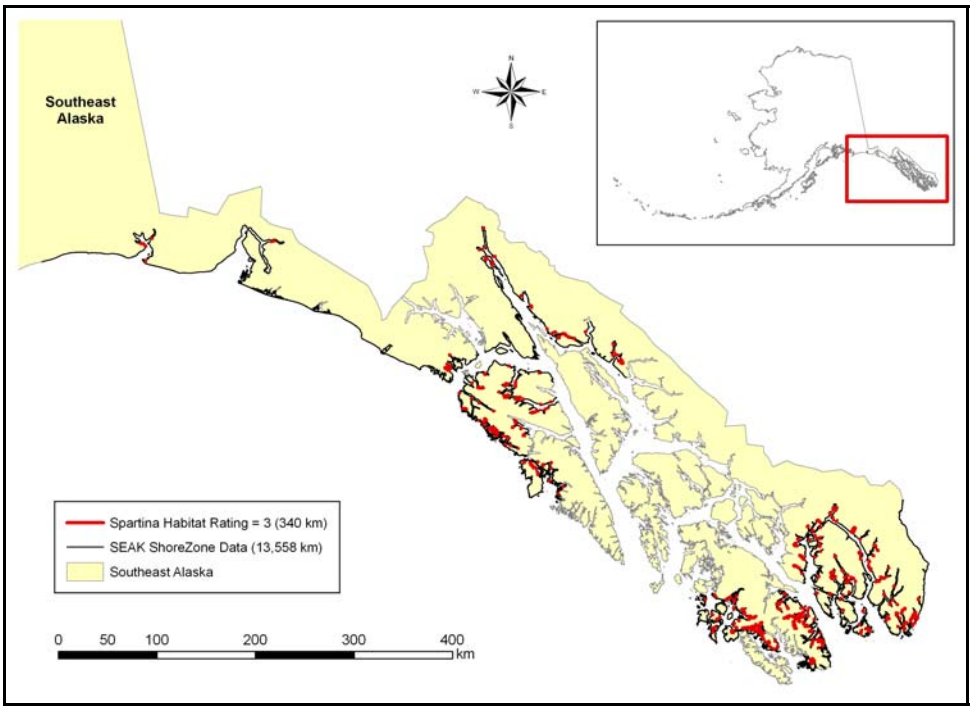
CORI Project: 2008-06 **December 2008**

Modeling habitat suitability for the invasive salt marsh cordgrass *Spartina* using ShoreZone coastal habitat mapping data in Southeast Alaska, British Columbia, and Washington State



Prepared for:
Alaska Department of Fish and Game
Sport Fish Division
Juneau, Alaska

Coastal & Ocean Resources Inc.

ShoreZone

Prepared by:
Jodi Harney, Ph.D.

COASTAL & OCEAN RESOURCES INC.
214-9865 West Saanich Road, Sidney BC V8L 5Y8 Canada
ph: 250.655.4035, email: jodi@coastalandoceans.com, web: www.coastalandoceans.com

SUMMARY

Four species of the invasive salt marsh cordgrass *Spartina* are considered noxious from California to British Columbia: *S. alterniflora* (smooth cordgrass), *S. anglica* (English cordgrass), *S. densiflora* (dense-flowered cordgrass), and *S. patens* (saltmeadow cordgrass). The invasive plant is aggressive, forming dense, monospecific stands, converting mudflats into marsh, and altering patterns of circulation and drainage. Colonization and proliferation can be rapid in suitable habitats.

In this study, a habitat suitability model constructed for *Spartina* identifies potential habitats in coastal Alaska, British Columbia, and Washington on the basis of requisite habitat attributes that are also elements in ShoreZone coastal habitat mapping databases. ShoreZone data consist of along-shore coastal units and across-shore zones, into which are mapped the geomorphic, sedimentary, and biologic features of the shoreline according to relative tidal elevation. The principal area of interest in ShoreZone is the intertidal zone, as well as some features of the supratidal and shallow subtidal zones.

To construct the habitat suitability model, literature review and expert surveys established ratings for potential habitat attributes with respect to their importance in the colonization success of *Spartina*. Survey questions referred to physical, oceanographic, and biotic habitat characteristics, whether or not the attributes were actually elements in the ShoreZone database. Survey results demonstrated the importance of tidal elevation, intertidal slope, sediment texture, and wave exposure for all species. Habitat attributes most favorable to *Spartina* colonization included bare mud or sand flats of the middle and high intertidal zones in very protected and protected settings. Estuaries were also considered favorable for all species. No significant differences existed between average habitat attribute ratings for *Spartina alterniflora* and *Spartina anglica*. Only one response was received for *Spartina densiflora* and two for *Spartina* spp. in general. These data were included in the calculation of average habitat attribute ratings, but the groups were not considered to have distinct habitat requirements.

There was some indication that wider intertidal zones were more favorable to colonization. This attribute was addressed using the coastal class distinction between wide and narrow flats and beaches. There was some indication that semi-protected wave exposures may provide suitable habitat for some species under some conditions, but semi-exposed settings were not considered highly favorable to colonization and thus were excluded from the final habitat suitability model. The survey revealed that neither specific salinities, the presence of native salt marsh vegetation, nor anthropogenic features were highly favorable to *Spartina* colonization. Deltas and narrow sand beaches may provide suitable habitat but were not considered highly favorable to colonization.

On the basis of these results, a habitat suitability model was constructed in which nested queries of the ShoreZone database identified shoreline units possessing habitat attributes considered favorable to colonization by all species of *Spartina*. Coastal units mapped in the ShoreZone database were rated (0-3) with respect to habitat suitability for *Spartina* on the

basis of how many of the following favorable habitat attributes co-occur within a single along-shore unit:

- Very protected or protected wave exposure
- Wide, sediment-dominated flats
- Estuaries

Shore units possessing all three attributes were assigned a habitat rating of 3, indicating these environments may be highly favorable to *Spartina* colonization. In Southeast Alaska, a database of 13,558 km was examined. Of this, 340 km of shoreline (3%) was rated as highly-suitable *Spartina* habitat, possessing all three attributes. In British Columbia, 32,809 km of mapped shoreline data was examined. Of this, 1,524 km (5%) of shoreline was given the highest rating for *Spartina* habitat suitability. In Washington, 4,936 km of mapped shoreline data was examined. Of this, 778 km of shoreline (16%) possessed all three *Spartina* attributes.

Highly-suitable habitat sites (representing a total shoreline length of 2,642 km) were identified from more than 51,000 km of coastal attribute data in Southeast Alaska, British Columbia, and Washington. These selected shorelines may represent potential habitat hotspots for the invasive cordgrass.

Accessible regional ShoreZone data and GIS shapefiles created in this study are summarized in Appendix B and provided on a Data DVD accompanying this report. A full protocol of the ShoreZone mapping technique (Harney et al. 2008) is included in PDF format and is also available online at www.coastalandoceans.com and at www.alaskafisheries.noaa.gov/maps/szintro.htm.

TABLE OF CONTENTS

Section	Page
Summary	i
Table of Contents	iii
List of Tables	iv
List of Figures	v
Introduction	1
Non-native *Spartina* Cordgrass in the Pacific Northwest	1
Purpose	2
ShoreZone Coastal Habitat Mapping Program	3
Study Areas	4
Southeast Alaska	4
British Columbia	4
Washington State	4
Methods	9
Expert Survey	9
Geodatabase Design	9
Results	11
Habitat Attribute Ratings Defined by Expert Surveys	11
Spartina Habitat Suitability Model Attributes	14
Wave Exposure	14
Sediment Flats	14
Estuaries	14
Results of Geodatabase Analyses	15
Regional Results of Individual Habitat Attributes	20
Southeast Alaska	20
British Columbia	20
Washington	20
Regional Results of Nested Habitat Attributes	30
Southeast Alaska	30
British Columbia	30
Washington	30
Discussion	37
Suitable Habitat Attributes	37
Wave Exposure	38
Estuaries	38
Interspecific Differences	39
Future Work	39
Conclusions	41
References	43
Acknowledgments	45
Appendix A: *Spartina* Habitat Suitability Survey	47
Appendix B: Digital Files	61

LIST OF TABLES

Table	Description	Page
1	List of ShoreZone data employed in this study (illustrated in Figs. 1-3).	10
2	Average *Spartina* habitat attribute ratings for wave exposure.	11
3	Average *Spartina* habitat attribute ratings for geomorphic features.	12
4	Average *Spartina* habitat attribute ratings for sediment texture.	12
5	Average *Spartina* habitat attribute ratings for across-shore intertidal slope.	12
6	Average *Spartina* habitat attribute ratings for cross-shore intertidal width.	13
7	Average *Spartina* habitat attribute ratings for supratidal vegetation.	13
8	Average *Spartina* habitat attribute ratings for salinity.	13
9	Average *Spartina* habitat attribute ratings for anthropogenic features.	13
10	Average *Spartina* habitat attribute ratings for tidal elevation.	13
11	Individual and nested query results for the Southeast Alaska ShoreZone geodatabase.	17
12	Individual and nested query results for the British Columbia ShoreZone geodatabase.	18
13	Individual and nested query results for the Washington ShoreZone geodatabase.	19
B-1	Digital files	62
B-2	Classification of shore types (BC Classes) employed in ShoreZone mapping.	63

LIST OF FIGURES

Figure	Description	Page
1	Extent of ShoreZone habitat mapping data in Southeast Alaska used in this study (13,558 km).	5
2	Extent of ShoreZone habitat mapping data in British Columbia (32,809 km).	6
3	Extent of ShoreZone habitat mapping data in Washington State (4,936 km).	7
4	Distribution of very protected and protected wave exposure in mapped areas of Southeast Alaska.	21
5	Distribution of mud flats, sand flats, and sand and gravel flats in mapped areas of Southeast Alaska.	22
6	Distribution of estuaries in mapped areas of Southeast Alaska.	23
7	Distribution of very protected and protected wave exposure in mapped areas of British Columbia.	24
8	Distribution of mud flats, sand flats, and sand and gravel flats in mapped areas of British Columbia.	25
9	Distribution of estuaries in mapped areas of British Columbia.	26
10	Distribution of very protected and protected wave exposure in mapped areas of Washington state.	27
11	Distribution of mud flats, sand flats, and sand and gravel flats in mapped areas of Washington state.	28
12	Distribution of estuaries in mapped areas of Washington state.	29
13	Results of nested queries of habitat attributes in Southeast Alaska. Shorelines shown in blue have a *Spartina* habitat suitability rating of 2	31
14	Results of nested queries of habitat attributes in Southeast Alaska. Shorelines shown in red have a *Spartina* habitat suitability rating of 3	32
15	Results of nested queries of habitat attributes in British Columbia. Shorelines shown in blue have a *Spartina* habitat suitability rating of 2	33
16	Results of nested queries of habitat attributes in British Columbia. Shorelines shown in red have a *Spartina* habitat suitability rating of 3.	34
17	Results of nested queries of habitat attributes in Washington. Shorelines shown in blue have a *Spartina* habitat suitability rating of 2	35
18	Results of nested queries of habitat attributes in Washington. Shorelines shown in red have a *Spartina* habitat suitability rating of 3	36
19	Location of known *Spartina* populations in coastal British Columbia.	40
20	Status of ShoreZone Coastal Habitat Mapping Program in Alaska.	40

INTRODUCTION

Non-native *Spartina* Cordgrass in the Pacific Northwest

The introduction and spread of non-native species is among the most serious pressures on habitat quality and biodiversity in coastal and marine environments (Drake et al. 1989, Grosholz 2002, Vitousek et al. 1997). Estuaries are particularly sensitive to the effects of invasions by non-native species, owing to the crucial role that these ecosystems and their processes play across the land-sea interface. Extensive estuarine areas of San Francisco Bay, California, and Willapa Bay, Washington, have been significantly altered by the invasion of *Spartina* species during the last century (e.g. Ayres et al. 2004, Feist and Simenstad 2000).

Spartina is a salt-tolerant cordgrass introduced to the Pacific coast of North America from the east coast of the United States in the late 1800s. Four species of *Spartina* are considered noxious from California to British Columbia: *S. alterniflora* (smooth cordgrass), *S. anglica* (English cordgrass), *S. densiflora* (dense-flowered cordgrass), and *S. patens* (saltmeadow cordgrass). Hybrid species have also been described. All *Spartina* species and hybrids are deep-rooted and perennial, spreading by both seed dispersal and vegetative growth of rhizomes. In its native range, *Spartina* is valued for its role in natural coastal stabilization.

As an invasive species, the cordgrass forms dense, monospecific stands, converting mudflats into marsh and altering patterns of circulation and drainage. It is aggressive, and its proliferation can be rapid in suitable habitats. In Willapa Bay, Washington, *S. alterniflora* has spread at a rate of 17% per year to cover one-third of the area's 45,000 acres of tide flats (WSDA 2007). Documented ecological effects in Washington include loss of habitat for shorebirds and foraging intertidal organisms, decreased water velocity, increased sedimentation, anoxia, changes in nutrient cycling, displacement of native plants such as *Salicornia* (pickleweed) and *Triglochin* (arrowgrass), reduced macrofaunal densities, reduced oyster fisheries, and loss of coastal access (Levin et al. 2006, Neira et al. 2006, Phillips et al. 2008). Experimental data also suggest that factors affecting diversity may decrease the magnitude and stability of "ecosystem services" such as production and nutrient cycling (France and Duffy 2006). Loss of native genotypes has occurred as a result of hybridization in San Francisco Bay, having both ecological and evolutionary consequences (Grosholz 2002).

While *Spartina* can tolerate a range of environmental conditions, particular habitat attributes are important in its colonization and establishment. In general, *Spartina* habitat lies in the intertidal zone, where the plant readily colonizes unvegetated flats, bays, and lagoons with a range of sediment textures, including mud, sand, and some mixed sediments (such as a cobble veneer over sand and mud). Although in its native range the plant rarely grows above mean high water, it has been observed growing in sand dunes, grasslands, and coastal scrub of the southeastern United States. Pacific populations appear to favor the geomorphic and bathymetric conditions of estuarine environments, being most successful in colonizing large, protected estuaries such as San Francisco Bay, California, and Willapa Bay, Washington. Feist and Simenstad (2000) modeled the spatial patterns of *S. alterniflora* in Willapa Bay,

examining the influence of estuarine circulation, bathymetry, predicted wave energy, sediment texture, oyster culture activities, and proximity to fresh water input. Of these factors, bathymetry demonstrated the strongest influence on the plant's spatial distribution.

Spartina is not common in southwest British Columbia (BC) but has been recorded in Vancouver and Boundary Bay (on the southern mainland) and in Baynes Sound and Comox (on eastern Vancouver Island) (Buffet 2005, Klinkenberg 2006). The spread of *Spartina* to coastal environments of Southeast Alaska is of great concern (AKEPIC 2005). Seeds are viable for up to a year, and dispersal may occur northward in the Davidson current, as suggested by drift card studies (Howard et al. 2006). The impact of *Spartina* invasion on habitats in northwest BC and southeast Alaska is not fully known, nor is the potential effect of such habitat change on commercially-important species such as salmon, sole, and Dungeness crab.

Between 1995 and 2000, *Spartina* coverage in Washington increased 250% (Hedge et al. 2003). Since then, millions of dollars spent on monitoring and eradication programs have effectively reduced the number of solid acres of *Spartina* invasion by 85% (Phillips et al. 2008). Early detection and removal of the invasive species is crucial to preventing widespread proliferation and damage to native coastal ecosystems. Identification of highly-suitable habitats may assist monitoring programs in the detection of new or expanding populations.

Purpose

Grosholz (2002) recognizes that the study of invasive species on broad landscape scales is among the most important gaps in the understanding of this widespread ecological problem, recommending the use of remote sensing and geographic information systems (GIS) to narrow this gap . The author also notes that the physical and biological characteristics of native communities not only influence the establishment of invaders, but may also affect the rate and extent of their geographical spread.

The principal objective of this study is the development of a **habitat suitability model** that appraises the sensitivity of intertidal and supratidal environments in the Pacific Northwest to colonization by the non-native saltmarsh cordgrass *Spartina*. The model integrates coastal **habitat attributes** mapped in the ShoreZone database with an understanding of *Spartina* habitat requirements in the Pacific Northwest, coastal BC, and Southeast Alaska. This approach is based on the rationale that successful colonization of the invasive cordgrass in the coastal zone is related to habitat attributes (such as geomorphology, wave exposure, sediment grain size, and tidal elevation) that can be distinguished, rated in terms of their importance in the plant's life-history strategy, and enumerated in the ShoreZone coastal mapping data. Predictions of suitable *Spartina* habitat may be useful in designing early detection and eradication efforts in areas not yet affected by the invasive species.

Each of the three regions examined in this study (Southeast Alaska (SEAK), British Columbia (BC), and Washington state (WA)) is discussed separately in this report. Maps and

GIS shapefiles generated by this study are provided for all regions on the Data DVD accompanying this report.

It is important to note that an analysis of oceanographic and biotic factors (such as water temperature, salinity, and currents) affecting *Spartina* dispersal and colonization is beyond the scope of this study. This work assumes that the plant's propagules are capable of arriving in these areas and that regional environmental variables are within its tolerable range.

ShoreZone Coastal Habitat Mapping Program

ShoreZone is a coastal habitat mapping and classification system in which aerial imagery is collected specifically for the interpretation and integration of geomorphic and biological features of the intertidal zone and nearshore environment. Oblique low-altitude aerial video and digital still imagery of the coastal zone is collected during summer low tides (zero tide level or lower), usually from a helicopter flying at <100 m altitude. The GPS flight trackline is recorded at 1-second intervals using electronic navigation software and is continuously monitored in-flight to ensure all shorelines have been imaged. Video and still images are spatially-referenced and time-synchronized. Video imagery is accompanied by continuous, simultaneous commentary by a geologist and a biologist aboard the aircraft.

The mapping system provides a spatial framework for coastal habitat assessment on local to regional scales. Imagery exists for nearly 45,000 km of coastline in the Gulf of Alaska and Southeast. In the Pacific Northwest, the ShoreZone Coastal Mapping Program also includes more than 45,000 km of mapped coastline in British Columbia and Washington state (from the Columbia River to the Alaska/BC border).

ShoreZone imagery and data in Alaska can be viewed, explored, and downloaded online at www.alaskafisheries.noaa.gov/maps/szintro.htm. For more information regarding the ShoreZone Coastal Habitat Mapping Program in Washington, BC, and Alaska, please visit www.coastalandoceans.com or www.CoastAlaska.net. The ShoreZone Coastal Habitat Mapping Protocol for Southeast Alaska (Harney et al. 2008) and various data summary reports are available for download at these sites.

Study Areas

The extent of ShoreZone data employed in this study is shown in the following three maps and briefly summarized in Table 1 of the Methods section. In addition, maps of the extent of imagery and mapping in the state of Alaska are provided in the last section of this report. The utility of the additional maps lies in understanding where ShoreZone data exist in Alaska for future applications of this and other habitat models.

Southeast Alaska

The ShoreZone Coastal Habitat Mapping Program in Alaska began in 2001, driven by concerns regarding the mitigation of potential oil spills (Harper and Morris 2004). The program is now comprised of more than twenty agencies that provide support, funding, and expertise for ShoreZone imaging and mapping in Southeast Alaska, Prince William Sound, and the Gulf of Alaska (Harney et al. 2008). Imagery collected between 2004 and 2006 has been entirely processed and mapped. Processing and mapping of imagery collected in 2007 is underway. Imagery collected in 2008 is currently not funded for mapping. The extent of available ShoreZone habitat mapping data in Southeast Alaska used in this study is shown in Figure 1 (13,558 km). Much of the imagery and data can be viewed online at www.alaskafisheries.noaa.gov/maps/szintro.htm.

British Columbia

The coastal zone of British Columbia, Canada, was mapped using the ShoreZone technique during the 1980s and 1990s (Howes et al. 1994). Unlike in Alaska and Washington, most BC ShoreZone data have not been made fully publicly available by the Integrated Land Management Branch of the BC Provincial Government. This imposes several limitations on the BC data set. First, data summary reports and aerial imagery for British Columbia are not accessible. Secondly, prior to 1992, biological data were not collected or mapped in the BC ShoreZone program. Biological data for the southwest island (Tofino to Victoria) were retrofitted using existing imagery after the biological mapping protocol was established in other parts of BC. Data quality in this area, where available, is therefore not comparable to post-1992 data. Thirdly, the Strait of Georgia and other areas of southern BC and Vancouver Island fall into the "incomplete data" polygon shown on the BC maps which follow. This data is largely unavailable and not included in this study. The extent of ShoreZone habitat mapping data in British Columbia used in this study is shown in Figure 2 (32,809 km).

Washington State

The coastal zone of Washington state was mapped using the ShoreZone technique between 1994 and 2000 (Berry et al. 2004). Both geomorphic and biological data are mapped and publicly available for the entire shoreline. The extent of ShoreZone habitat mapping data in Washington used in this study is shown in Figure 3 (4,936 km).

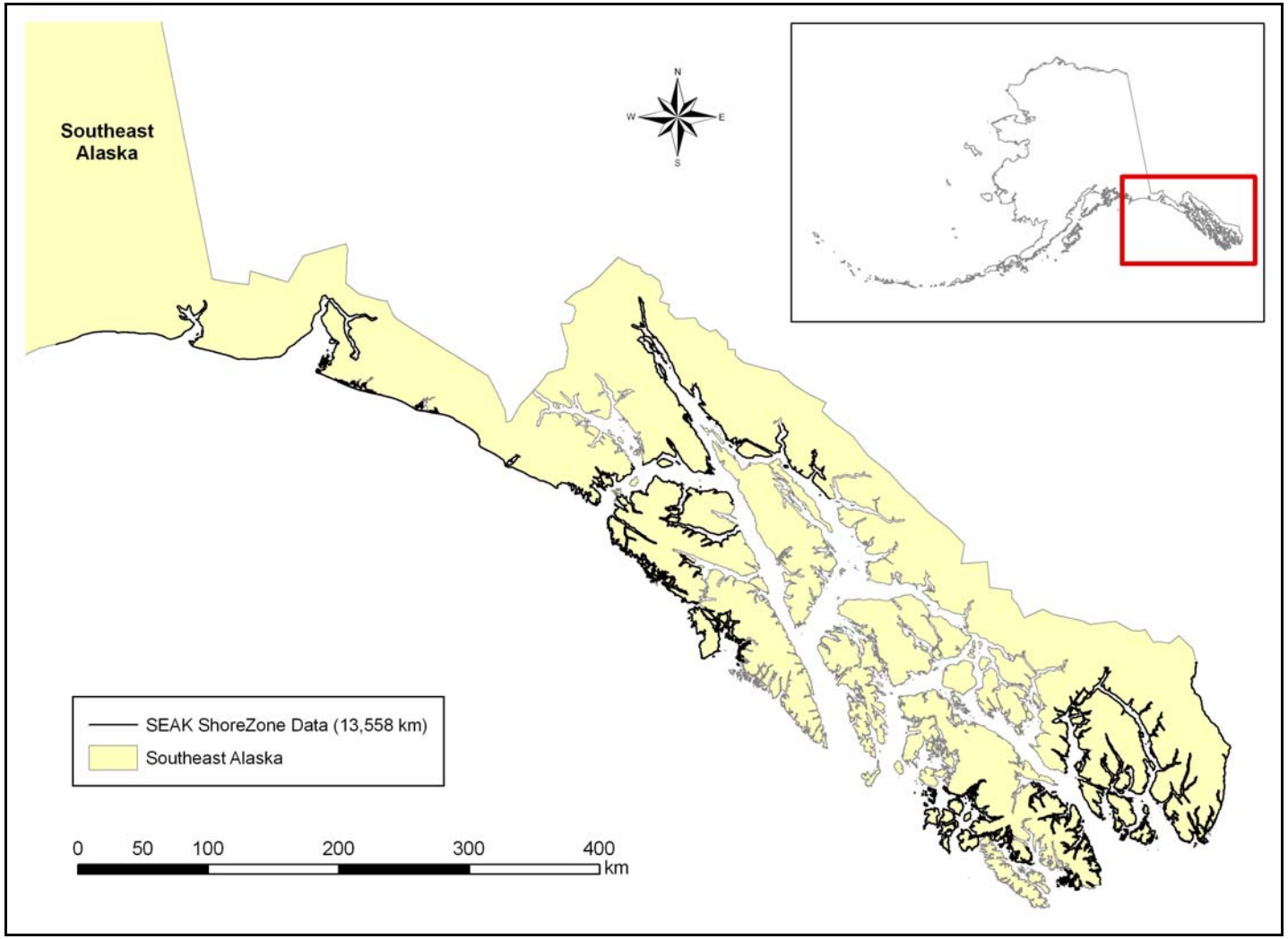


Figure 1. Extent of ShoreZone habitat mapping data in Southeast Alaska used in this study (13,558 km). [Shapefile: seak_shorezone_data_oct08.shp; Map: seak_shorezone_data_oct08.jpg]

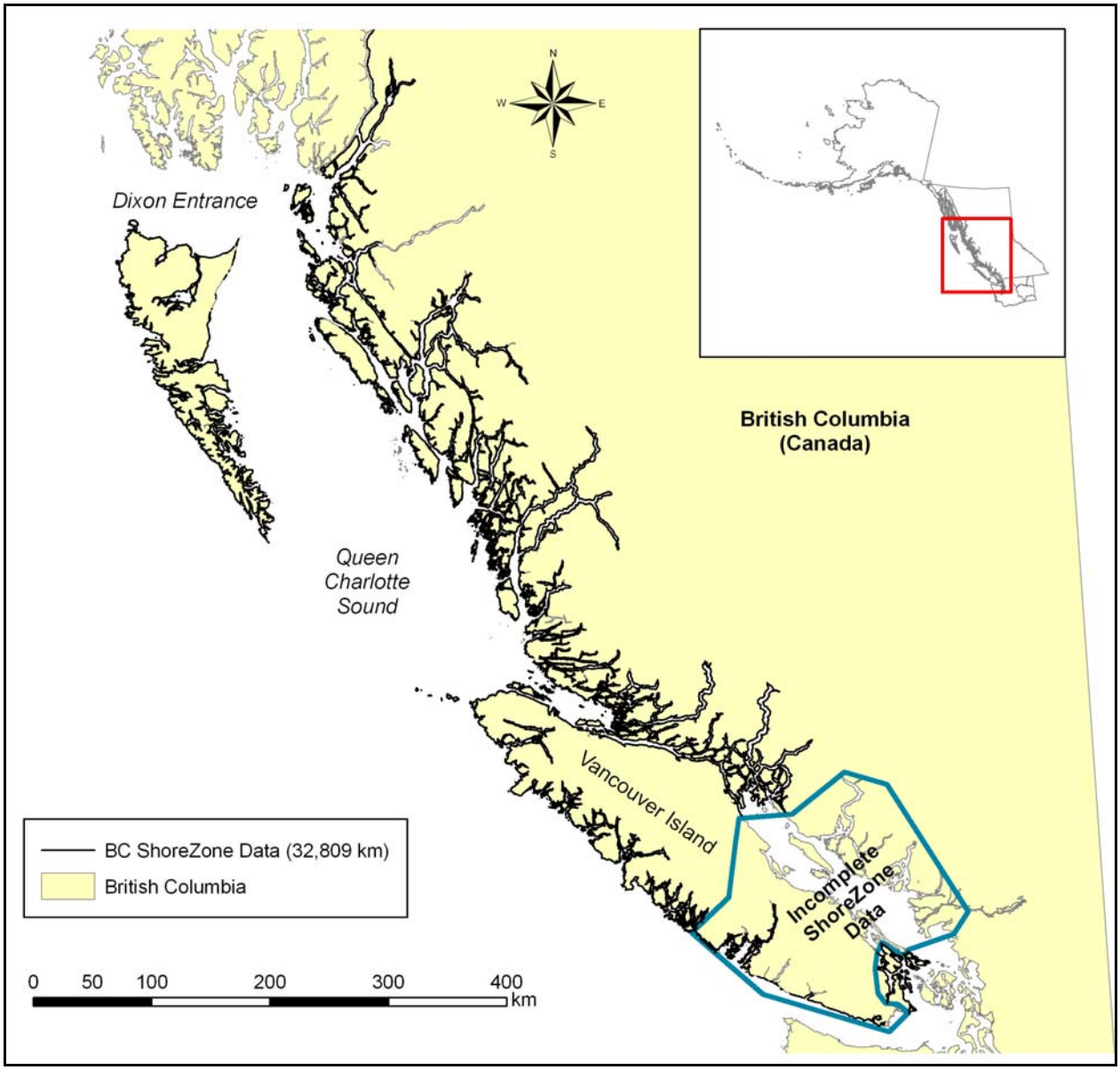


Figure 2. Extent of ShoreZone habitat mapping data in British Columbia (32,809 km). The "incomplete ShoreZone data" area represents shorelines for which data is incomplete or unavailable (see text).
[Shapefile: bc_shorezone_data_sep08.shp; Map: bc_shorezone_data_sep08.jpg]

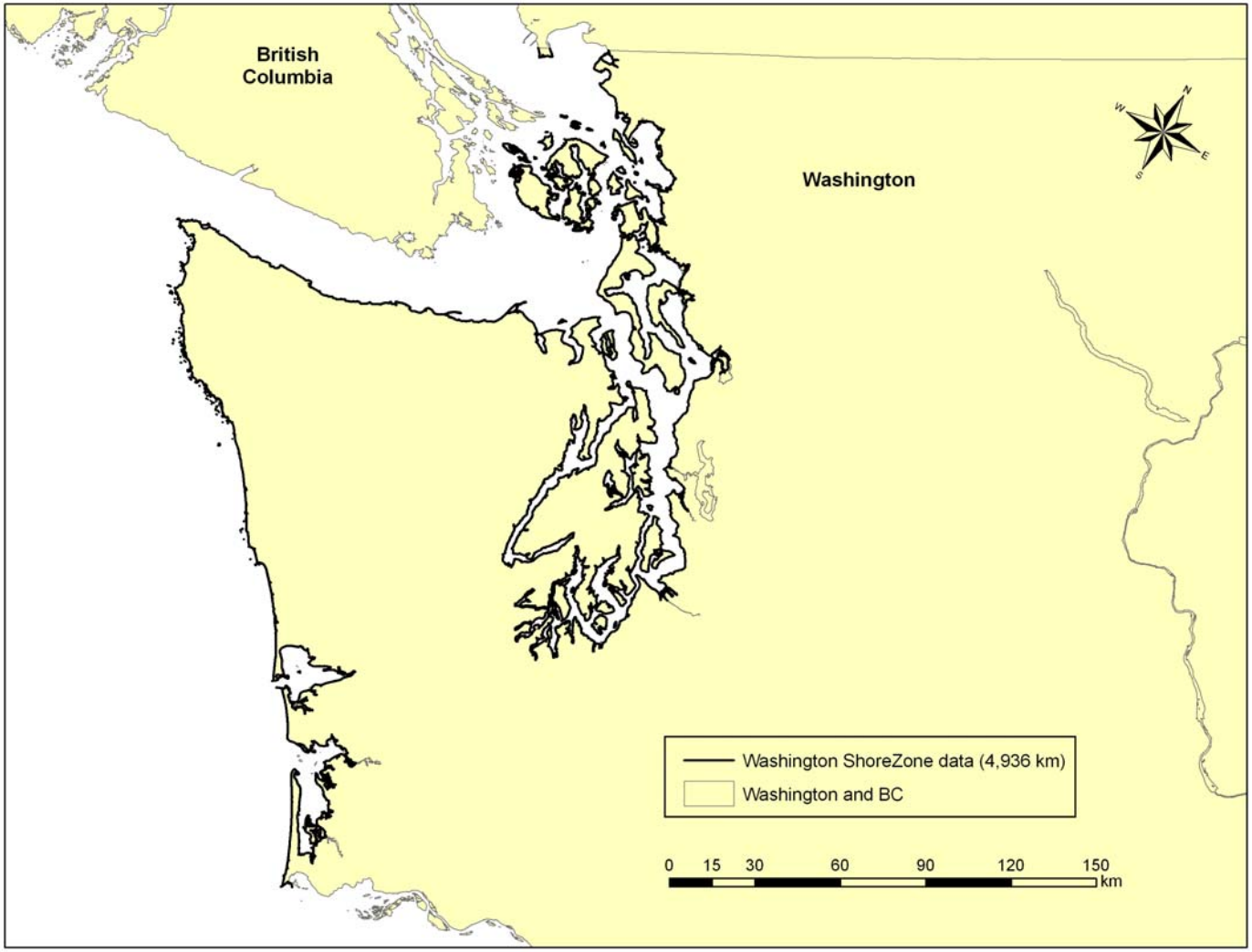


Figure 3. Extent of ShoreZone habitat mapping data in Washington State (4,936 km). [Shapefile: wa_shorezone_data_sep08.shp; Map: wa_shorezone_data_sep08.jpg]

METHODS

Expert Survey

In addition to a literature search, an online questionnaire was used to gather information regarding *Spartina* habitat characteristics from experts who study the invasive plant. The purpose of the survey was to ask experts to rate the relative favorability of various habitat characteristics in the life requisites of four species of invasive salt marsh cordgrass (genus *Spartina*) in the Pacific Northwest. Experts were identified during literature review and either possessed advanced degrees or extensive field experience regarding *Spartina*. The survey was posted online at SurveyMonkey.com, and experts were invited to participate. Eleven survey responses were received. The survey is provided in this report for reference (Appendix A).

As suggested by initial reviewers of the survey (see acknowledgements), respondents were first asked to specify to which *Spartina* species their answers applied. More than one species could be selected if the habitat requirements were considered similar. Respondents could complete the survey more than once for different species with different habitat requirements. For each habitat attribute listed, survey respondents assigned a rating (0-4) to reflect his or her opinion about the necessity of that attribute in supporting *Spartina* colonization. Attributes considered highly favorable for *Spartina* colonization were given the highest rating (4). Respondents could choose to not answer the question by entering "no comment." These answers, blanks, and zeros were not used in the final assessments. The survey also gave respondents the opportunity to enter comments and clarifying statements.

Habitat attribute ratings were tabulated from each of 11 survey responses. There were four responses for *S. alterniflora*, four for *S. anglica*, one for *S. densiflora*, and two for *Spartina* spp. in general (including hybrid species). No responses were collected for *S. patens*, therefore that species was excluded from the study. Average scores for each attribute were calculated by dividing the sum of the individual ratings by the number of responses received. Zeros and "No comment" responses were not counted. Average scores were tested for statistical significance between species (and between some attributes for a single species) using unpaired, two-tailed t-tests at the 95% confidence interval.

Geodatabase Design

A separate ArcGIS project (*.mxd file) was created for each of the three regions (SEAK, BC, and WA). Included in each ArcGIS project were ShoreZone spatial and attribute data, as well as standard regional basemaps to provide context. All project files, shapefiles, and maps are included on the Data DVD accompanying this report (Appendix B).

For Southeast Alaska (SEAK), the most recent ShoreZone data were compiled into a single ArcGIS geodatabase, reflecting shorelines mapped in separate years and under separate projects (2004-2006) but using the same imaging and mapping protocols. Metadata was

updated to reflect the combination of several years of survey information. ArcEditor was used to establish relationships between spatial data (digitized shorelines) and mapped attributes (geomorphic and biologic features observed along-shore and across-shore) on the basis of a unique "physical identifier" (PHY_IDENT) present in all ShoreZone databases. This identifier is a combination of the region, area, unit, and subunit fields in the database, separated by slashes (e.g. 10/05/0001/0). Spatially-explicit regions and areas defined for Alaska, BC, and Washington prevent overlapping or duplicate ShoreZone PHY_IDENTs. For more information, please refer to the ShoreZone Coastal Habitat Mapping Protocol for the Gulf of Alaska (Harney et al. 2008) included with this report.

For British Columbia and Washington, Microsoft Access databases housing publicly-available ShoreZone data were imported into separate ArcGIS projects. Relationships between spatial information and attribute data were established on the basis of PHY_IDENT as described. Analysis of each of the three geodatabase was performed using the "Select by attributes" tool in ArcGIS.

Table 1. List of ShoreZone data employed in this study (illustrated in Figures 1-3).

Region	Mapped Shoreline (km)	Figure	Data File
Southeast Alaska	13,558	1	seak_shorezone_data_oct08.shp
British Columbia	32,809	2	bc_shorezone_data_sep08.shp
Washington State	4,936	3	wa_shorezone_data_sep08.shp

RESULTS

Habitat Attribute Ratings Defined by Expert Surveys

Four responses each were received for *S. alterniflora* and *S. anglica*; one response was received for *S. densiflora*; and two responses for were received for *Spartina* spp. in general (or hybrids). No responses were received for *S. patens*. Survey participants had the option of not answering questions, or parts of questions, thus the sample size was not the same for every attribute or for every species. Average habitat attribute ratings were calculated by dividing the sum of individual ratings by the total number of ratings. Results are summarized in Tables 2-10.

Very protected and protected wave exposures scored high for all species (Table 2). There was some indication of the tolerance of *S. anglica* to a broad range of wave energies, from semi-exposed to very protected. However, differences in average ratings for all attributes between *S. anglica* and *S. alterniflora* were not significant (t-test of unpaired data at the 95% confidence interval).

Geomorphic features that scored high for all species included estuaries, mud flats, and sand flats (Table 3). Attribute ratings indicate the importance of sediment texture in defining *Spartina* habitat suitability (Table 4). Mud and fine sand were considered highly-favorable attributes for all species (all ratings >3). Results suggested settings in which coarser sediments (such as pebbles and cobbles) were a veneer over finer sediments could also provide suitable habitat. Flat and wide intertidal zones were favorable for all species, particularly when bare of other vegetation (Tables 5-7). Although it was clear that estuarine environments were considered conducive to *Spartina* colonization (Table 3), specific salinity ranges did not score particularly high (Table 8). The presence of anthropogenic features was not considered favorable to colonization by any *Spartina* species (Table 9). Tidal elevation scored high for all species, placing the zone of suitable *Spartina* colonization at the mid-to high-intertidal level (Table 10).

Table 2. Average *Spartina* habitat attribute ratings for wave exposure.

Exposure	***Spartina alterniflora***	***Spartina anglica***	***Spartina densiflora***	***Spartina* spp (general)**
Very protected (VP)	3.00	2.50	3.00	3.00
Protected (P)	3.00	2.75	3.00	3.00
Semi-protected (SP)	2.50	2.75	2.75	3.00
Semi-exposed (SE)	1.00	2.67	1.33	0.00
Exposed (E)	1.00	1.33	1.00	0.00

Table 3. Average *Spartina* habitat attribute ratings for geomorphic features.

Geomorphic Feature	***Spartina alterniflora***	***Spartina anglica***	***Spartina densiflora***	***Spartina* spp (general)**
Channel	1.00	1.00	1.25	1.00
Delta	3.50	2.75	2.25	4.00
Estuary	3.50	3.50	3.00	4.00
Mud flats (bare)	3.50	3.50	3.50	4.00
Mud flats (veg)	3.00	2.50	2.75	4.00
River influence	3.00	1.75	2.00	4.00
Sand beach	2.50	2.00	1.75	3.00
Sand flats (bare)	3.00	2.75	2.33	4.00
Sand flats (veg)	3.00	2.67	2.00	4.00
Supratidal berm	1.50	1.00	1.00	1.00

Table 4. Average *Spartina* habitat attribute ratings for sediment texture.

Sediment Texture	***Spartina alterniflora***	***Spartina anglica***	***Spartina densiflora***	***Spartina* spp (general)**
Mud (<63 um)	3.50	3.25	3.25	4.00
Fine sand (63 um - 0.5 mm)	3.50	3.50	3.00	4.00
Medium/coarse sand (0.5-2 mm)	3.50	3.00	2.50	4.00
Granules/pebbles (2 mm - 6 cm)	2.50	1.75	2.00	3.00
Cobbles (6-25 cm)	2.00	1.25	1.25	2.00
Boulders (>25 cm)	1.00	1.00	1.00	1.00

Table 5. Average *Spartina* habitat attribute ratings for across-shore intertidal slope.

Cross-shore Slope	***Spartina alterniflora***	***Spartina anglica***	***Spartina densiflora***	***Spartina* spp (general)**
Flats (<= 5 degrees)	3.50	3.50	4.00	3.50
Inclined slopes (5-19 degrees)	2.75	2.67	4.00	3.00
Steep slopes (>= 20 degrees)	1.50	1.00	1.00	1.00

Table 6. Average *Spartina* habitat attribute ratings for cross-shore intertidal width.

Cross-shore Width	***Spartina alterniflora***	***Spartina anglica***	***Spartina densiflora***	***Spartina* spp (general)**
<30 m	2.00	2.50	0.00	0.00
31-50 m	2.00	2.50	0.00	3.00
>50 m	2.50	3.00	0.00	3.00

Table 7. Average *Spartina* habitat attribute ratings for the presence of vegetation.

Vegetation	***Spartina alterniflora***	***Spartina anglica***	***Spartina densiflora***	***Spartina* spp (general)**
Dune grass (GRA)	2.00	1.67	2.00	2.00
Marsh grasses (PUC)	1.75	2.00	2.00	2.50
Sedges (SED)	1.75	1.67	2.00	2.50

Table 8. Average *Spartina* habitat attribute ratings for salinity.

Cross-shore Width	***Spartina alterniflora***	***Spartina anglica***	***Spartina densiflora***	***Spartina* spp (general)**
Fresh water	1.50	1.50	3.00	3.00
Brackish	2.33	2.50	3.00	3.00
Sea water	2.75	2.75	2.00	2.00
Hypersaline	1.00	1.00	1.00	1.00

Table 9. Average *Spartina* habitat attribute ratings for anthropogenic features.

Cross-shore Width	***Spartina alterniflora***	***Spartina anglica***	***Spartina densiflora***	***Spartina* spp (general)**
Ferry or shipping terminal	1.50	2.00	0.00	0.00
Marina	1.50	0.00	0.00	0.00
Fill	2.00	0.00	0.00	0.00
Aquaculture site	2.00	0.00	0.00	0.00

Table 10. Average *Spartina* habitat attribute ratings for tidal elevation.

Cross-shore Width	***Spartina alterniflora***	***Spartina anglica***	***Spartina densiflora***	***Spartina* spp (general)**
Supratidal	1.25	1.50	2.00	2.00
High intertidal	3.50	3.00	3.00	3.50
Mid intertidal	3.50	3.25	4.00	3.00
Low intertidal	1.75	2.50	4.00	2.50

Spartina **Habitat Suitability Model Attributes**

On the basis of habitat attribute ratings, three principal factors emerged as favorable habitat for all species: protected or very protected wave exposure, sediment flats, and estuaries. These attributes are elements mapped in all ShoreZone coastal databases.

Wave Exposure

Protected and very protected settings scored highest for all species. While data suggest that *S. alterniflora* may be tolerant of semi-protected (and even semi-exposed) conditions, no significant differences existed between average attribute ratings between species (as shown by t-tests at the 95% confidence interval). Only protected and very protected settings were included as suitable habitat in this study.

Sediment Flats

Mud and sand flats also scored high for all species, particularly those flats considered "wide." In the ShoreZone system, the BC Classes for mud flats (BC Class 29) and sand flats (BC Class 28) are both defined as wide shorelines (>30 m in across-shore intertidal zone width). These classes were considered suitable *Spartina* habitat, as were wide sand beaches (BC Class 27). Survey data and literature review also suggested that *Spartina* may colonize wide sand flats with a veneer of coarse material such as cobbles. Thus, wide "sand and gravel flats" (BC Class 24) were also included as potentially suitable habitat in this study. Narrow sand and gravel beaches, narrow sand and gravel flats, and narrow sand beaches (BC Classes 25, 26, and 30 respectively) were excluded from this analysis. Details regarding BC Class assignments in the ShoreZone system are provided in the ShoreZone Coastal Habitat Mapping Protocol for the Gulf of Alaska (Harney et al. 2008). A table of BC Classes is provided for reference in Appendix D.

Estuaries

Estuaries scored high as potential habitat for all *Spartina* species. By definition, the shore type classification for an estuary (BC Class 31) is a shore segment (along-shore unit) dominated by organic material, or one in which salt marsh represents >50% of the combined supratidal and intertidal area of the unit. Terrestrial marshes are not mapped in the ShoreZone system and are thus excluded from BC Class 31 assignments. No reference to width is included in BC Class 31.

Results of Geodatabase Analyses

Suitable *Spartina* habitat attributes (wave exposure, sediment flats, and estuaries) are the same in Alaska, BC, and Washington. The distribution of each *individual* attribute is examined first, by region. Results of *nested* queries of two and three habitat attributes were examined second, also by region. Subtle differences exist between databases, and queries were modified when necessary. Queries and their results are summarized in Tables 11-13 for SEAK, BC, and WA, respectively.

First, queries were run in each regional ArcGIS geodatabase to identify the location and extent of shore units possessing each of the three individual *Spartina* habitat attributes. For example, to identify shorelines with very protected and protected wave exposures from the SEAK geodatabase, a query was performed to select shore units for which the field "BioExpObs" was set to "VP" (very protected) or "P" (protected). The total length of shoreline in the SEAK geodatabase meeting this criteria was 5,874.5 km (Table 11). Similar queries were performed on the "BioExpObs" field of the BC geodatabase (Table 12) and the "Exp_Class" field of the WA geodatabase (Table 13).

To identify shorelines classified as mudflats, a query was performed to select shore units for which the "BC_CLASS" field was set to "29." The total along-shore lengths for each attribute in each regional geodatabase were calculated in ArcGIS. Shapefiles (*.shp) and maps (*.jpg) were created and exported for each individual attribute examined in each geodatabase. This information is summarized in the tables below and in Appendix B. All files are provided on the Data DVD accompanying this report. Additional information regarding fields within ShoreZone databases, and their definitions, can be found in the ShoreZone Coastal Habitat Mapping Protocol accompanying this report (Harney et al. 2008).

Nested queries were then performed using combinations of two and three attributes to identify shorelines possessing more than one suitable habitat attribute. For example, the wave exposure query was run first to identify very protected and protected shorelines. Of those selected units, a second (nested) query then identified the presence of sediment flats *or* estuaries (BC_CLASS = 24, 27, 28, 29, or 31) (Tables 11-13). These shorelines were assigned a *Spartina* habitat suitability rating of 2. This approach was the same in all three regional databases. Shapefiles (*.shp) and maps (*.jpg) were created and exported for each set of nested attributes examined in each regional geodatabase.

Triple-nested queries were more complicated, and the approach was modified slightly for each regional geodatabase, depending on which fields of ShoreZone data were available (Tables 11-13). In the SE Alaska geodatabase, the wave exposure query was run first (to select "VP" or "P" settings), followed by the query for sediment flats (BC_CLASS = 24, 27, 28, or 29), followed by a third (nested) query for estuary habitat classes ("HAB_CLASS"="*_E").

In the BC geodatabase, the wave exposure query was run first, followed by the query for sediment flats. Because the HAB_CLASS attribute that was not available in the public BC database, a proxy for estuaries was used: the presence of the "SAL" bioband in the supratidal

zone. In the BC ShoreZone program, the SAL bioband indicated the presence of salt-tolerant vegetation (including *Salicornia*, *Triglochin*, *Carex*, and *Spartina*). The third (nested) query selected shorelines for which the SAL field was set to patchy ("P") or continuous ("C").

In the Washington database, the wave exposure query was run first, followed by the query for sediment flats, followed by a third (nested) query to identify estuary habitat classes ("HAB_CALC"=8). The HAB_CALC field in the Washington ShoreZone database is analogous to the HAB_CLASS field in the SE Alaska ShoreZone database.

In each of these three cases, shorelines selected by the nesting of three queries were assigned a *Spartina* habitat suitability rating of 3, indicating they possessed suitable wave exposure, sediment flats, and estuarine environments.

Table 11. Individual and nested query results for the Southeast Alaska ShoreZone geodatabase.

SEAK ShoreZone	**km**	**Description**	**Shapefile**	**Jpg**
SEAK ShoreZone (project)	--	ArcGIS project that houses all shapefiles, data, and maps	spartina_seak_habitat_model.mxd	--
Alaska shoreline polygon	--	Basemap for display only; distinguishes land from water	ak_coast63poly_anad83.shp	--
SEAK ShoreZone 2004-2006 data	13,557.9	Mapped shoreline in SE Alaska (from 2004-2006 projects)	seak_shorezone_data_oct08.shp	seak_shorezone_data_oct08.jpg
SEAK Results: Single Attribute	**km**	**Description**	**Shapefile**	**Jpg**
Exposure (VP, P)	5,874.5	BioExpObs = very protected or protected	seak_exposure_vp_p_5875km.shp	seak_exposure_vp_p.jpg
Mud Flats	109.8	BC_Class = 29	seak_class29_mudflats_110km.shp	{
Sand Flats (including wide sand beaches, excluding narrow sand beaches)	562.6	BC_Class = 27 or 28	seak_class2728_sand_flats_563km.shp	{ seak_mud_sand_sndgrvl_flats.jpg
Sand and Gravel Flats (wide)	1,626.9	BC_Class = 24	seak_class24_sandgravel_flats_1627km.shp	{
Estuaries	2,001.9	BC_Class = 31	seak_class31_estuaries_2002km.shp	seak_estuaries.jpg
SEAK Results: Nested Attributes	**km**	**Description**	**Shapefile**	**Jpg**
Spartina Habitat Rating = 2	2,423.2	VP or P + flats (classes 24, 27, 28, 29) or estuary (class 31)	seak_rating2_exp_class2427282931_2423km	seak_rating2.jpg
Spartina Habitat Rating = 3	1,424.3	VP or P + flats (classes 24, 27, 28, 29) + HAB_CLASS = P_E or VP_E	seak_rating3_exposure_flats_estuary_340km.shp	seak_rating3.jpg

Table 12. Individual and nested query results for the British Columbia ShoreZone geodatabase.

BC ShoreZone	**km**	**Description**	**Shapefile**	**Jpg**
BC ShoreZone (project)	--	ArcGIS project that houses all shapefiles, data, and maps	spartina_bc_habitat_model.mxd	--
BC, AK, WA shoreline polygon	--	Basemap for display only; distinguishes land from water	ak_bc_wash_bcalbers.shp	--
BC shoreline polygon	--	Basemap for display only; distinguishes land from water	CHS_highwaterpoly_BCAlbers	--
BC ShoreZone "incomplete" polygon	--	Shows areas in BC lacking complete across-shore and bioband data	incomplete_sz_polygon.shp	--
BC ShoreZone data extent	32,809.2	Mapped shoreline data in BC (includes some areas of "incomplete data")	bc_shorezone_data_sep08.shp	bc_shorezone_data_sep08.jpg
BC Results: Single Attribute	**km**	**Description**	**Shapefile**	**Jpg**
Exposure (VP, P)	14,875.9	BioExpObs = very protected or protected	bc_exposure_vp_p_14876km.shp	bc_exposure_vp_p.jpg
Mud Flats	159.8	BC_Class = 29	bc_class29_mudflats_160km.shp	{
Sand Flats (including wide sand beaches, excluding narrow sand beaches)	1,906.6	BC_Class = 27 or 28	bc_class2728_sand_flats_1907km.shp	{bc_mud_sand_sndgrvl_flats.jpg
Sand and Gravel Flats (wide)	1,768.5	BC_Class = 24	bc_class24_sandgravel_flats_1769km.shp	{
Estuaries	1,592.3	BC_Class = 31	bc_class31_estuaries_1592km.shp	bc_estuaries.jpg
BC Results: Nested Attributes	**km**	**Description**	**Shapefile**	**Jpg**
Spartina Habitat Rating = 2	3,893.3	VP or P + flats (classes 24, 27, 28, 29) or estuary (class 31)	bc_rating2_exp_class2427282931_3893km.shp	bc_rating2.jpg
Spartina Habitat Rating = 3	2,932.0	VP or P + flats (classes 24, 27, 28, 29) + SAL = P or C	bc_rating3_exposure_flats_estuary_1524km.shp	bc_rating3.jpg

Table 13. Individual and nested query results for the Washington ShoreZone geodatabase.

WA ShoreZone	**km**	**Description**	**Shapefile**	**Jpg**
WA ShoreZone (project)	--	ArcGIS project that houses all shapefiles, data, and maps	spartina_wa_habitat_model.mxd	--
WA, BC, AK shoreline polygon	--	Basemap for display only; distinguishes land from water	ak_bc_wash_bcalbers.shp	--
WA ShoreZone data	4,935.7	Mapped shoreline in Washington	wa_shorezone_data_sep08.shp	wa_shorezone_data_sep08.jpg
WA Results: Single Attribute	**km**	**Description**	**Shapefile**	**Jpg**
Exposure (VP, P)	3,242.3	Exp_Class = very protected or protected	wa_exposure_vp_p_3242km.shp	wa_exposure_vp_p.jpg
Mud Flats	301.7	BC_Class = 29	wa_class29_mudflats_302km.shp	{
Sand Flats (including wide sand beaches, excluding narrow sand beaches)	870.6	BC_Class = 27 or 28	wa_class2728_sand_flats_871km.shp	{wa_mud_sand_sndgrvl_flats.jpg
Sand and Gravel Flats (wide)	399.3	BC_Class = 24	wa_class24_sandgravel_flats_399km.shp	{
Estuaries	869.6	BC_Class = 31	wa_class31_estuaries_870km.shp	wa_estuaries.jpg
WA Results: Nested Attributes	**km**	**Description**	**Shapefile**	**Jpg**
Spartina Habitat Rating = 2	1,811.7	VP or P + flats (classes 24, 27, 28, 29) or estuary (class 31)	wa_rating2_exp_class2427282931_1812km.shp	wa_rating2.jpg
Spartina Habitat Rating = 3	1,613.2	VP or P + flats (classes 24, 27, 28, 29) + HAB_CALC=8	wa_rating3_exposure_flats_estuary_778km.shp	wa_rating3.jpg

Regional Results of Individual Habitat Attributes

The spatial distribution and extent of individual habitat attributes (protected and very protected wave exposure, sediment flats, and estuaries) were determined by querying the regional geodatabases as described. Maps of the single-attribute query results follow for each region.

Southeast Alaska

Protected and very protected wave exposures occurred along 5,875 km of shoreline in Southeast Alaska (43% of mapped area) (Figure 4). Of this, very protected shorelines comprised only 667 km (~5% of mapped shorelines). Mud flats, sand flats, and sand and gravel flats occurred along 2,299 km of shoreline (17% of mapped area) (Figure 5). Estuaries occurred along 2,002 km of shoreline (15%) (Figure 6).

British Columbia

Protected and very protected wave exposures occurred along 14,876 km of shoreline in British Columbia (45% of the provincial coastline) (Figure 7). Of this, very protected shorelines comprised only 302.6 km (<1% of mapped areas). Mud flats, sand flats, and sand and gravel flats occurred along 3,835 km of shoreline (12% of mapped area) (Figure 8). Estuaries occurred along 1,152 km of shoreline (5%) (Figure 9).

Washington

Protected and very protected wave exposures occurred along 3,242 km of shoreline in Washington (66% of the state coastline) (Figure 10). Of this, very protected shorelines comprised 920 km (19% of mapped areas). Mud flats, sand flats, and sand and gravel flats occurred along 1,572 km of shoreline (32% of mapped area) (Figure 11). Estuaries occurred along 870 km of shoreline (18%) (Figure 12).

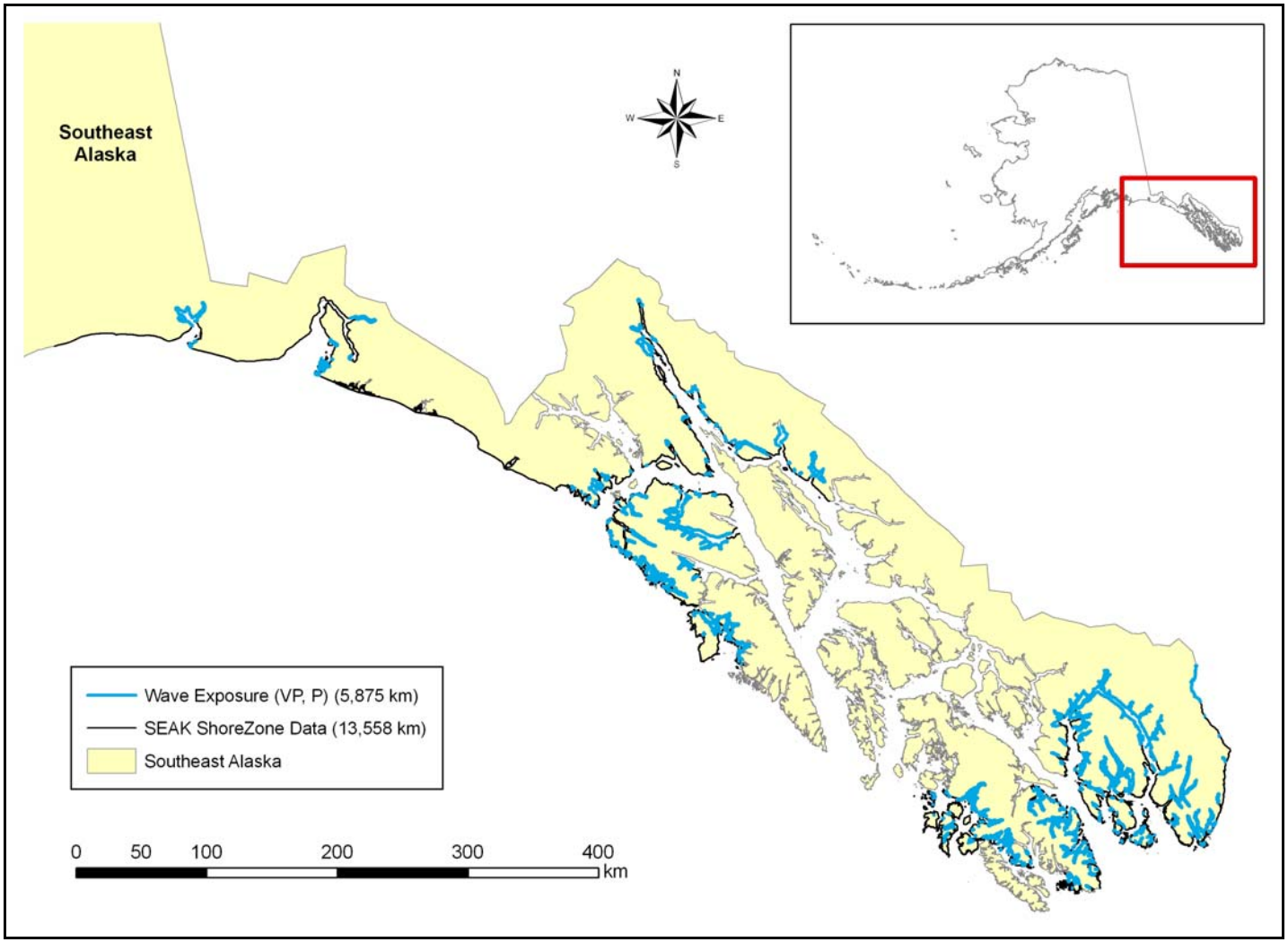


Figure 4. Distribution of very protected and protected wave exposure in mapped areas of Southeast Alaska. [Shapefile: seak_exposure_vp_p_5875km.shp; Map: seak_exposure_vp_p_5875km.jpg]

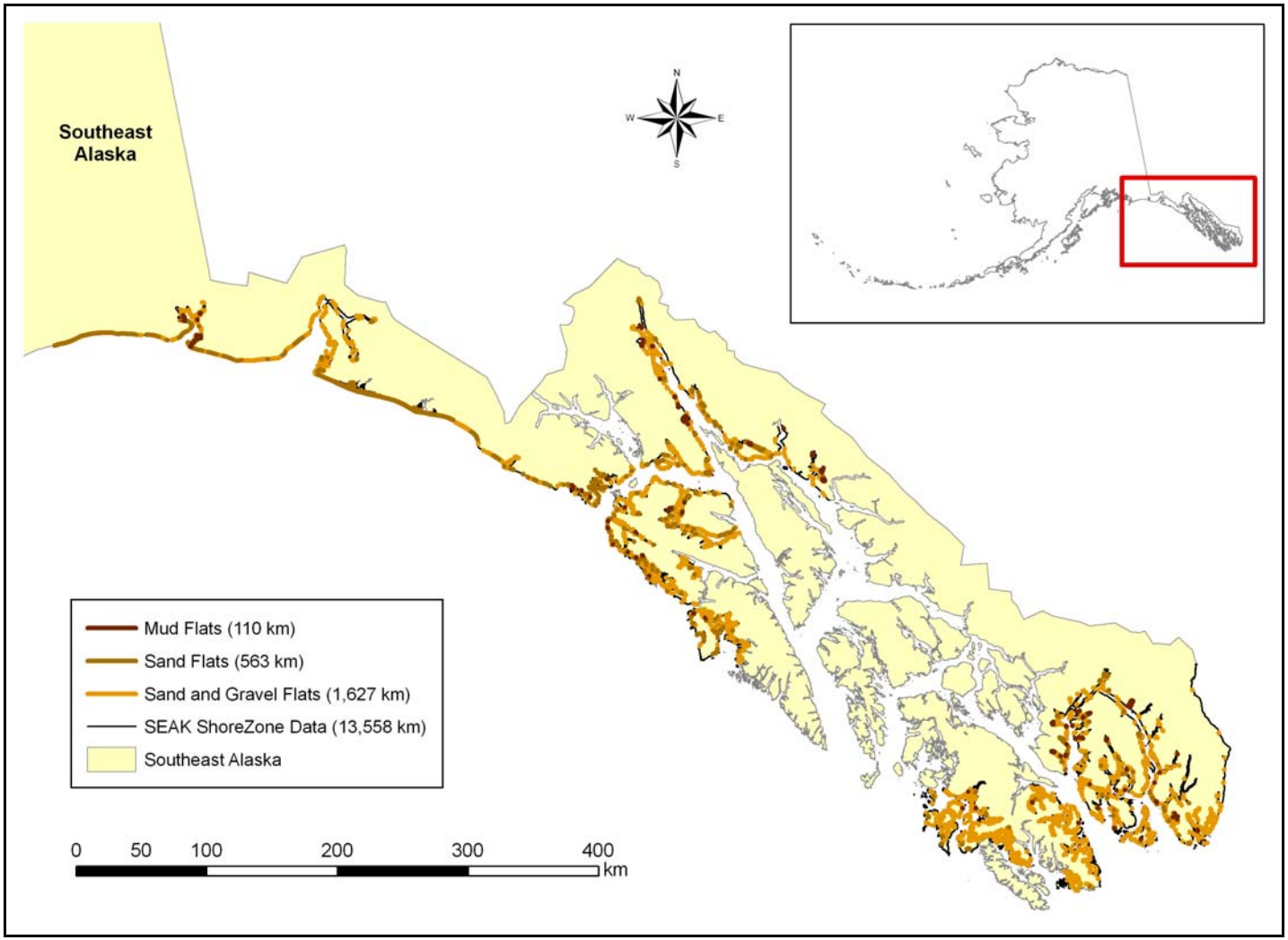


Figure 5. Distribution of mud flats, sand flats, and sand and gravel flats in mapped areas of Southeast Alaska. [Shapefiles: seak_class29_mudflats_110km.shp, seak_class2728_sand_flats_563km.shp, seak_class24_sandgravel_flats_1627km.shp; Map: seak_mud_sand_sndgrvl_flats.jpg]

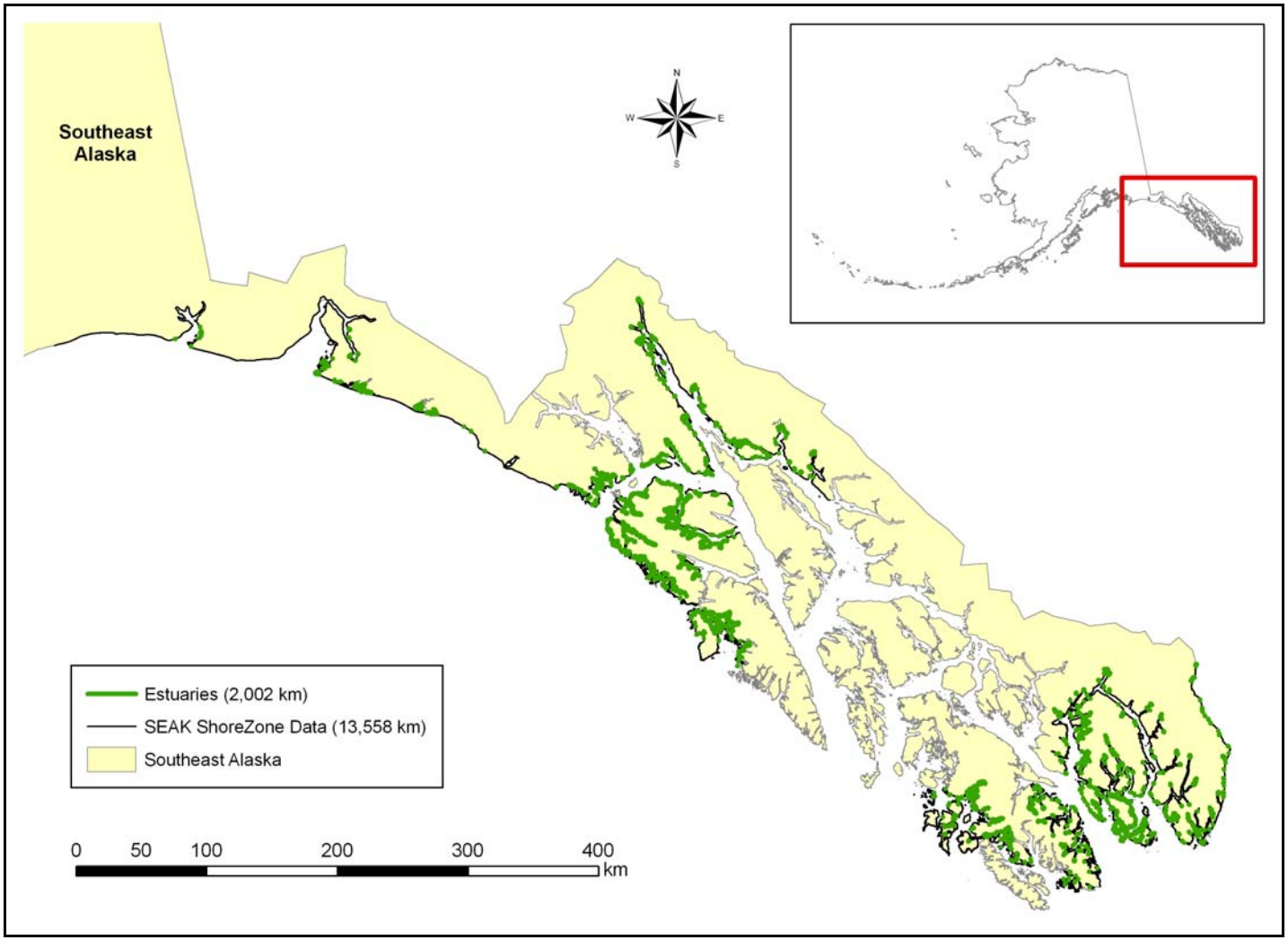


Figure 6. Distribution of estuaries in mapped areas of Southeast Alaska.
[Shapefile: seak_class31_estuaries_2002km.shp; Map: seak_estuaries.jpg]

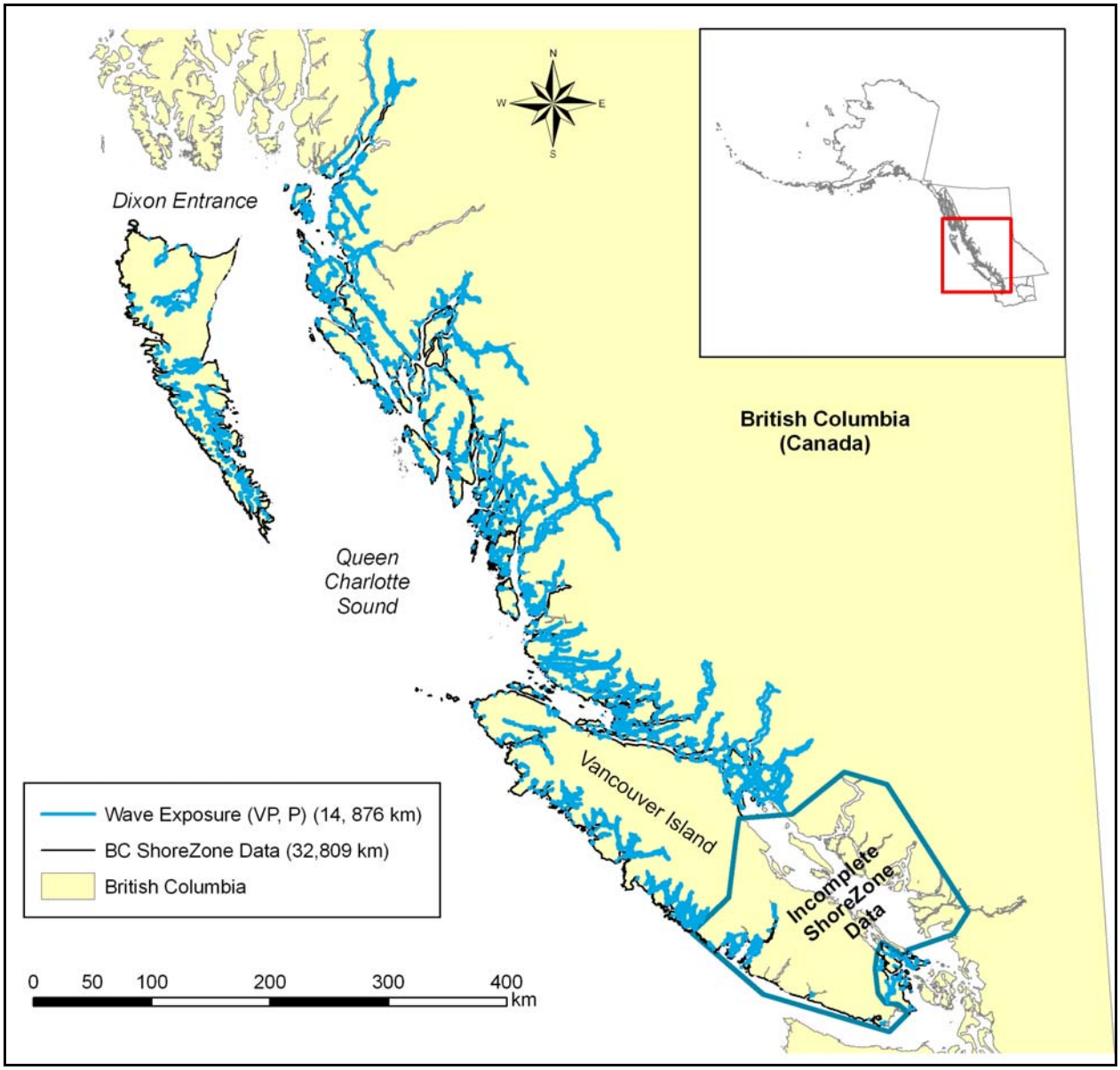


Figure 7. Distribution of very protected and protected wave exposure in mapped areas of British Columbia.
[Shapefile: bc_exposure_vp_p_14876km.shp; Map: bc_exposure_vp_p.jpg]

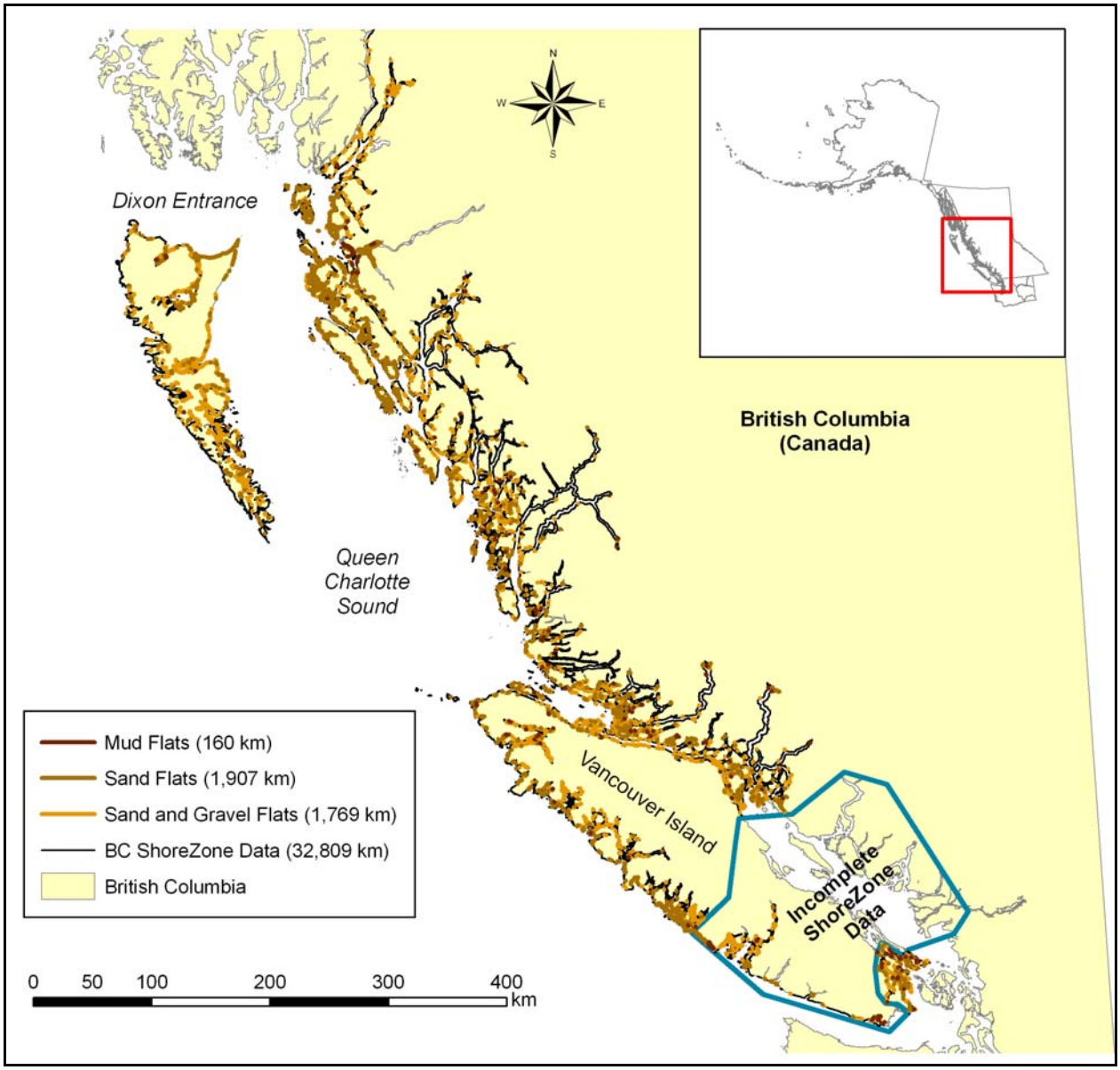


Figure 8. Distribution of mud flats, sand flats, and sand and gravel flats in mapped areas of British Columbia.
[Shapefiles: bc_class29_mudflats_160km.shp, bc_class2728_sand_flats_1907km.shp, bc_class24_sandgravel_flats_1769km.shp; Map: bc_mud_sand_sndgrvl_flats.jpg]

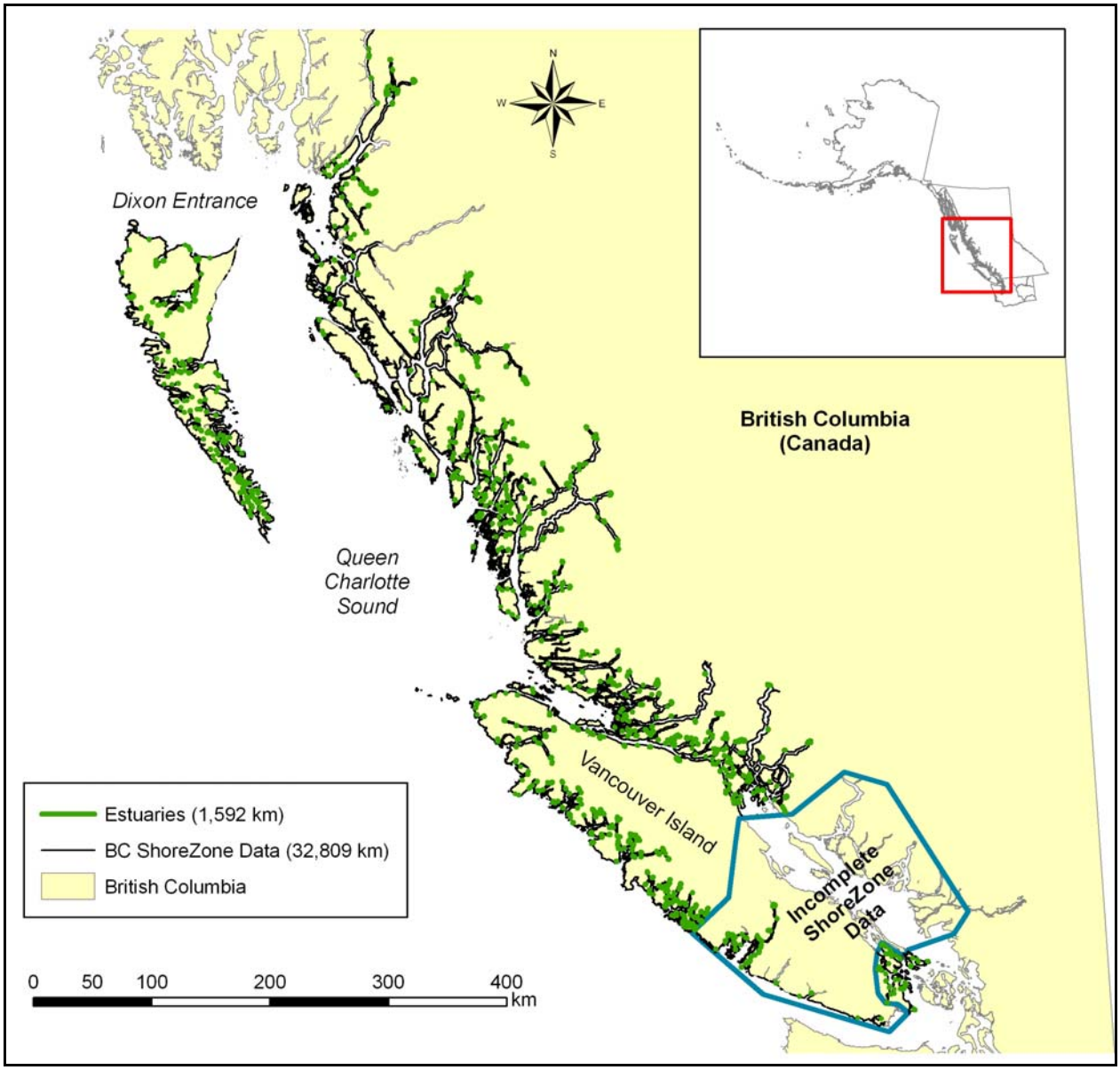


Figure 9. Distribution of estuaries in mapped areas of British Columbia. [Shapefile: bc_class31_estuaries_1592km.shp; Map: bc_estuaries.jpg]

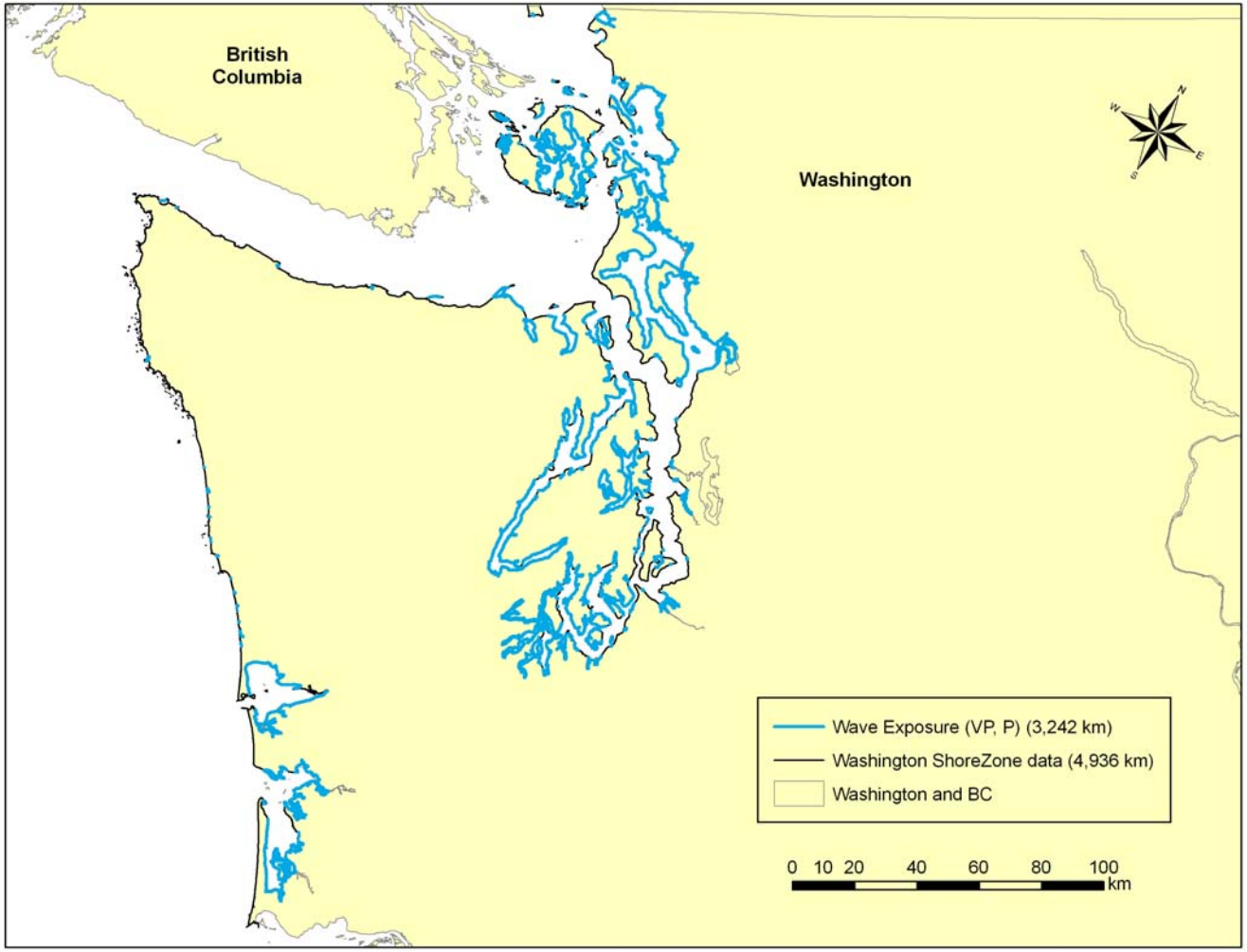


Figure 10. Distribution of very protected and protected wave exposure in mapped areas of Washington state.
[Shapefile: wa_exposure_vp_p_3242km.shp; Map: wa_exposure_vp_p.jpg]

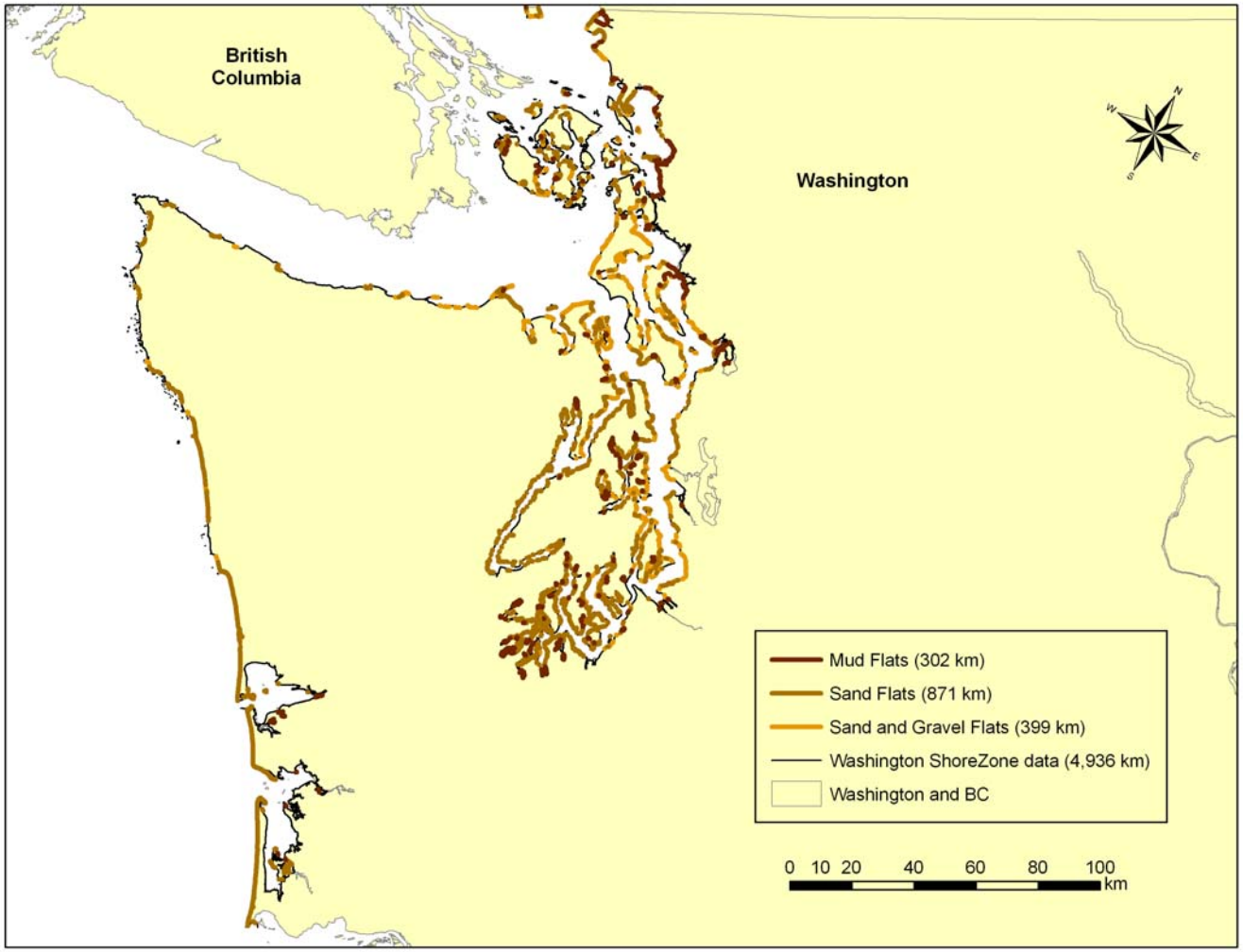


Figure 11. Distribution of mud flats, sand flats, and sand and gravel flats in mapped areas of Washington state.
[Shapefiles: wa_class29_mudflats_302km.shp, wa_class2728_sand_flats_871km.shp, wa_class24_sandgravel_flats_399km.shp; Map: wa_mud_sand_sndgrvl_flats.jpg]

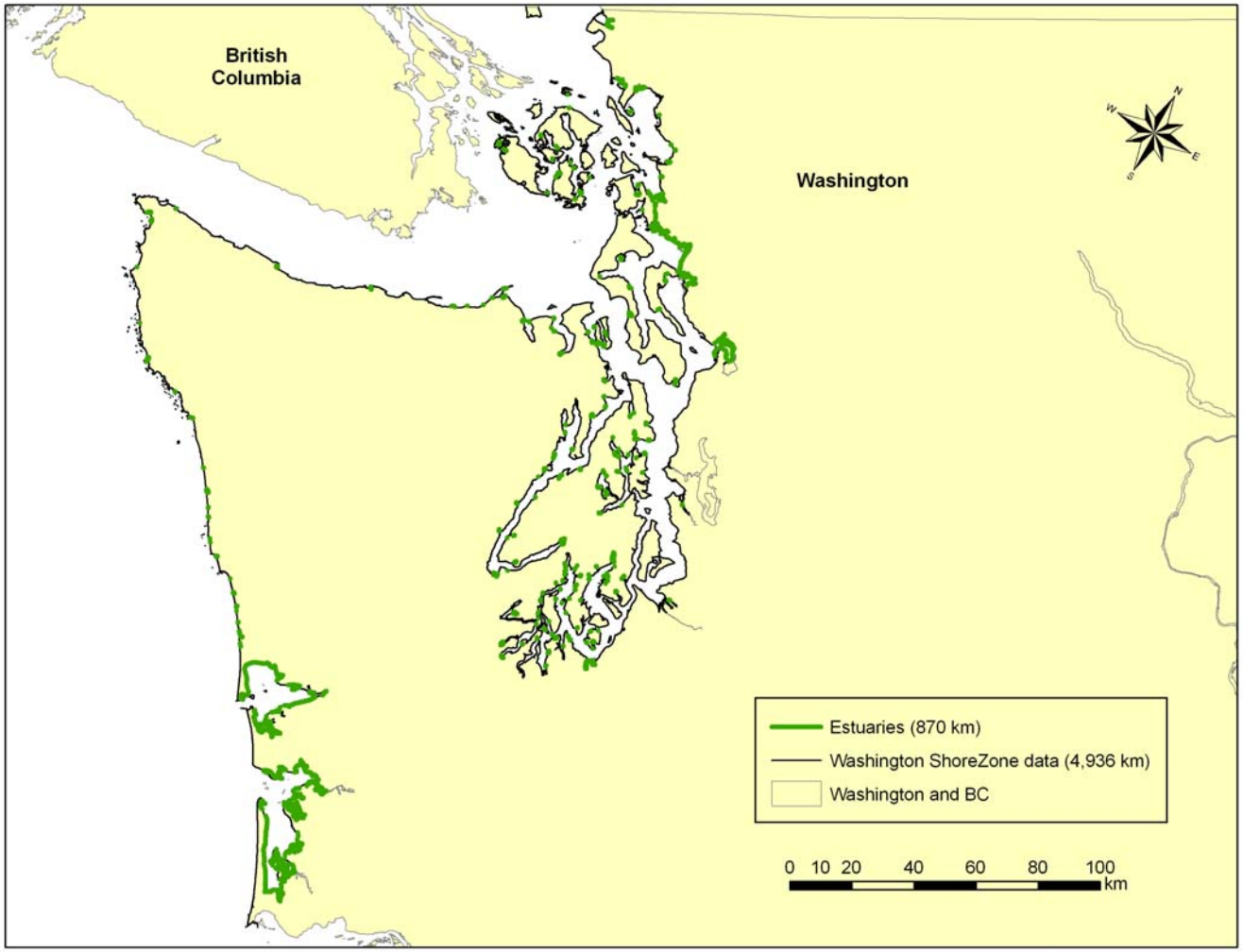


Figure 12. Distribution of estuaries in mapped areas of Washington state.
[Shapefile: wa_class31_estuaries_870km.shp; Map: wa_estuaries.jpg]

Regional Results of Nested Habitat Attributes

As described in the Methods section, highly-suitable *Spartina* habitat can be selected from thousands of kilometers of shoreline by employing nested queries of two or more suitable individual habitat attributes. This approach was based on the assumption that multiple favorable attributes offer overall more favorable habitat, and thus a higher probability of colonization success. A "habitat attribute rating" can be assigned to every shoreline unit, which reflects the number of favorable attributes mapped within that unit. Shorelines within very protected or protected wave exposures and *also* possessing sediment flats *or* estuarine environments were assigned a habitat attribute rating of 2 (of a possible 3). Shorelines that met both of these criteria *and* were also classified as estuarine environments were assigned a rating of 3 (of a possible 3), suggesting these were the most highly-suitable habitats. Shorelines rated 3 may represent potential "hot spots" for *Spartina* colonization.

Southeast Alaska

Nested queries of the SEAK geodatabase revealed 2,423 km of shoreline possessed two suitable habitat attributes within the mapped shore units: very protected or protected wave exposure *and* either sediment flats *or* estuarine environments (Figure 13). The triple-nested query for wave exposure, sediment flats, *and* estuarine environments predicted 340 km of highly-suitable potential *Spartina* habitat, which represents 3% of mapped areas in Southeast Alaska (Figure 14).

British Columbia

Nested queries of the BC geodatabase revealed 3,893 km of shoreline possessed two suitable habitat attributes within the mapped shore units: very protected or protected wave exposure *and* either sediment flats *or* estuarine environments (Figure 15). The triple-nested query for wave exposure, sediment flats, *and* estuarine environments predicted 1,524 km of highly-suitable potential *Spartina* habitat, which represents 5% of mapped areas in British Columbia (Figure 16).

Washington

Nested queries of the WA geodatabase revealed 1,1812 km of shoreline possessed two suitable habitat attributes within the mapped shore units: very protected or protected wave exposure *and* either sediment flats *or* estuarine environments (Figure 17). The triple-nested query for wave exposure, sediment flats, *and* estuarine environments predicted 778 km of highly-suitable potential *Spartina* habitat, which represents 16% of mapped areas in Washington (Figure 18).

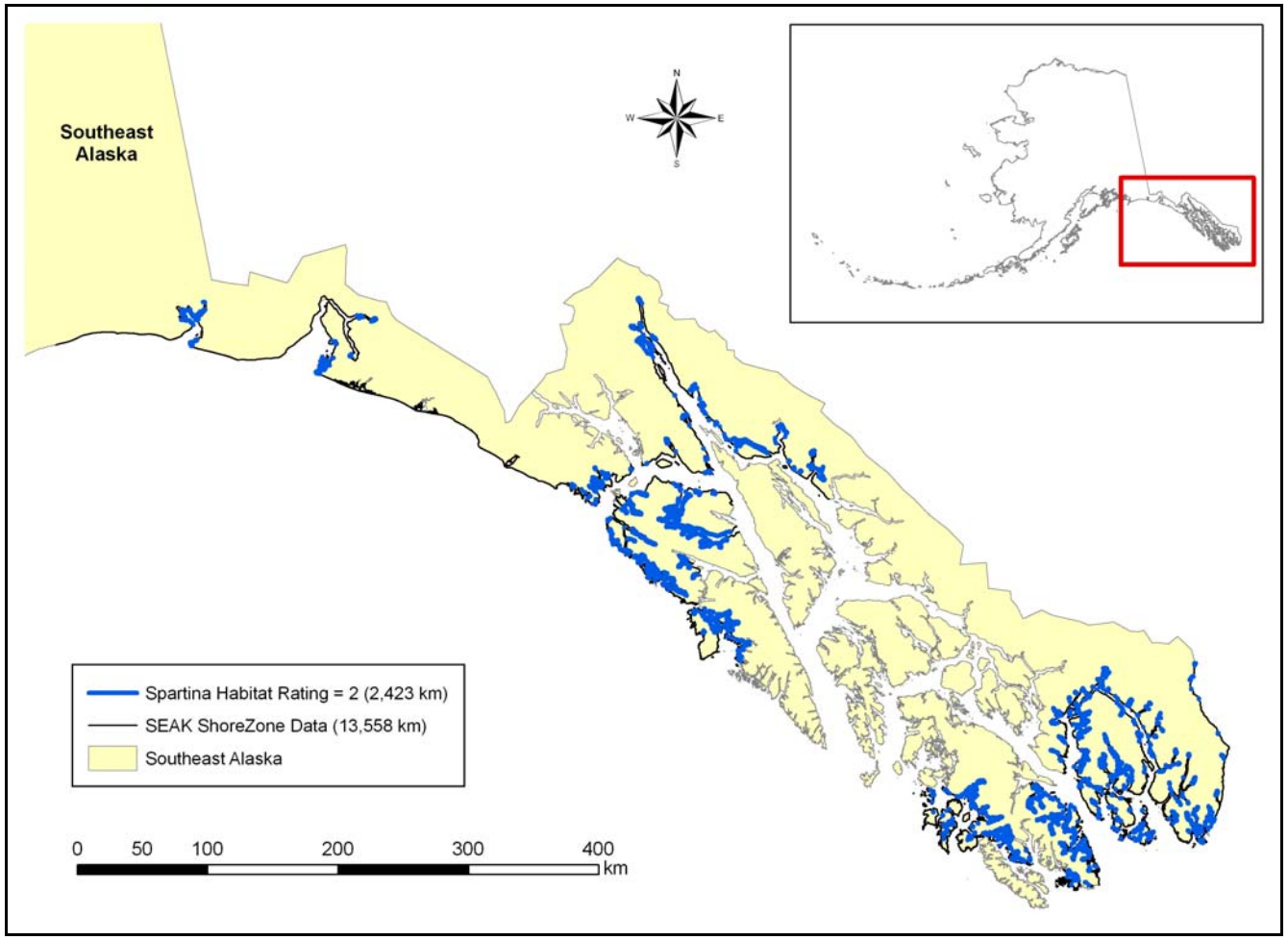


Figure 13. Results of nested queries of habitat attributes in Southeast Alaska. Shoreline units shown in blue have a *Spartina* habitat suitability rating of 2, meeting the criteria of very protected or protected wave exposure plus one other attribute, either sediment flats or estuaries. From a database of 13,558 km, approximately 18% of shorelines have a suitability rating of 2 (2,423 km).
[Shapefile: seak_rating2_exp_class2427282931_2423km.shp; Map: seak_rating2.jpg]

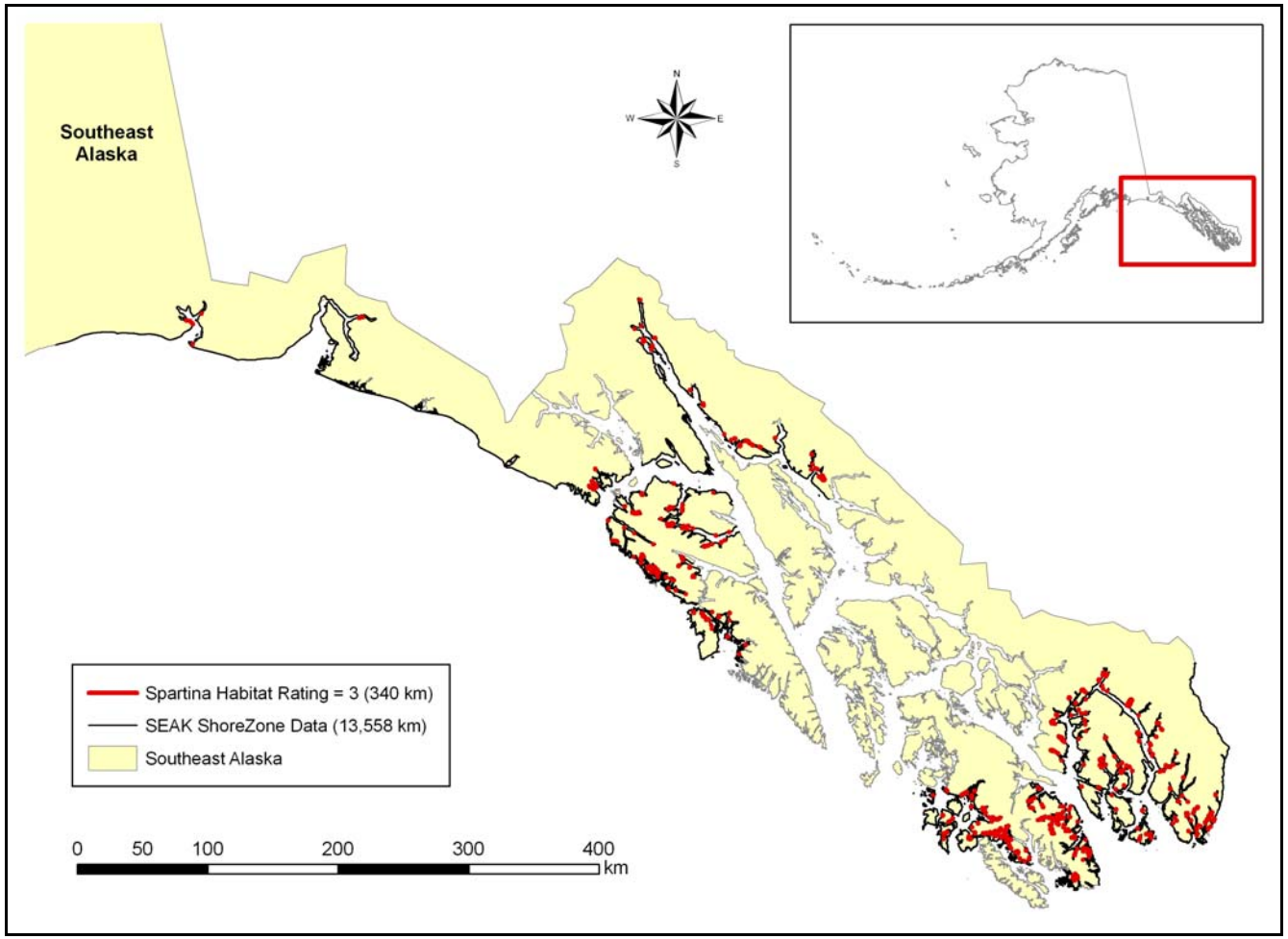


Figure 14. Results of nested queries of habitat attributes in Southeast Alaska. Shorelines shown in red have a *Spartina* habitat suitability rating of 3, meeting the criteria of very protected or protected wave exposure, as well as the presence of both sediment flats and estuaries. From a database of 13,558 km, approximately 3% of shorelines have a suitability rating of 3 (340 km).
[Shapefile: seak_rating3_exposure_flats_estuary_340km.shp; Map: seak_rating3.jpg]

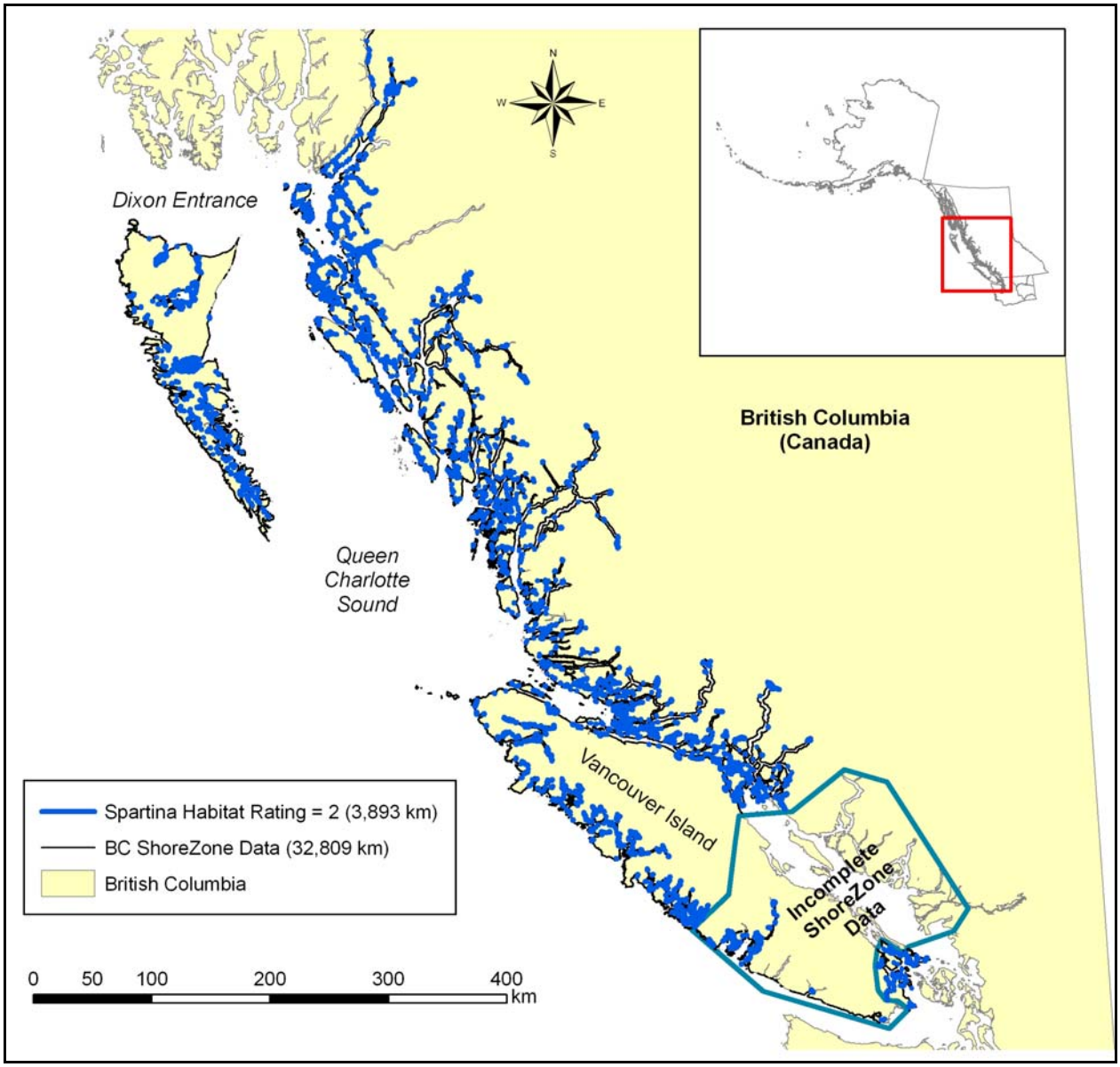


Figure 15. Results of nested queries of habitat attributes in British Columbia. Shorelines shown in blue have a *Spartina* habitat suitability rating of 2, meeting the criteria of very protected or protected wave exposure plus one other attribute, either sediment flats or estuaries. From a database of 32,809 km, approximately 12% of shorelines have a suitability rating of 2 (3,893 km).
[Shapefile bc_exp_class2427282931_3893km.shp; Map: bc_rating2.jpg]

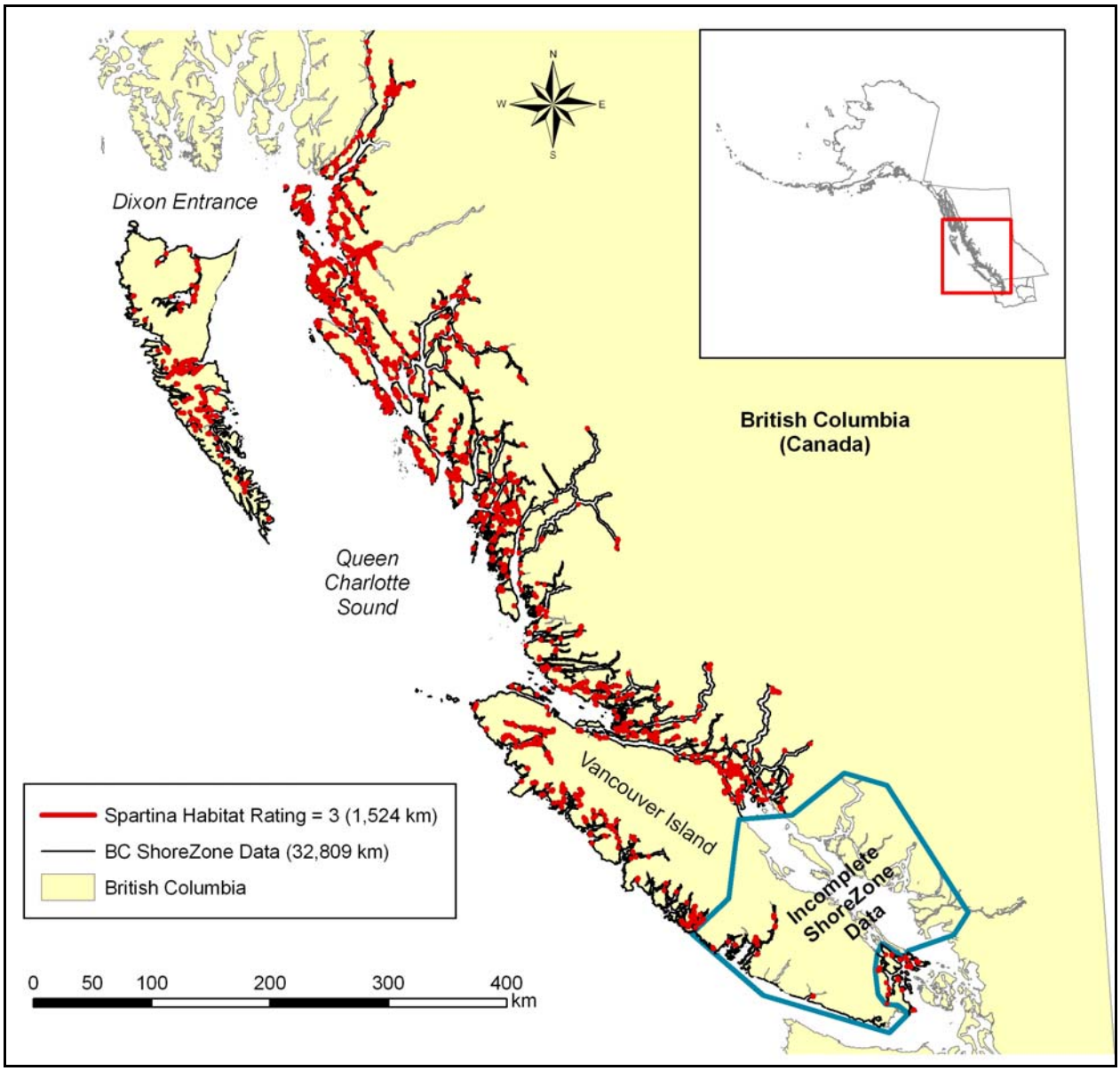


Figure 16. Results of nested queries of habitat attributes in British Columbia. Shorelines shown in red have a *Spartina* habitat suitability rating of 3, meeting the criteria of very protected or protected wave exposure, as well as the presence of both sediment flats and estuaries. From a database of 32,809 km, approximately 5% of shorelines have a suitability rating of 2 (1,524 km).
[Shapefile: bc_rating3_exposure_flats_estuary_1524km.shp; Map: bc_rating3.jpg]

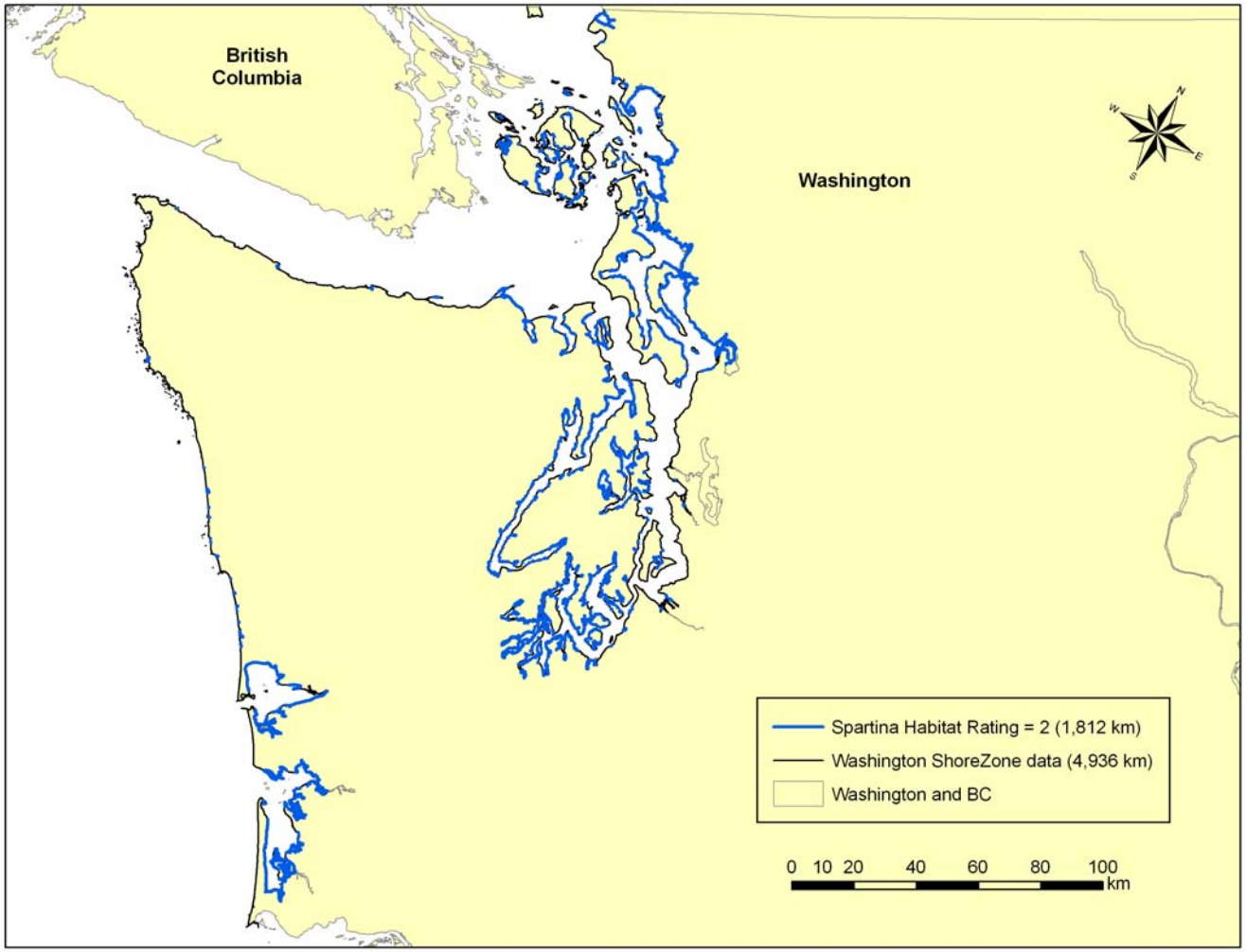


Figure 17. Results of nested queries of habitat attributes in Washington. Shorelines shown in blue have a *Spartina* habitat suitability rating of 2, meeting the criteria of very protected or protected wave exposure plus one other attribute, either sediment flats or estuaries. From a database of 4,936 km, approximately 37% of shorelines have a suitability rating of 2 (1,812 km). [Shapefile: wa_rating2_exp_class2427282931_1812km.shp; Map: wa_rating2.jpg]

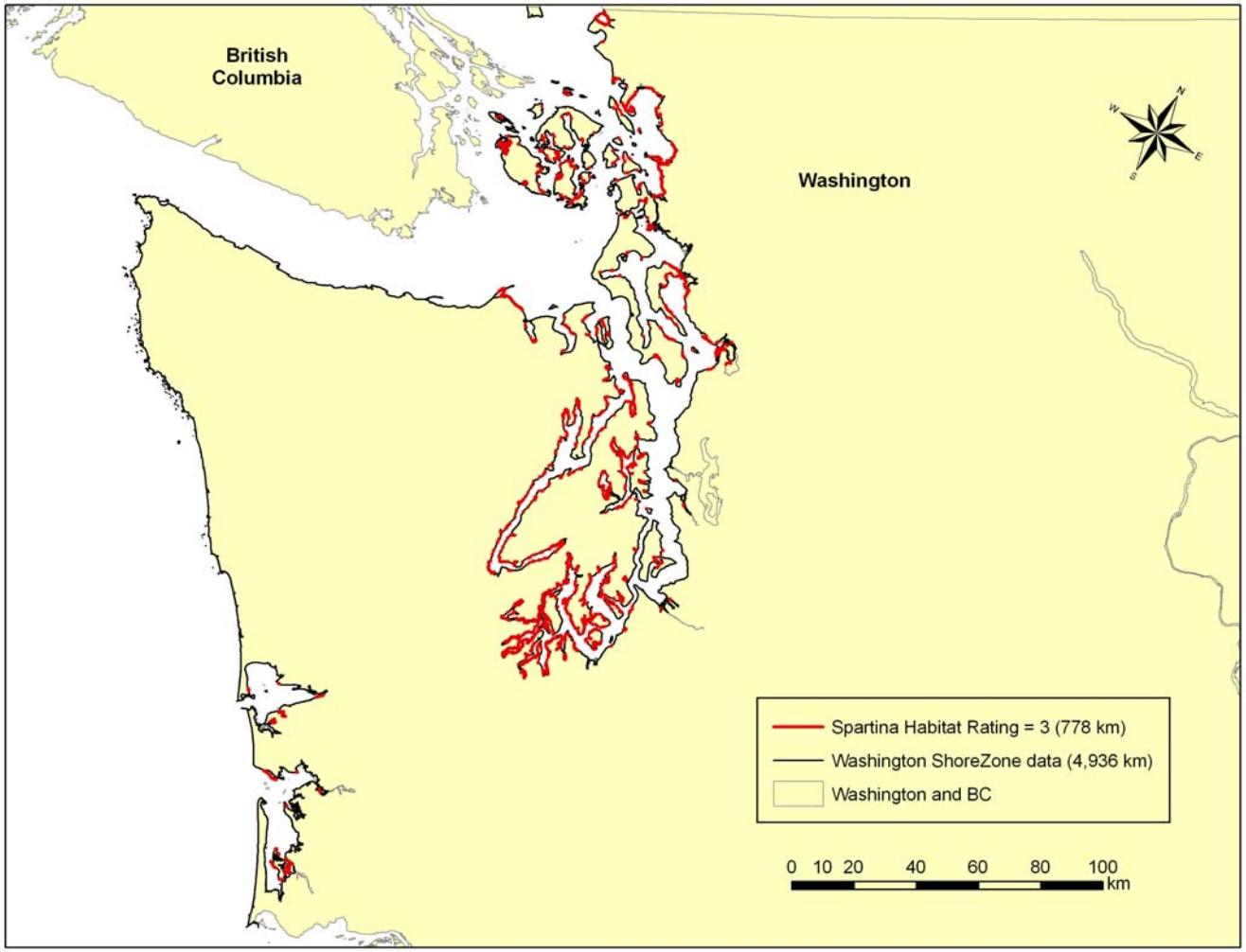


Figure 18. Results of nested queries of habitat attributes in Washington. Shorelines shown in red have a *Spartina* habitat suitability rating of 3, meeting the criteria of very protected or protected wave exposure, as well as the presence of both sediment flats and estuaries. From a database of 4,936 km, approximately 16% of shorelines have a suitability rating of 3 (778 km).
[Shapefile: wa_rating3_exposure_flats_estuary_778km.shp; Map: wa_rating3.jpg]

DISCUSSION

Suitable Habitat Attributes

Survey results demonstrated the importance of tidal elevation, shoreface slope, sediment texture, wave exposure, and estuarine environments for all species. Tidal elevation scored high for all species, placing the zone of potential *Spartina* colonization at the mid-to high-intertidal level. ShoreZone data is primarily focused on the intertidal zone, from the zero-meter tide level to the upper limit of the marine influence (supratidal), suggesting ShoreZone is a useful tool in the prediction of *Spartina* habitat suitability, particularly when dealing with large areas.

Analysis of attribute ratings established that flat, sediment-dominated shorelines were highly favorable for *Spartina* colonization. Habitat attribute ratings also suggested that wider intertidal zones may be more favorable for colonization, although a specific width was not a habitat requirement. Habitat suitability model queries developed in this study utilized along-shore unit classifications (BC Class) to identify estuaries and wide sediment flats. This approach was preferred because it could be applied in all three regional databases. While this approach established consistency between regional analyses, it resulted in the *exclusion* of some potentially-suitable habitats (such as mixed rock and sediment shorelines) and the *inclusion* of some marginal environments (such as deltas, which are often classified as wide sand flats).

Mixed rock and sediment classes (BC Classes 6-20) were not included in habitat suitability model queries developed in this study because, while some of these environments may be suitable for *Spartina* colonization (such as a wide pocket beach adjacent to a rock platform), the range of variability within these classes limited their prognostic use in this study. In the second case, survey results showed that wide sand flats were favorable habitat attributes, but deltas were not.

Wide sand and gravel flats (BC Class 24) were included in the habitat suitability model, but it should be noted that these settings may only be appropriate when all other suitable attributes are *also* present. That is, wide sand and gravel flats in very protected or protected areas that are *also* classified as estuaries represent highly-suitable *Spartina* habitat (rating = 3). The inference here is that wide flats in protected settings would have a veneer of coarser material (such as pebbles and cobbles) overlying sand and mud. The additional nested query for estuaries improves the favorability of this BC Class in low-energy environments.

To address these issues and to target tidal flats with particular widths and sediment characteristics, queries could be performed on the Alaska ShoreZone database that examine detailed across-shore data. This approach would enable the exclusion of deltaic units classified as wide sand flats, while including some mixed rock and sediment shorelines that meet specific width, slope, and texture criteria. This approach was not pursued in this study because most of British Columbia and Washington lack such data, and the general model was

constructed to apply to all three regions. Future studies in Southeast Alaska could build on the general model and pursue a greater level of detail.

Wave Exposure

Protected and very protected settings scored highest for all species. While data suggest that *Spartina alterniflora* may be tolerant of semi-protected (and even semi-exposed) conditions, no significant differences existed between wave exposure ratings nor between species (as shown by t-tests at the 95% confidence interval). The inclusion of semi-protected settings would expand predicted suitable habitat on the basis of wave energy to include 78% of mapped shorelines in BC and 82% in Alaska, reducing the model's ability to select the most highly-suitable habitat. Thus, only very protected (VP) and protected (P) wave exposures were considered suitable for *Spartina* in this study. As with the previous examples, targeted queries could be developed that address the analysis of semi-protected environments while attempting to exclude shore segments with unfavorable attributes. For example, nested queries of semi-protected environments that meet specific width, slope, and sediment texture characteristics could be performed on across-shore data in Southeast Alaska to identify potential habitats in more marginal environments. This approach could be modified for portions of the Washington state shoreline as well.

Estuaries

Recall that estuaries were identified using BC Class 31 for *individual* habitat attributes in each region. *Nested* queries of all three habitat attributes required a method of identifying estuaries by an attribute *other* than BC Class. That is, wide sediment flats were first selected on the basis of BC Class (24, 27, 28 , or 29). The nested model then sought to identify which of those units *also* possess estuarine environments. Because a unit can have only one BC Class assignment, another method of identifying estuaries was developed. In Southeast Alaska and Washington, an additional unit classification is assigned on the basis of observed biotic assemblages. This "habitat class" specifically identifies estuaries, whether or not they are also a BC Class 31 (shown in Tables 11 and 13). In British Columbia, this habitat class based on biotic observations has not been made publicly available by the province. A proxy for estuarine environments (the presence of salt marsh vegetation; Table 12) was used. While this is the best approach given the data constraints, it may result in the exclusion of some potential habitats in small estuaries or those lacking extensive supratidal salt marsh vegetation. The *Spartina* habitat suitability model produced in this study could be improved for British Columbia if the complete ShoreZone data set was released by the Province.

Interspecific Differences

Survey results suggested that *Spartina densiflora* and *Spartina* hybrids may have the ability to colonize a greater range of habitats, with a higher tolerance for changes in salinity or for the presence of other vegetation. However, because only one survey response was received for *Spartina densiflora* and two for *Spartina* spp. in general, conclusions could not be drawn, and neither group was considered to have habitat requirements that were distinct from *S. alterniflora* and *S. anglica*. While simple unpaired, two-tailed t-tests performed on habitat attribute ratings did not detect significant differences in habitat requirements between *Spartina* species, future studies with greater sample sizes could more rigorously test this observation.

Survey results indicated that the presence of anthropogenic features was not highly-favorable to colonization by any *Spartina* species, suggesting there may not be a direct relationship between potential propagule introduction through human activities and sites of colonization. Integrating the results of this study with an analysis of currents and potential seed dispersal pathways could identify the most likely sites for initial colonization on the basis of both delivery and establishment in suitable habitats. Similarly, the highly-suitable potential hotspots identified in this study may be useful as starting points for modeling future dispersal from intermediate populations.

Future Work

A similar habitat suitability model developed for the invasive green crab (*Carcinus maenas*) was evaluated using species occurrence data on western Vancouver Island (Harney 2007, 2008). Comparisons between known green crab occurrence locations and predictions of suitable habitat revealed that the ShoreZone-based model was capable of identifying highly-suitable potential habitats from thousands of kilometers of shoreline attribute data. While *Spartina* has not been observed in Alaska, several populations have been identified in British Columbia, including Vancouver and Boundary Bay (on the southern mainland) and in Baynes Sound and Comox (on eastern Vancouver Island) (Buffet 2005, Klinkenberg 2006) (Figure 19). Because these sites lie within the "incomplete data" area, effective evaluation of the habitat suitability model produced in this study would require access to data currently held by the Province of BC.

In Washington, *Spartina* has colonized extensive areas in Willapa Bay, Grays Harbor, Birch Bay, Turners Cove, Skagit Bay, Puget Sound, Hood Canal, and Triangle Cove (Camano Island). Tabular or spatial data on the distribution and extent of *Spartina* colonies in these areas could be integrated with the results of this study to evaluate habitat suitability model predictions.

As the ShoreZone coastal habitat mapping program continues in Alaska (Figure 20), the habitat suitability model developed in this study can be applied more extensively.

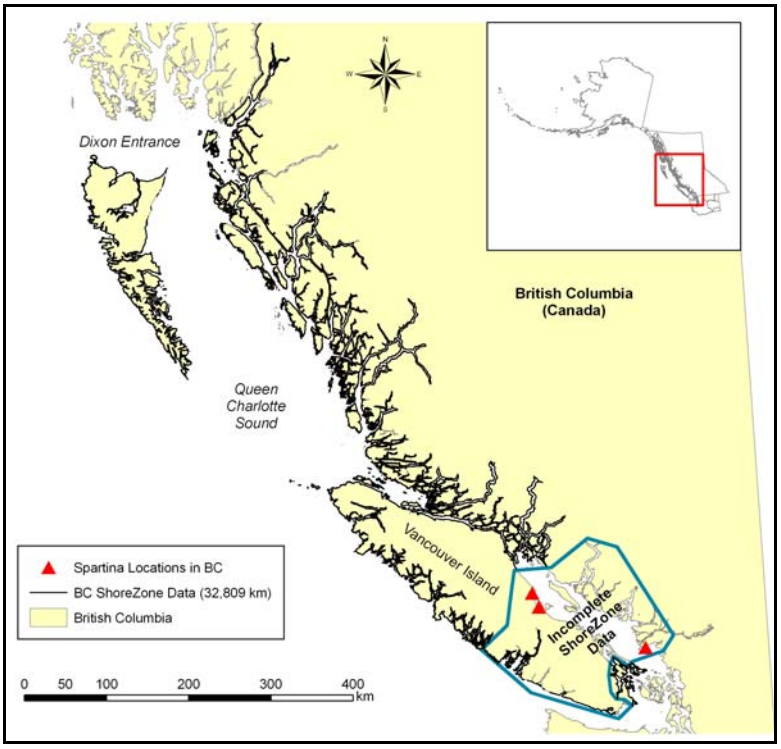


Figure 19. Location of known *Spartina* populations in coastal British Columbia.

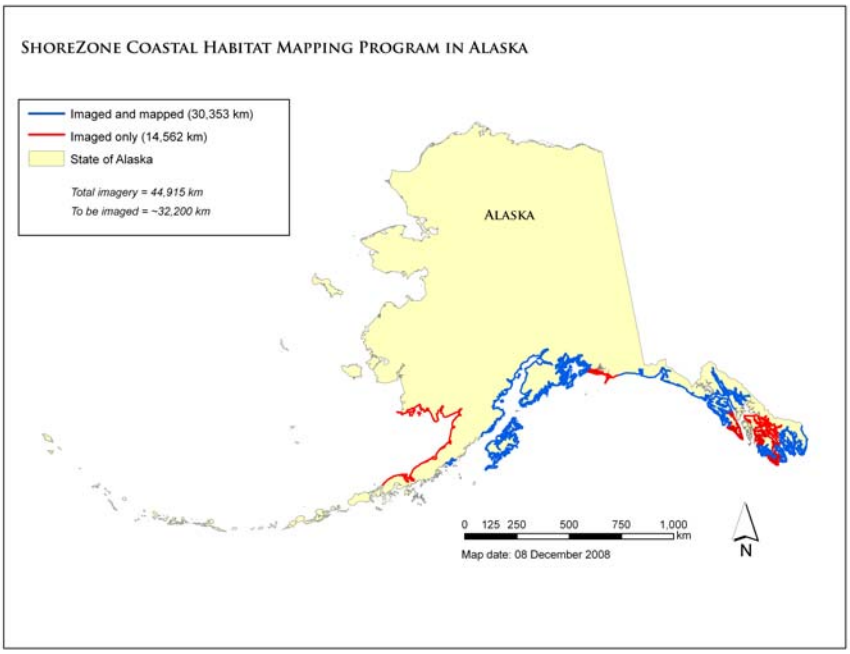


Figure 20. Status of ShoreZone Coastal Habitat Mapping Program in Alaska.

CONCLUSIONS

The most selective use of the *Spartina* habitat suitability model involved a fully-nested query of all critical habitat attributes:

- Very protected or protected wave exposure
- Wide, sediment-dominated flats
- Estuaries

Shorelines were rated with respect to habitat suitability on the basis of the number of critical habitat attributes that co-occurred with a single along-shore unit (0-3). The highest rating of 3 was assigned to along-shore units in which all three attributes co-occur, suggesting these locations are highly suitable *Spartina* habitat and potential "hot spots" for colonization.

In Southeast Alaska, a database of 13,558 km was examined. Of this, 340 km of shoreline (3%) was rated as highly-suitable *Spartina* habitat, possessing all three attributes. In British Columbia, 32,809 km of mapped shoreline data was examined. Of this, 1,524 km (5%) of shoreline was given the highest rating for *Spartina* habitat suitability. In Washington, 4,936 km of mapped shoreline data was examined. Of this, 778 km of shoreline (16%) possessed all three *Spartina* attributes.

While some studies suggests there are subtle differences in the preferred habitat of different *Spartina* species, average ratings for each habitat attribute formulated in this study were not statistically significant between *Spartina alterniflora* and *S. anglica*, the two species with the most individual ratings (t-tests at the 95% confidence interval).

Applications of suitable habitat predictions include site selection for monitoring and modeling efforts. Using the highest-rated site predictions generated by the ShoreZone model (rated 3 of 3), suitable *Spartina* habitat can be identified within the range of existing ShoreZone data in Alaska, British Columbia, and Washington.

The *Spartina* habitat suitability model produced in this study can be integrated with other types of spatial data from Southeast Alaska, British Columbia, and Washington. Individual and nested query results performed in ArcGIS were exported as separate shapefiles (*.shp files) and included in the Arc project file (*.mxd file). These shapefiles can be combined with other types of spatial and tabular data in the ArcGIS environment.

Upon completion of mapping of imagery collected in 2007 (SE07) and 2008 (SE08), this and other habitat suitability models may be applied to an additional 11,000 km of shoreline in Southeast Alaska. ShoreZone data also exists for most of the northern Gulf of Alaska from Yakutat to Bristol Bay.

REFERENCES

AKEPIC: Alaska Exotic Plant Information Clearinghouse Database Collaborator's Manual. 2005. 47 p. Available at: http://akweeds.uaa.alaska.edu.

Ayres, D. R., D. I. Zaremba, K. Klohr, and D. R. Strong. 2004. Spread of exotic cordgrasses and hybrids (Spartina sp.) in the tidal marshes of San Francisco Bay. Biological Invasions 6:221–231.

Berry, H.D., Harper, J.R., Mumford, T.F., Jr., Bookheim, B.E., Sewell, A.T., and Tamayo, L.J. 2004. Washington State ShoreZone Inventory User's Manual, Summary of Findings, and Data Dictionary. Reports prepared for the Washington State Dept. of Natural Resources Nearshore Habitat Program. Available online at: www.dnr.wa.gov/ ResearchScience/Topics/AquaticHabitats/Pages/aqr_nrsh_inventory_projects.aspx.

Buffett, D. 2005. Fraser River Delta Spartina Project (2004): Invasive Plant Management Proposal for *Spartina anglica* - English cordgrass management in Boundary Bay Wildlife Mgmt Area and surrounds, Spartina Project (#15). Report prepared for Ducks Unlimited Canada. 21 p.

Drake, J.A., H.A. Mooney, F. DiCastri, R.H Groves, F.J. Kruger, M. Rejmanek, and M. Williamson. 1989. Biological Invasion: A Global Perspective. John Wiley and Sons, Chichester UK. 550 p.

Feist, B.E., and Simenstad, C.A. 2000. Expansion rates and recruitment frequency of exotic smooth cordgrass, *Spartina alterniflora* (Loisel), colonizing unvegetated littoral flats in Willapa Bay, Washington. Estuaries 23:267-274.

Grosholz, E. D. 2002. Ecological and evolutionary consequences of coastal invasions. Trends in Ecology and Evolution 17:22–27.

Harney, J.N. 2007. ShoreZone Habitat Capability Modeling: A study of potential suitable habitat for the invasive European green crab (*Carcinus maenas*) in Southeast Alaska, British Columbia, and Washington State. Report prepared for NOAA National Marine Fisheries Service by Coastal and Ocean Resources Inc. 75 p. Available online at www.coastalandoceans.com/downloads.html.

Harney, J.N. 2008. Evaluation of a habitat suitability model for the invasive European green crab (*Carcinus maenas*) using species occurrence data from western Vancouver Island, British Columbia. Report prepared for NOAA National Marine Fisheries Service by Coastal and Ocean Resources Inc. 51 p. Available online at www.coastalandoceans.com/downloads.html.

Harney, J.N., Morris, M., and Harper, J.R. 2008. ShoreZone Coastal Habitat Mapping: Protocol for the Gulf of Alaska. 157 p. Available online at www.coastalandoceans.com/down-loads.html.

Harper, J.R., and Morris, M.C. 2004. ShoreZone Mapping Protocol for the Gulf of Alaska. Report prepared by Coastal and Ocean Resources Inc. for the Exxon Valdez Oil Spill Trustee Council (Anchorage, AK). 61 p.

Hedge, P., Kriwoken, L., and Patten, K. 2003. A review of *Spartina* management in Washington State. Journal of Aquatic Plant Management 41: 82-90.

Howes, D., Harper, J.R., and Owens, E.H. 1994. Physical Shore-Zone Mapping System for British Columbia. Report prepared by Environmental Emergency Services, Ministry of Environment (Victoria, BC), Coastal and Ocean Resources Inc. (Sidney, BC), and Owens

Coastal Consultants (Bainbridge, WA). Submitted to the Province of British Columbia, Resources Inventory Committee (RIC). 71 p. Available online at http://ilmbwww.gov.bc.ca/risc/pubs/coastal/pysshore/index.htm.

Klinkenberg, B. (ed.) 2006. E-Flora BC: Electronic Atlas of the Plants of British Columbia. Lab for Advanced Spatial Analysis, Department of Geography, University of British Columbia, Vancouver. Available at: http://www.eflora.bc.

Levin, L.A., Neira, C., and Grosholz, E.D. 2006. Invasive cordgrass modifies wetland trophic function. Ecology 87(2): 419-432.

Neira, C., E.D. Grosholz, L.A. Levin, and R. Blake. 2006. Mechanisms generating modification of benthos following tidal flat invasion by a *Spartina* hybrid. Ecological Applications 16:1391-1404.

Phillips, C.H., Anderson, K.D., and Ketel, K.O. 2008. Progress of the 2007 Spartina Eradication Program. Report prepared by the Washington State Dept. of Agriculture. 52 p.

Vitousek, P.M., H.A. Mooney, J. Lubchenco, and J.M. Melillo. 1997. Human domination of Earth's ecosystems. Science 277:494-499.

WSDA: Washington State Department of Agriculture Legislative Report 2007. 52 p. Available at: http://agr.wa.gov/PlantsInsects/Weeds/Spartina/docs/LegReport 2007.pdf.

Zuboy, J.R. 1981. A new tool for fishery managers: the Delphi technique. North Am. J. Fish. Mgmt. 1:55-59.

ACKNOWLEDGMENTS

Model development and application was dependent on the contributions and expertise of many individuals, including: Megan Dethier, Blake Feist, and Mary Morris. We thank the Alaska Department of Fish and Game for their support of this study.

The ShoreZone Coastal Habitat Mapping Program is a partnership of scientists, GIS specialists, web specialists, nonprofit organizations, and governmental agencies. The multi-agency program offers the opportunity to build a contiguous, integrated coastal resource database that extends from the mouth of the Columbia River, through BC, the Gulf of Alaska, Bristol Bay, and northwards to the Arctic coast (on the order of 100,000 km). We thank the program partners for their continued support.

APPENDIX A

Spartina Habitat Suitability Survey

In addition to a literature search, the following questionnaire was used to gather information regarding *Spartina* habitat characteristics. The survey was posted online at SurveyMonkey.com. Experts were identified during literature review and invited to participate. Four responses each were received for *S. alterniflora* and *S. anglica*; one response each was received for *S. densiflora* and *Spartina* spp. in general (or hybrids). No responses were received for *S. patens*. Survey participants had the option of not answering questions, or parts of questions, thus the sample size was not the same for every attribute or for every species.

Spartina Habitat Suitability Survey (June 2008)

1. Introduction

The purpose of this survey is to ask experts to rate the relative favorability of various habitat characteristics in the life requisites of the invasive salt marsh cordgrass (genus Spartina) in the Pacific Northwest. Responses will be used to construct a habitat suitability model on the basis of attributes mapped in the ShoreZone Coastal Habitat Database for Washington, British Columbia, and Southeast Alaska.

In our usage, “habitat” is a spatial entity that possesses physical and biological attributes that support particular organisms or communities. An analysis of oceanographic factors is not included in this study, thus it is assumed that regional environmental variables are within the tolerable range of the plant and its seeds. The questions refer to the attributes present what would influence the establishment of Spartina once the plant or its seeds is introduced to the area.

There are 10 questions in this survey. The first asks to which species of Spartina your responses pertain (alterniflora, anglica, patens, densiflora, or Spartina sp. in general). Please complete the survey more than once if you are knowledgable of more than one species.

The rating system is identical for each question, in which the highest number (4) represents the most favorable habitat characteristics, and the lowest number (1) indicates the least favorable (or unfavorable) characteristics. Answers are not required, but you can choose "0 No comment" if you don't have an opinion. Zero values will not be used in the final habitat attribute ratings. You can go back and edit your answers using the “Previous” button at the bottom of each page.

Write in comments as needed. This survey is intended to be iterative and will benefit from your suggestions and feedback.

If you have questions about the survey or the procedures, please contact:
Dr. Jodi Harney
Coastal and Ocean Resources
ph: 250-655-4035
e: jodi@coastalandoceans.com

To learn more about the ShoreZone Coastal Habitat Mapping program, please visit the Coastal and Ocean Resources web site at www.coastalandoceans.com.

Thank you very much for your time. You will be acknowledged as a participant.

Spartina Habitat Suitability Survey (June 2008)

2. Contact Information

1. Please enter your contact information (name, email, and affiliation).

Spartina Habitat Suitability Survey (June 2008)

3. Spartina habitat attribute ratings

1. To what Spartina species do your reponses pertain? You may choose more than one species if you feel the habitat requirements are the same. Please complete the survey more than once if you have knowledge of more than one species.

- ☐ Spartina sp. in general
- ☐ Spartina alterniflora
- ☐ Spartina anglica
- ☐ Spartina patens
- ☐ Spartina densiflora

Comment

2. How favorable are these general levels of wave and current exposure with respect to potential Spartina habitat?

	4 Critical	3 Highly favorable	2 Somewhat favorable	1 Unfavorable	0 No comment
Very protected	○	○	○	○	○
Protected	○	○	○	○	○
Semi-protected	○	○	○	○	○
Semi-exposed	○	○	○	○	○
Exposed	○	○	○	○	○

Comment:

3. How favorable are each of the following geomorphic features in the colonization success of Spartina?

	4 Critical	3 Highly favorable	2 Somewhat favorable	1 Unfavorable	0 No comment
Current-dominated channel	○	○	○	○	○
Delta	○	○	○	○	○
Estuary	○	○	○	○	○
Mud flats (bare)	○	○	○	○	○
Mud flats (vegetated)	○	○	○	○	○
River or stream influence	○	○	○	○	○
Sand beach	○	○	○	○	○
Sand flats (bare)	○	○	○	○	○
Sand flats (vegetated)	○	○	○	○	○
Supratidal berm	○	○	○	○	○

Comment:

4. How favorable is sediment texture (grain size) in the colonization success of Spartina?

	4 Critical	3 Highly favorable	2 Somewhat favorable	1 Unfavorable	0 No comment
Mud (<63 um)	○	○	○	○	○
Fine sand (63 um - 0.5 mm)	○	○	○	○	○
Medium/coarse sand (0.5-2 mm)	○	○	○	○	○
Granules/pebbles (2 mm - 6 cm)	○	○	○	○	○
Cobbles (6-25 cm)	○	○	○	○	○
Boulders (>25 cm)	○	○	○	○	○

Comment:

Spartina Habitat Suitability Survey (June 2008)

5. How favorable is shoreface slope in the establishment of Spartina?

	4 Critical	3 Highly favorable	2 Somewhat favorable	1 Unfavorable	0 No comment
Flats (<= 5 degrees)	○	○	○	○	○
Inclined slopes (5-19 degrees)	○	○	○	○	○
Steep slopes (>= 20 degrees)	○	○	○	○	○

Comment:

6. How favorable is shoreface width in the establishment of Spartina?

	4 Critical	3 Highly favorable	2 Somewhat favorable	1 Unfavorable	0 No comment
<30 m	○	○	○	○	○
31-50 m	○	○	○	○	○
>50 m	○	○	○	○	○

Comment:

7. How favorable is the presence of supratidal vegetation in the colonization success of Spartina? Please mark one response for each row/group.

	4 Critical	3 Highly favorable	2 Somewhat favorable	1 Unfavorable	0 No comment
Dune grass (e.g. Leymus mollis, syn. Elymus mollis)	○	○	○	○	○
Marsh grasses, herbs, and sedges (e.g. Puccinellia, Triglochin, Salicornia)	○	○	○	○	○
Sedges (e.g. Carex, Eleocharis)	○	○	○	○	○

Comment:

Spartina Habitat Suitability Survey (June 2008)

8. In general, how favorable is salinity in the establishment of Spartina?

	4 Critical	3 Highly favorable	2 Somewhat favorable	1 Unfavorable	0 No comment
Fresh water	○	○	○	○	◉
Brackish	○	○	○	○	○
Sea water	○	○	○	○	○
Hypersaline	○	○	○	○	○

Comment:

9. How favorable is the presence of these anthropogenic features in the establishment of Spartina?

	4 Critical	3 Highly favorable	2 Somewhat favorable	1 Unfavorable	0 No comment
Ferry or shipping terminal	○	○	○	○	○
Marina	○	○	○	○	○
Fill	○	○	○	○	○
Aquaculture site	○	○	○	○	○

Comment:

10. Are there other coastal habitat characteristics that would be highly favorable (or unfavorable) to Spartina colonization that have not been mentioned in this survey?

4. Thank You

1. Please provide additional comments and suggestions here. If there are others you feel would be interested in participating in this Spartina habitat suitability survey, include their names and email addresses.

Please complete the survey again if you have knowledge of more than one species of Spartina.

Thank you for your time and participation!

APPENDIX B

Digital Files

Accessible ShoreZone data and GIS shapefiles created in this study are provided on a Data DVD with this report (summarized in Table B-1).

Table B-1. Summary of digital files included with this report. All shapefiles are in NAD83 datum, BC Albers projection.

SE Alaska ShoreZone	km	Description	Shapefile	Jpg
SEAK ShoreZone (project)	--	ArcGIS project that houses all shapefiles, data, and maps	spartina_seak_habitat_model.mxd	--
Alaska shoreline polygon	--	Basemap for display only; distinguishes land from water	ak_coast63poly_anad83.shp	--
SEAK ShoreZone 2004-2006 data	13,557.9	Mapped shoreline in SE Alaska (from 2004-2006 projects)	se04_05_06_unit_lines_oct08.shp	seak_shorezone_data_oct08.jpg
SEAK Results: Single Attribute	**km**	**Description**	**Shapefile**	**Jpg**
Exposure (VP, P)	5,874.5	BioExpObs = very protected or protected	seak_exposure_vp_p_5875km.shp	seak_exposure_vp_p.jpg
Mud Flats	109.8	BC_Class = 29	seak_class29_mudflats_110km.shp	{
Sand Flats (including wide sand beaches, excluding	562.6	BC_Class = 27 or 28	seak_class2728_sand_flats_563km.shp	{ seak_mud_sand_sndgrvl_flats.jpg
Sand and Gravel Flats (wide)	1,626.9	BC_Class = 24	seak_class24_sandgravel_flats_1627km.shp	{
Estuaries	2,001.9	BC_Class = 31	seak_class31_estuaries_2002km.shp	seak_estuaries.jpg
SEAK Results: Nested Attributes	**km**	**Description**	**Shapefile**	**Jpg**
Spartina Habitat Rating = 2	2,423.2	VP or P flats (classes 24, 27, 28, 29) or estuary (class 31)	seak_rating2_exp_class2427282931_2423km.shp	seak_rating2.jpg
Spartina Habitat Rating = 3	340.2	VP or P + flats (classes 24, 27-29) + HAB_CLASS = P_E or VP_E	seak_rating3_exposure_flats_estuary_340km.shp	seak_rating3.jpg
BC ShoreZone	**km**	**Description**	**Shapefile**	**Jpg**
BC ShoreZone (project)	--	ArcGIS project that houses all shapefiles, data, and maps	spartina_bc_habitat_model.mxd	--
BC, AK, WA shoreline polygon	--	Basemap for display only; distinguishes land from water	ak_bc_wash_bcalbers.shp	--
BC shoreline polygon	--	Basemap for display only; distinguishes land from water	CHS_highwaterpoly_BCAlbers	--
BC ShoreZone "incomplete" polygon	--	Shows areas in BC lacking complete across-shore and bioband data	incomplete_sz_polygon.shp	--
BC ShoreZone data extent	32,809.2	Mapped shoreline data in BC (includes some areas of "incomplete data")	bc_shorezone_data_sep08.shp	bc_shorezone_data_sep08.jpg
BC Results: Single Attribute	**km**	**Description**	**Shapefile**	**Jpg**
Exposure (VP, P)	14,875.9	BioExpObs = very protected or protected	bc_exposure_vp_p_14876km.shp	bc_exposure_vp_p.jpg
Mud Flats	159.8	BC_Class = 29	bc_class29_mudflats_160km.shp	{
Sand Flats (including wide sand beaches, excluding	1,906.6	BC_Class = 27 or 28	bc_class2728_sand_flats_1907km.shp	{ bc_mud_sand_sndgrvl_flats.jpg
Sand and Gravel Flats (wide)	1,768.5	BC_Class = 24	bc_class24_sandgravel_flats_1769km.shp	{
Estuaries	1,592.3	BC_Class = 31	bc_class31_estuaries_1592km.shp	bc_estuaries.jpg
BC Results: Nested Attributes	**km**	**Description**	**Shapefile**	**Jpg**
Spartina Habitat Rating = 2	3,893.3	VP or P flats (classes 24, 27, 28, 29) or estuary (class 31)	bc_rating2_exp_class2427282931_3893km.shp	bc_rating2.jpg
Spartina Habitat Rating = 3	1,523.9	VP or P + flats (classes 24, 27, 28, 29) + SAL = P or C	bc_rating3_exposure_flats_estuary_1524km.shp	bc_rating3.jpg
WA ShoreZone	**km**	**Description**	**Shapefile**	**Jpg**
WA ShoreZone (project)	--	ArcGIS project that houses all shapefiles, data, and maps	spartina_wa_habitat_model.mxd	--
WA, BC, AK shoreline polygon	--	Basemap for display only; distinguishes land from water	ak_bc_wash_bcalbers.shp	--
WA ShoreZone data	4,935.7	Mapped shoreline in Washington	wa_shorezone_data_sep08.shp	wa_shorezone_data_sep08.jpg
WA Results: Single Attribute	**km**	**Description**	**Shapefile**	**Jpg**
Exposure (VP, P)	3,242.3	Exp_Class = very protected or protected	wa_exposure_vp_p_3242km.shp	wa_exposure_vp_p.jpg
Mud Flats	301.7	BC_Class = 29	wa_class29_mudflats_302km.shp	{
Sand Flats (including wide sand beaches, excluding	870.6	BC_Class = 27 or 28	wa_class2728_sand_flats_871km.shp	{ wa_mud_sand_sndgrvl_flats.jpg
Sand and Gravel Flats (wide)	399.3	BC_Class = 24	wa_class24_sandgravel_flats_399km.shp	{
Estuaries	869.6	BC_Class = 31	wa_class31_estuaries_870km.shp	wa_estuaries.jpg
WA Results: Nested Attributes	**km**	**Description**	**Shapefile**	**Jpg**
Spartina Habitat Rating = 2	1,811.7	VP or P + flats (classes 24, 27, 28, 29) or estuary (class 31)	wa_rating2_exp_class2427282931_1812km.shp	wa_rating2.jpg
Spartina Habitat Rating = 3	777.8	VP or P + flats (classes 24, 27, 28, 29) + HAB_CALC=8	wa_rating3_exposure_flats_estuary_778km.shp	wa_rating3.jpg

Table B-2. Classification of shore types employed in ShoreZone mapping (derived from the Howes et al. [1994] "BC Class" system in British Columbia)

SUBSTRATE	SEDIMENT	WIDTH	SLOPE	COASTAL CLASS	NO.
ROCK	N/A	WIDE (>30 m)	STEEP (>20°)	n/a	
			INCLINED (5-20°)	Rock Ramp, wide	1
			FLAT (<5°)	Rock Platform, wide	2
		NARROW (<30 m)	STEEP (>20°)	Rock Cliff	3
			INCLINED (5-20°)	Rock Ramp, narrow	4
			FLAT(<5°)	Rock Platform, narrow	5
ROCK & SEDIMENT	GRAVEL	WIDE (>30 m)	STEEP (>20°)	n/a	
			INCLINED (5-20°)	Ramp with gravel beach, wide	6
			FLAT (<5°)	Platform with gravel beach, wide	7
		NARROW (<30 m)	STEEP (>20°)	Cliff with gravel beach	8
			INCLINED (5-20°)	Ramp with gravel beach	9
			FLAT (<5°)	Platform with gravel beach	10
	SAND & GRAVEL	WIDE (>30 m)	STEEP (>20°)	n/a	
			INCLINED (5-20°)	Ramp w gravel & sand beach, wide	11
			FLAT (<5°)	Platform with G&S beach, wide	12
		NARROW (<30 m)	STEEP (>20°)	Cliff with gravel/sand beach	13
			INCLINED (5-20°)	Ramp with gravel/sand beach	14
			FLAT (<5°)	Platform with gravel/sand beach	15
	SAND	WIDE (>30 m)	STEEP (>20°)	n/a	
			INCLINED (5-20°)	Ramp with sand beach, wide	16
			FLAT (<5°)	Platform with sand beach, wide	17
		NARROW (<30 m)	STEEP (>20°)	Cliff with sand beach	18
			INCLINED (5-20°)	Ramp with sand beach, narrow	19
			FLAT (<5°)	Platform with sand beach, narrow	20
SEDIMENT	GRAVEL	WIDE (>30 m)	FLAT (<5°)	Gravel flat, wide	21
		NARROW (<30 m)	STEEP (>20°)	n/a	
			INCLINED (5-20°)	Gravel beach, narrow	22
			FLAT (<5°)	Gravel flat or fan	23
	SAND & GRAVEL	WIDE (>30 m)	STEEP (>20°)	n/a	
			INCLINED (5-20°)	n/a	
			FLAT (<5°)	Sand & gravel flat or fan	24
		NARROW (<30 m)	STEEP >20°)	n/a	
			INCLINED (5-20°)	Sand & gravel beach, narrow	25
			FLAT (<5°)	Sand & gravel flat or fan	26
	SAND / MUD	WIDE (>30m)	STEEP (>20°)	n/a	
			INCLINED (5-20°)	Sand beach	27
			FLAT (<5°)	Sand flat	28
			FLAT (<5°)	Mudflat	29
		NARROW (<30m)	STEEP (>20°)	n/a	
			INCLINED (5-20°)	Sand beach	30
			FLAT (<5°)	n/a	n/a
	ORGANICS	n/a	n/a	Estuaries	31
ANTHRO-POGENIC	Man-made	n/a	n/a	Man-made, permeable	32
			n/a	Man-made, impermeable	33
CHANNEL	Current	n/a	n/a	Channel	34
GLACIER	Ice	n/a	n/a	Glacier	35