware Bay are realized, they could not possibly support shorebird numbers that are even only fractions of their current sizes.

This study also illustrates an important general point about the likely effects of climate change on ecological resources: climate change does not happen in a vacuum. The impacts of climate change will interact with other already existing stressors. For example, our modeling predicts that the extent of habitat loss at any site will depend on local factors. These include local land surface movements and human exploitation patterns (e.g., of aquifers). At sites where crustal movements exacerbate the rate of sea level rise, the loss of feeding habitat is likely to be accelerated. For example, we predict that by 2100 under the 50 percent scenario, southern San Francisco Bay will have lost about 70 percent of its intertidal feeding habitat. Comparison with the corresponding prediction for northern San Francisco Bay (39 percent loss) shows that much of the habitat loss in the southern bay is likely to be due to factors unrelated to, but exacerbating, the rise in sea level. In parts of southern San Francisco Bay, the land surface has historically been subsiding because of, at least in part, aquifer depletion and compaction. It is this crustal subsidence, superimposed on global sea level rise that is responsible for the predicted large habitat loss. In contrast, we predict comparatively modest rates of habitat loss at Willapa Bay. At this site, global sea level rise is being mitigated by crustal elevation (i.e., orthostatic rebound).

All of the above model predictions assume that no new coastal protection structures will be installed. However, it is likely that the local human populations at these sites will protect themselves from the consequences of sea level rise. To evaluate the likely influence of human responses, we considered one simple protection scenario for Bolivar Flats in which all current dry land areas will be protected with new sea walls. This resulted in reductions in the amount of upland habitat predicted to be lost, but a 20 percent increase in tidal habitat loss by 2100 under the 50 percent scenario. Thus, the protection measures work in the sense that upland habitats are protected. However, this is at the expense of intertidal habitats where the rate of loss is exacerbated.

In this study, we did not evaluate the potential effects of climate change-induced habitat loss for shorebirds in their breeding areas. It is in the high-latitude areas where shorebirds breed that the greatest impacts of climate change may occur. Climate-induced habitat changes may already be occurring in arctic and subarctic areas of North America (Chapin et al. 1995). The combined effects of habitat change on their breeding areas and intertidal habitat loss at their wintering and migratory staging sites could, potentially, have even more severe effects than could be brought about by any one factor. In future research we hope to adopt a "life-cycle" approach by incorporating climate change-induced effects on the wintering and breeding grounds. This should provide a more comprehensive appraisal of the likely effects of climate change on this group of migratory birds.

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Table 1— *Current extents (ha) and projected future percent changes in intertidal and upland habitat at Willapa and Humboldt Bays under three sea level rise scenarios.*

		Historical rate of sea level change[a]		50% Probability[b]		5% Probability[c]	
Habitat	**Current**	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Willapa Bay							
Tidal Flats	21,157	-0.7	-0.7	-7.5	-18.1	-25.8	-61.5
Salt marsh	3,455	12.8	12.8	9.5	10.5	13.6	12.8
Upland and other	62,389	-0.5	-0.5	-0.5	-0.7	-0.8	-1.3
Humboldt Bay							
Tidal flats	1,078	-0.1	-0.1	-13.0	-28.6	-42.4	-91.3
Salt marsh	40	72.6	72.6	88.9	175.6	229.2	1,886
Upland and other	12,750	-0.2	-0.2	-0.3	-0.6	-0.7	-6.0

[a] The historical rate of sea level change projections are based on actual past sea level changes measured at the site.
[b] The 50 percent probability projections represent future sea level change with an assumed 2^0 C warming (U.S. EPA's "best estimate" temperature scenario).
[c] 5 percent probability projections represent future sea level change with an assumed 4.7^0C warming (U.S. EPA's 5 percent probability temperature scenario)

Table 2— *Current extents (ha) and projected future percent changes in intertidal and upland habitat at northern and southern San Francisco Bays under three sea level rise scenarios.*

Habitat	Current	Historical rate of sea level change[a] 2050	Historical rate of sea level change[a] 2100	50% probability[b] 2050	50% probability[b] 2100	5% probability[c] 2050	5% probability[c] 2100
Northern							
Tidal flats	4,117	0.0	-4.0	-11.9	-39.4	-35.9	-80.7
Salt Marsh	613	0.0	0.0	0.0	0.0	0.0	-18.1
Upland and other	1,294	0.0	0.0	0.0	0.0	0.0	0.0
Southern							
Tidal flats	12,039	-12.9	-53.9	-24.0	-69.9	-42.9	-83.1
Salt marsh	3,534	0.8	-50.7	-2.2	-63.2	-11.6	-82.9
Upland and other	75,694	0.0	-0.2	-0.1	-0.5	-0.2	-0.6

[a]The historical rate of sea level change projections are based on actual past sea level changes measured at the site.
[b]The 50 percent probability projections represent future sea level change with an assumed 2^0 C warming (U.S. EPA's "best estimate" temperature scenario).
[c]5 percent probability projections represent future sea level change with an assumed 4.7^0C warming (U.S. EPA's 5 percent probability temperature scenario)

Table 3— *Current extents (ha) and projected future percent changes in intertidal and upland habitat at Bolivar Flats and Delaware Bay under three sea level rise scenarios.*

Habitat	Current	Historical rate of sea level change[a] 2050	Historical rate of sea level change[a] 2100	50% probability[b] 2050	50% probability[b] 2100	5% probability[c] 2050	5% probability[c] 2100
Bolivar Flats							
Tidal flats	398	-14.6	-93.8	-37.6	1.8	-80.6	1,073
Salt marsh	5,774	4.3	40.9	4.7	48.5	14.2	53.5
Upland and other	18,275	-1.3	-12.9	-1.4	-17.6	-4.4	-53.1
Delaware Bay							
Tidal flats	2,665	-6.1	-23.0	-19.8	-57.4	-43.1	19.8
Salt marsh	13,766	6.4	9.3	9.0	12.2	11.3	-4.2
Upland and other	20,538	-3.5	-5.5	-5.3	-7.5	-6.9	-11.3

[a]The historical rate of sea level change projections are based on actual past sea level changes measured at the site.
[b]The 50 percent probability projections represent future sea level change with an assumed 2^0 C warming (U.S. EPA's "best estimate" temperature scenario).
[c]5 percent probability projections represent future sea level change with an assumed 4.7^0C warming (U.S. EPA's 5 percent probability temperature scenario)