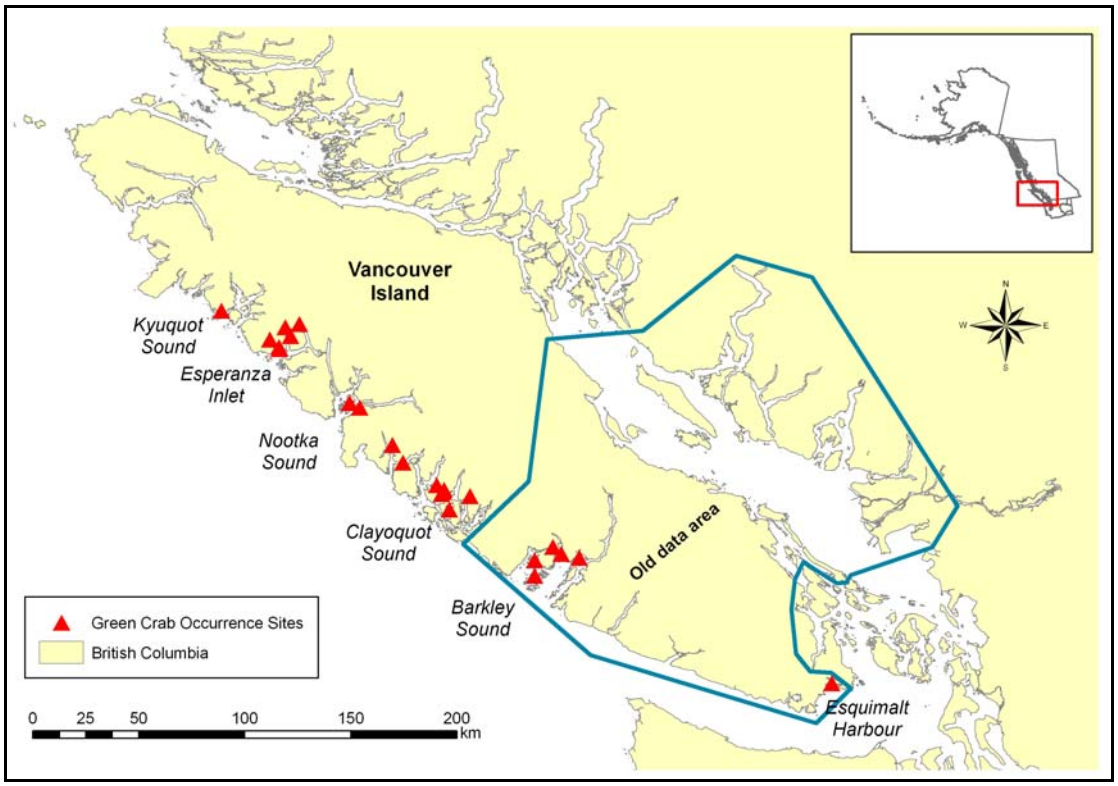
CORI Project: 2008-11 **14 July 2008**

Evaluation of a Habitat Suitability Model for the Invasive European Green Crab (*Carcinus maenas*) Using Species Occurrence Data from Western Vancouver Island, British Columbia



Prepared for:
NOAA National Marine Fisheries Service
Juneau, Alaska

Prepared by:
Jodi Harney, Ph.D.

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

SUMMARY

A habitat suitability model constructed for the European green crab (*Carcinus maenas*) identifies potentially suitable habitats for the invasive species in coastal Alaska, British Columbia, and Washington on the basis of "critical" habitat attributes that are mapped in the ShoreZone database (Harney 2007). ShoreZone data consist of along-shore coastal units and across-shore components, into which are mapped the geomorphic and biologic features of the shoreline. A full protocol of the ShoreZone mapping technique (Harney et al. 2007) is available online at www.coastalandoceans.com.

In the habitat suitability model, nested queries of the ShoreZone database identify shoreline units possessing one or more habitat attributes that are critical to green crab colonization: protected or semi-protected wave exposure, mud or sand flats in the intertidal, eelgrass in the subtidal, and salt marsh vegetation in the supratidal. Each along-shore coastal unit is rated (0-4) with respect to habitat suitability for the green crab on the basis of the number of critical habitat attributes that co-occur within a single along-shore unit. In this manner, highly-suitable habitat sites, on the order of tens to hundreds of meters in shoreline length, are identified from more than 50,000 km of coastal attribute data in Washington, British Columbia, and Southeast Alaska. The full habitat suitability modeling report (Harney 2007) is available online at www.coastalandoceans.com.

While green crabs have not yet been observed in Southeast Alaska, the species is documented on the west coast of Vancouver Island (Gillespie et al. 2007). A total of 21 sites on western Vancouver Island possess both green crab occurrence data and ShoreZone coastal habitat attribute data. Of these, 15 sites possess complete physical and biological ShoreZone attributes and are compared to model predictions with respect to all four critical habitat attributes. With respect to the individual habitat attributes at each of these 15 sites:

- Protected (P) or Semi-Protected (SP) wave exposure categories are mapped at all 15 sites (100%).
- Sand or mud flats are mapped in 7 of the 15 sites (47%).
- Eelgrass is mapped in 7 of the 15 sites (47%).
- Salt marsh vegetation is mapped in the supratidal zone of 10 of the 15 sites (67%).

Of the 15 sites, all but one possess at least two of the four critical habitat attributes (wave exposure and one other attribute), earning a habitat model rating of 2 or better. Three sites (Little Espinosa Inlet, Warn Bay, and Pretty Girl Cove) have a habitat rating of 3. In each case of these cases, eelgrass is the missing attribute. Four sites (Cypress Bay, Whitepine Cove, Mooyah Bay, and Zeballos) have a habitat rating of 4, possessing all four attributes in the same location.

Five of the 21 green crab occurrence locations sites (all in Barkley Sound) lack complete ShoreZone data and are more difficult to compare to model predictions, owing to the variable number of mapped attributes available at each site. These sites possess only one or two of the four critical habitat attributes.

Comparisons between known green crab occurrence locations and predictions of suitable habitat reveal that the ShoreZone-based model is capable of identifying highly-suitable potential habitats from thousands of kilometers of shoreline attribute data. It should be noted that multiple nested

queries identify the highest-rated sites but may exclude some suitable potential habitats. This study clarifies some aspects of the habitat suitability model that may be adjusted to avoid such exclusions and to improve the accuracy of predictions.

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 4 of 4), suitable green crab habitat can be identified within the range of existing ShoreZone data in British Columbia and Southeast Alaska. Twelve example sites of highly-suitable green crab habitat (of 615 along-shore units with a rating of 4 identified by the model) are shown in Appendix A. ShoreZone data also extend

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INTRODUCTION

The land-sea interface is a crucial realm for terrestrial and marine organisms, human activities, and dynamic processes. ShoreZone is a mapping and classification system that specializes in the collection and interpretation of aerial imagery of the intertidal zone and nearshore environment. Its objective is to produce an integrated, searchable inventory of physical and biological features which can be used as a tool for science, education, management, and environmental hazard planning.

A "habitat suitability" model constructed for the European green crab (*Carcinus maenas*) identifies potentially suitable habitats for the invasive species in coastal Alaska, British Columbia, and Washington on the basis of physical, geomorphic, and biological shoreline attributes mapped in the ShoreZone Coastal Habitat Mapping Database (Harney 2007; report available for download at www.coastalandoceans.com). The model is based on the rationale that successful green crab colonization in the coastal zone is related to habitat attributes that can be distinguished and rated in terms of their importance in the crab's life-history strategy. "Critical" habitat attributes are identified through a process of literature review and expert interviews (the "delphi" approach; Busch and Lary 1996, Demarchi et al. 1999, Zuboy 1981). Four habitat attributes that are identified as critical are also features in the ShoreZone Coastal Habitat Mapping database. These attributes can be queried and plotted spatially to predict the location of potential green crab habitat:

- Protected or semi-protected wave exposures
- Sand or mud flats (fine sediment in the lower intertidal)
- Eelgrass in the lower intertidal or shallow subtidal
- Salt marsh vegetation in the supratidal zone.

It is important to note that an analysis of oceanographic and biotic factors (such as water temperature, salinity, and currents) affecting the dispersal and colonization of the green crab is beyond the scope of this study. This work assumes that regional environmental variables are within the tolerable range of the organism. This assumption is generally validated by the documented occurrence of *Carcinus maenas* in the Pacific Northwest and British Columbia (Behrens Yamada 2005, Gillespie et al. 2007). Recent laboratory experiments and oceanographic models also suggest that ocean surface temperature and salinity are within the habitable range of the green crab, permitting its northward dispersal (Hines et al. 2004; de Rivera et al. 2006).

Nested queries of the ShoreZone database for British Columbia (housed in ArcView GIS) identify shoreline "units" in which the critical habitat attributes listed are mapped (Figures 1 and 2; Harney 2007). Shorelines are then rated with respect to habitat suitability on the basis of the number of critical habitat attributes that co-occur with a single along-shore unit (0-4). Shorelines with habitat rating of 2 possess two attributes in a single along-shore unit (wave exposure and sand or mud flats; Figure 3). Shorelines with a habitat rating of 3 possess three of the four critical attributes within a single unit (Figures 4 and 5). The highest rating of 4 is assigned to shoreline units in which all four attributes co-occur, suggesting these locations are highly suitable green crab habitat and potential "hot spots" for colonization. In BC, a total of 434 km of shoreline are classified with this highest habitat suitability rating (from a database of 37,605 km; Figure 6).

Purpose

While green crabs have not yet been observed in Southeast Alaska, the species is documented on the west coast of Vancouver Island (Gillespie et al. 2007), offering the opportunity to test the habitat suitability model predictions for British Columbia with known locations of green crab occurrence. The purpose of this report is to examine habitat attributes mapped in the BC ShoreZone database at these locations, to evaluate if the model predicts the sites as suitable habitat, and to identify improvements to the model.

Data Accessibility

Unlike in Alaska and Washington, most BC ShoreZone data have not been widely distributed by the Integrated Land Management Branch of the Provincial government. For these and other reasons, a data summary report and aerial imagery for British Columbia is not accessible. Other issues of data accessibility include:

1. The Strait of Georgia and other areas of southern BC and Vancouver Island fall into the "old data area" shown on some of the following maps. This data was compiled in the early 1980s, is either incomplete or inaccessible, and is not fully available for model testing.
2. Prior to 1992, biological data were not collected 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 is not comparable to post-1992 data.
3. The BC ShoreZone database is housed entirely in ArcView GIS rather than in MS Access 2000. Querying and model comparisons are thus performed in this software platform only.

For more information regarding the ShoreZone Coastal Habitat Mapping Program in Washington, BC, and Alaska, please visit www.coastalandoceans.com/shorezone.html or www.CoastAlaska.net. The ShoreZone Coastal Habitat Mapping Protocol for Southeast Alaska (Harney et al. 2007) and various data summary reports are available for download at these sites. Thousands of kilometers of ShoreZone imagery and data in Alaska can be viewed and downloaded online at www.alaskafisheries.noaa.gov/maps/szintro.htm.

Digital Files

Accessible ShoreZone data and GIS shapefiles created in this study are provided on a Data DVD with this report. Please see Appendix B for a summary.

METHODS

Green crab occurrence data for western Vancouver Island (British Columbia) are summarized in Gillespie et al. (2007), including: location and collection data from public reports of green crab observations compiled between 1999 and 2006 (Table 1 in Gillespie et al. 2007); green crab trap survey data collected between May and September of 2006 (Tables 4 and 5 in Gillespie et al. 2007); and intertidal NIS data from green crab surveys conducted between May and July 2006 (Table 7 in Gillespie et al. 2007). These green crab occurrence locations are plotted in ArcView GIS, along with ShoreZone coastal habitat attribute data layers.

Green crab occurrence sites (point data) from the Gillespie et al. (2007) report are matched with the appropriate along-shore coastal habitat attribute information mapped in ShoreZone (line data). In some cases, the precise location of green crab occurrence is difficult to discern, owing to the resolution of the GPS locations in Gillespie et al. (2007), which are reported to the minute or to the minute with one decimal place only. Some locations were improved through personal communication with G. Gillesipie (2008). The green crab occurrence site is assigned the nearest ShoreZone unit within 500 meters linear distance. Similarly, critical habitat attributes must occur within 500 meters of the green crab site to be considered attributes at that site.

A total of 21 sites on western Vancouver Island possess both green crab occurrence data and ShoreZone coastal habitat attribute data (Table 1, Figure 7). Of these, 15 sites possess complete physical and biological ShoreZone attributes and are compared to model predictions with respect to all four critical habitat attributes: wave exposure, mud or sand flats, eelgrass in the subtidal, and salt marsh vegetation in the supratidal. Note that in the BC ShoreZone database, the occurrence of the salt marsh vegetation (SAL) bioband indicates an assemblage of salt-tolerant herbs and grasses (including *Salicornia*, *Puccinellia*, *Distichlis*, *Triglochlin*, and/or dune grass, among other species). Nested queries in the green crab habitat suitability model require the SAL bioband to be mapped as continuous ("C"), indicating >50% cover within the along-shore unit.

Of the 21 sites, five possess "old" ShoreZone data lacking biological attributes and are compared to model predictions with respect to the two physical attributes only: wave exposure and mud and sand flats. One site (Esquimalt Harbour) lacks ShoreZone data and is excluded from the comparison analysis.

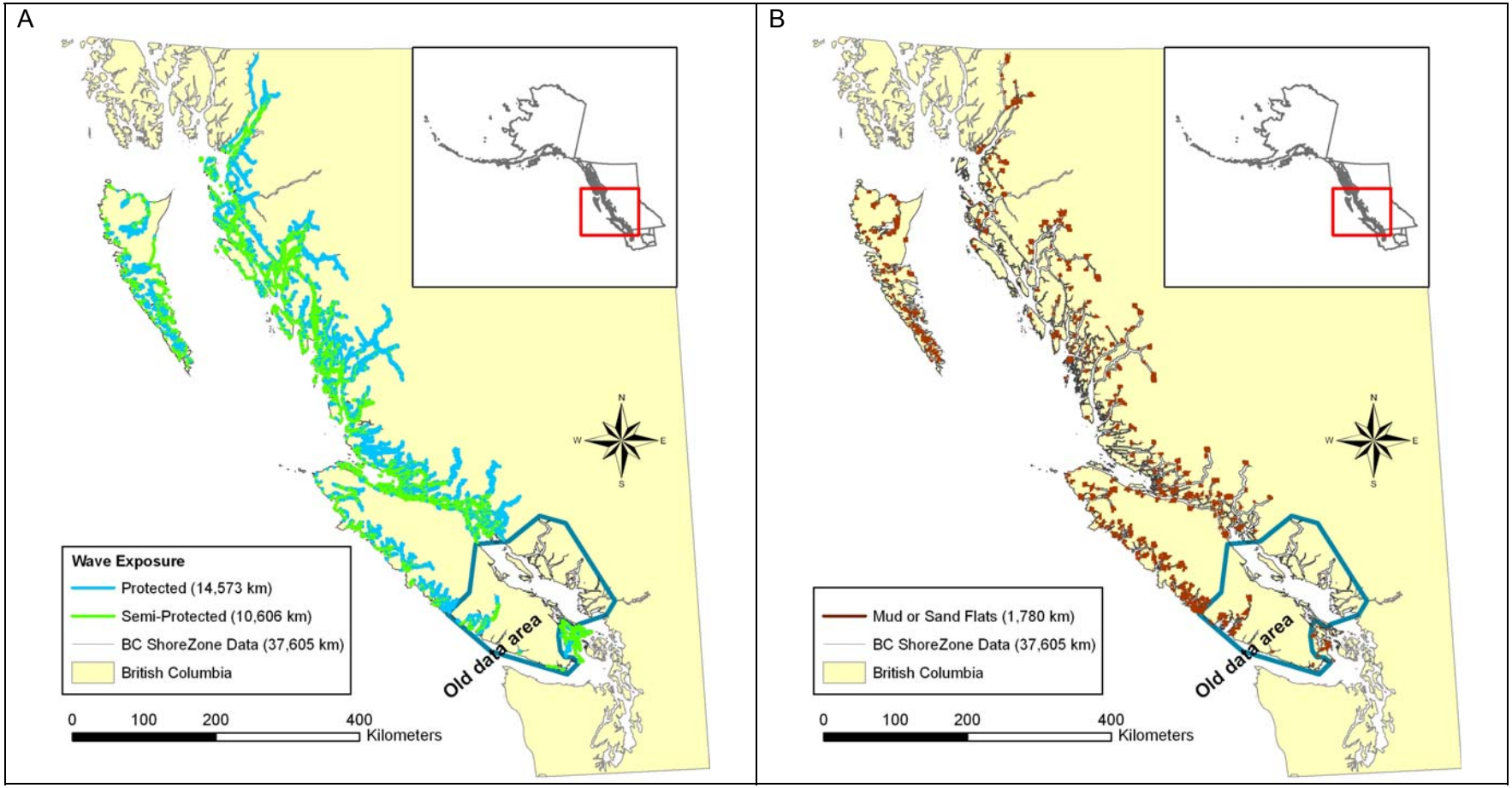

Figure 1. Distribution of individual green crab habitat attributes in coastal British Columbia (Harney 2007). The total length of shoreline mapped in the ShoreZone database for BC is 37,605 km. Protected and semi-protected wave exposures are mapped along 25,179 km of shoreline (A, blue and green combined). Mud or sand flats are mapped along 1,780 km of shoreline (B). Old data area is incomplete or inaccessible in places (see text). [Shapefiles: bc_gi_shorezone.shp, bc_exposure_p_sp.shp, bc_mudflats_sandflats.shp]

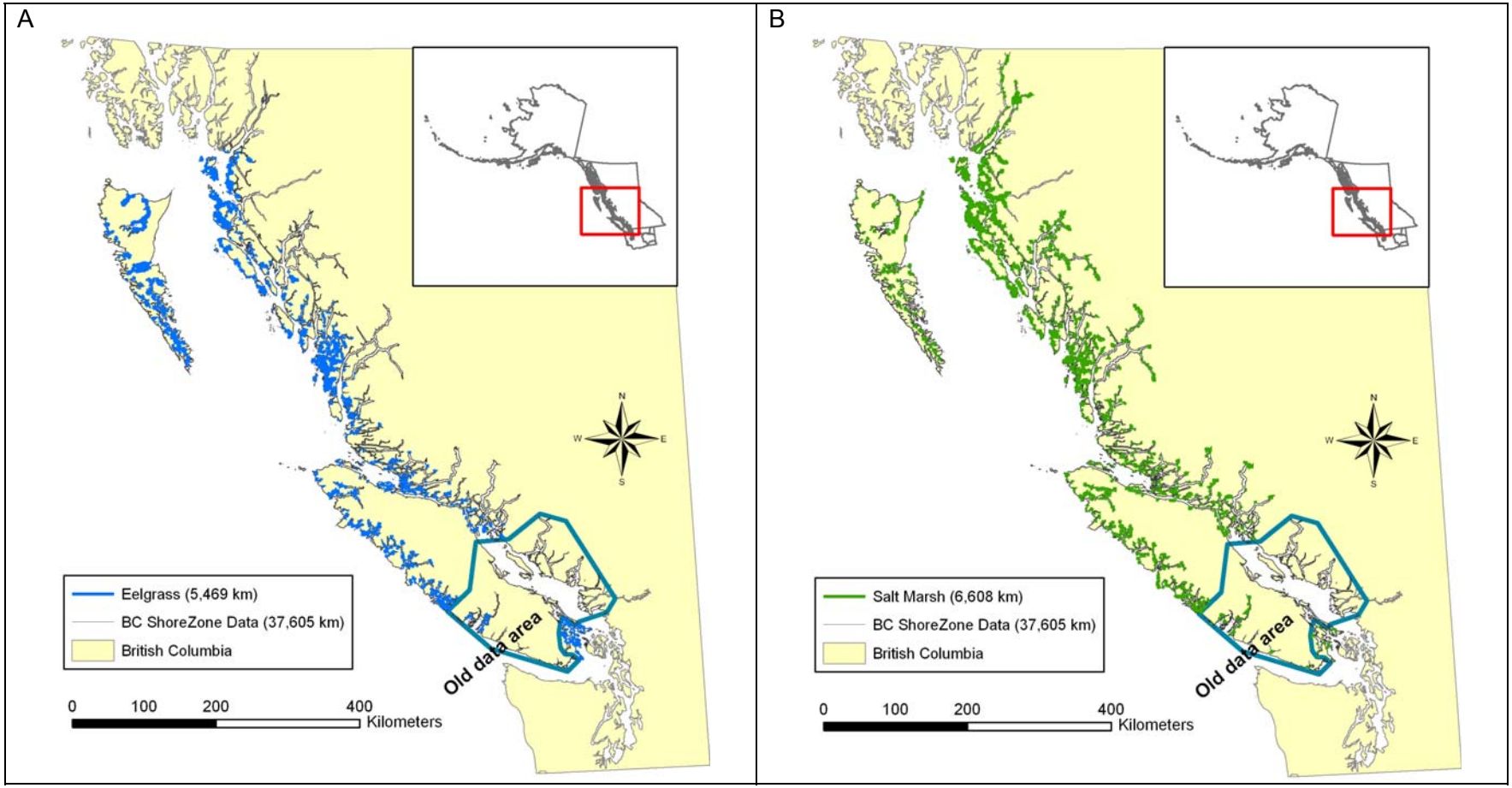

Figure 2. Distribution of individual green crab habitat attributes in coastal British Columbia (Harney 2007). The total length of shoreline mapped in the ShoreZone database for BC is 37,605 km. Eelgrass is mapped along 5,469 km of shoreline (A). Fringing coastal salt marsh vegetation (including *Salicornia*, *Puccinellia*, *Distichlis*, *Triglochlin*, and/or dune grass, among other species) is mapped along 6,608 km of shoreline in BC. Old data area is incomplete or inaccessible in places (see text). [Shapefiles: bc_eelgrass.shp, bc_saltmarsh.shp]

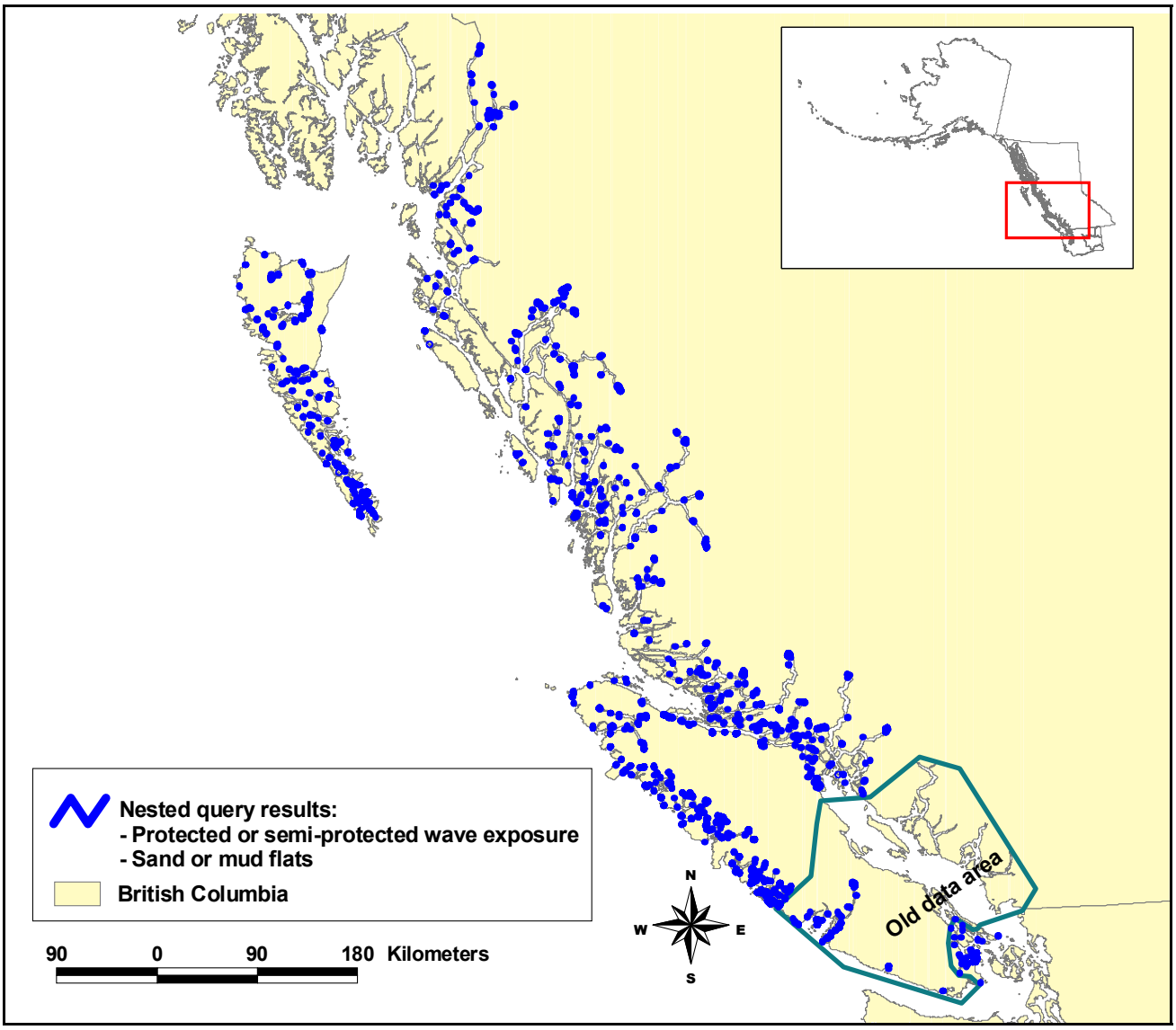

Figure 3. Results of nested queries of protected or semi-protected wave exposures with sand or mud flats in the lower intertidal (Harney 2007). Shoreline units meeting these two criteria (having a habitat rating of 2) are shown in blue, representing 1,699 km of shoreline in BC. Old data area is incomplete or inaccessible in places (see text). [Shapefile: rating2_flat_sp_p.shp]

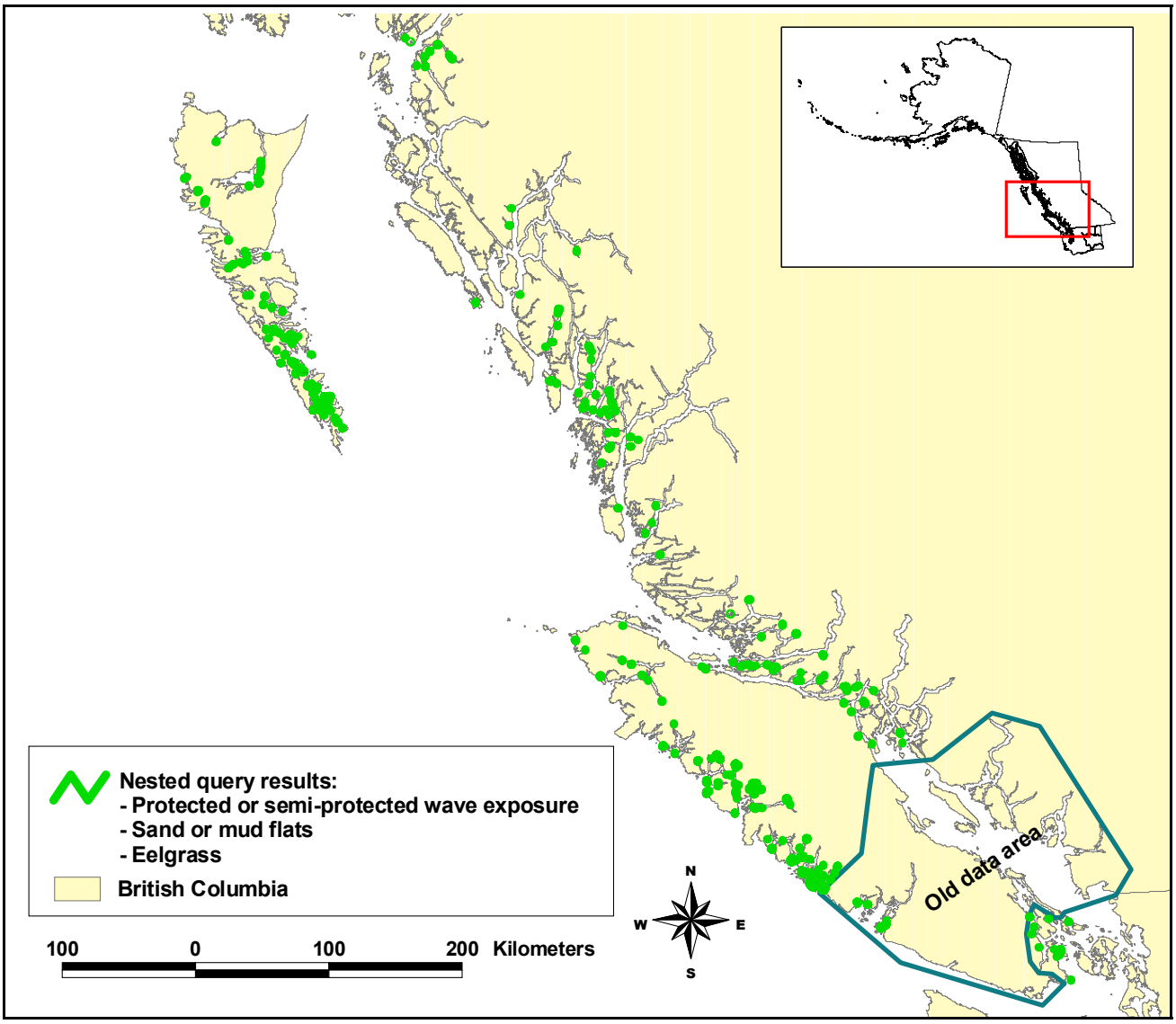

Figure 4. Results of nested queries of protected or semi-protected wave exposures, sand or mud flats in the lower intertidal, and the presence of eelgrass (Harney 2007). Old data area is incomplete or inaccessible in places (see text). Shoreline units meeting these three criteria (having a habitat rating of 3) are shown in light green, representing 498 km of shoreline in BC. [Shapefile: rating3_flat_sp_p_zos.shp]

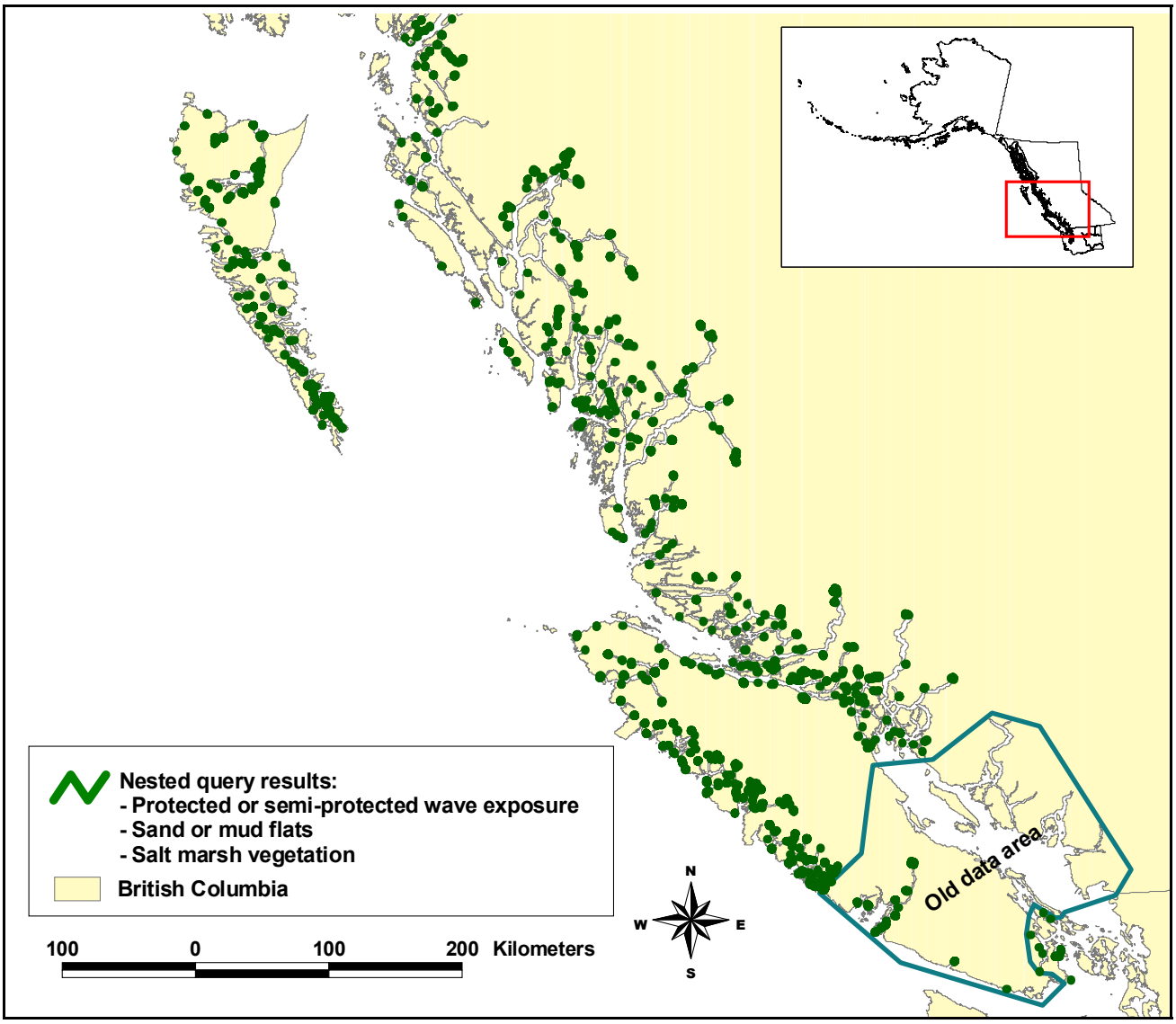

Figure 5. Results of nested queries of protected or semi-protected wave exposures, sand or mud flats in the lower intertidal, and the presence of salt marsh vegetation in the supratidal (Harney 2007). Old data area is incomplete or inaccessible in places (see text). Shoreline units meeting these three criteria (having a habitat rating of 3) are shown in dark green, representing 1,471 km of shoreline in BC. [Shapefile: rating3_flat_sp_p_sal.shp]

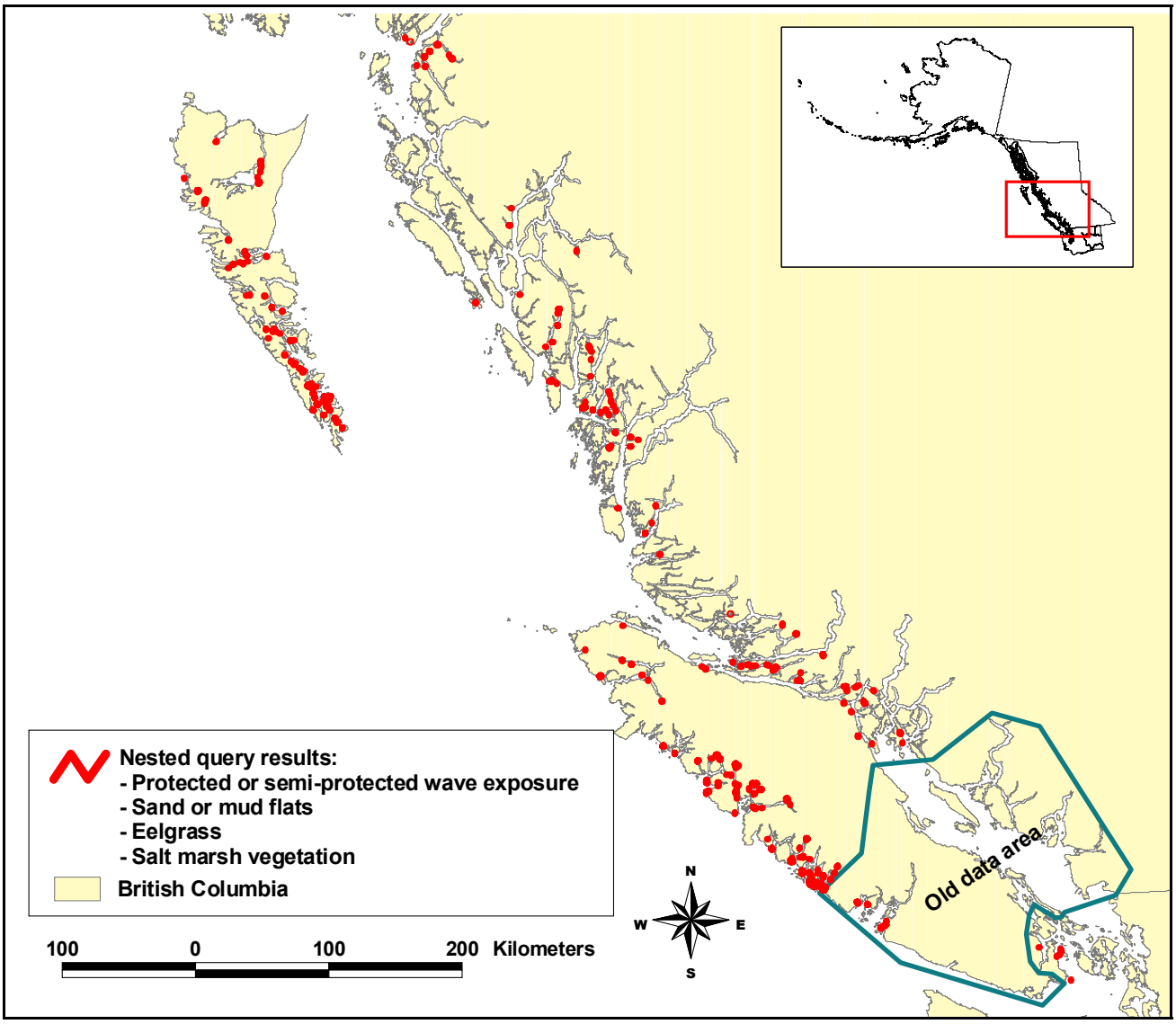

Figure 6. Results of nested queries of protected or semi-protected wave exposures, sand or mud flats in the lower intertidal, the presence of salt marsh vegetation in the supratidal, and the presence of eelgrass (Harney 2007). Old data area is incomplete or inaccessible in places (see text). Shoreline units meeting all four criteria (having a habitat rating of 4) are shown in red, representing 434 km of shoreline in BC. [Shapefile: rating4_flat_sp_p_zos_sal.shp]

Table 1. Summary of locations of known green crab occurrence on western Vancouver Island (from Tables 1, 5, and 7 in Gillespie et al. 2007).

SiteNo	Region	SiteName	Latitude	Longitude	# Crabs Reported Table 1 (1999-2006)	# Crabs Trapped Table 5 (May-Sep 2006)	# Crabs Reported Table 7 (May-Jul 2006)	ShoreZone *15 site analysis
1	Kyuquot Sound	Kyuquot	50.033	127.367	5 (2005)	-	-	*
2	Esperanza Inlet	Port Eliza	49.915	127.045	1 (2002)	1	-	*
3	Esperanza Inlet	Queen Cove Upper	49.88376667	126.9824667	-	31	2 molts	*
4	Esperanza Inlet	Queen Cove Entrance	49.87443333	126.9815167	-	20	1 dead	*
5	Esperanza Inlet	Espinosa Inlet	49.96833333	126.9433333	-	1	-	*
6	Esperanza Inlet	Little Espinosa Inlet	49.93	126.907	3 (2002); 1 (2003); 6 (2005)	1	-	*
7	Esperanza Inlet	Zeballos	49.98166667	126.8516667	-	1	-	*
8	Nootka Sound	Bligh Island	49.65	126.517	1 (2000)	1	-	*
9	Nootka Sound	Mooyah Bay	49.63	126.45	-	1	-	*
10	Clayoquot Sound	Pretty Girl Cove	49.47383333	126.2351667	-	17	5 molts	*
11	Clayoquot Sound	Whiskey Jenny Beach	49.39911667	126.1675333	-	11	1 live, 3 molts	*
12	Clayoquot Sound	Whitepine Cove	49.30276667	125.9484833	-	4	1 live, 3 molts	*
13	Clayoquot Sound	Cypress Bay	49.275	125.905	-	9	-	*
	Clayoquot Sound	Cypress Bay1	49.26666667	125.9166667	-	-	2 molts	
	Clayoquot Sound	Cypress Bay2	49.28333333	125.9	-	-	1 molt	
14	Clayoquot Sound	Lemmens Inlet	49.2	125.8666667	2 (2000)	0	-	*
15	Clayoquot Sound	Warn Bay	49.25606667	125.7315667	-	0	1 molt	*
16	Barkley Sound	Pipestem Inlet	49.03966667	125.1993333	1 molt (2005)	274	1 molt	old data
17	Barkley Sound	Vernon Bay	49.00866667	125.1434167	-	2	1 live	old data
18	Barkley Sound	Useless Inlet	48.9915	125.0293833	5 (1999)	2	-	old data
19	Barkley Sound	Mayne Bay	48.983	125.317	1 (2006)	-	-	old data
20	Barkley Sound	Pacific Rim National Park	48.918	125.317	1 (2006)	-	-	old data
21	SE Vancouver Island	Esquimalt Harbour	48.433	123.433	1 (1999)	1	-	no data

Sites are listed in general order from north to south, and the site number in the first column pertains to data in this report only. Note that three locations for Cypress Bay are considered one site (13). Improved GPS locations were obtained through personal communication with G. Gillespie (2008) for Queen Cove, Pretty Girl Cove, Whiskey Jenny Beach, Warn Bay, Useless Inlet, Pipestem Inlet, Whitepine Cove, and Vernon Bay. Of the 21 sites listed, 15 possess complete physical and biological ShoreZone attributes (indicated by an asterisk in the last column) and can be compared to model predictions with respect to all four habitat attributes (wave exposure, mud and sand flats, eelgrass in the subtidal, and salt marsh vegetation in the supratidal). Five of the 21 sites possess mapped physical attributes only ("old data" lacking observations of eelgrass and salt marsh vegetation; see text). One site (Esquimalt Harbour) lacks ShoreZone data and is excluded from the analysis (labeled "no data"). The location of all 21 sites is shown in Figure 7.

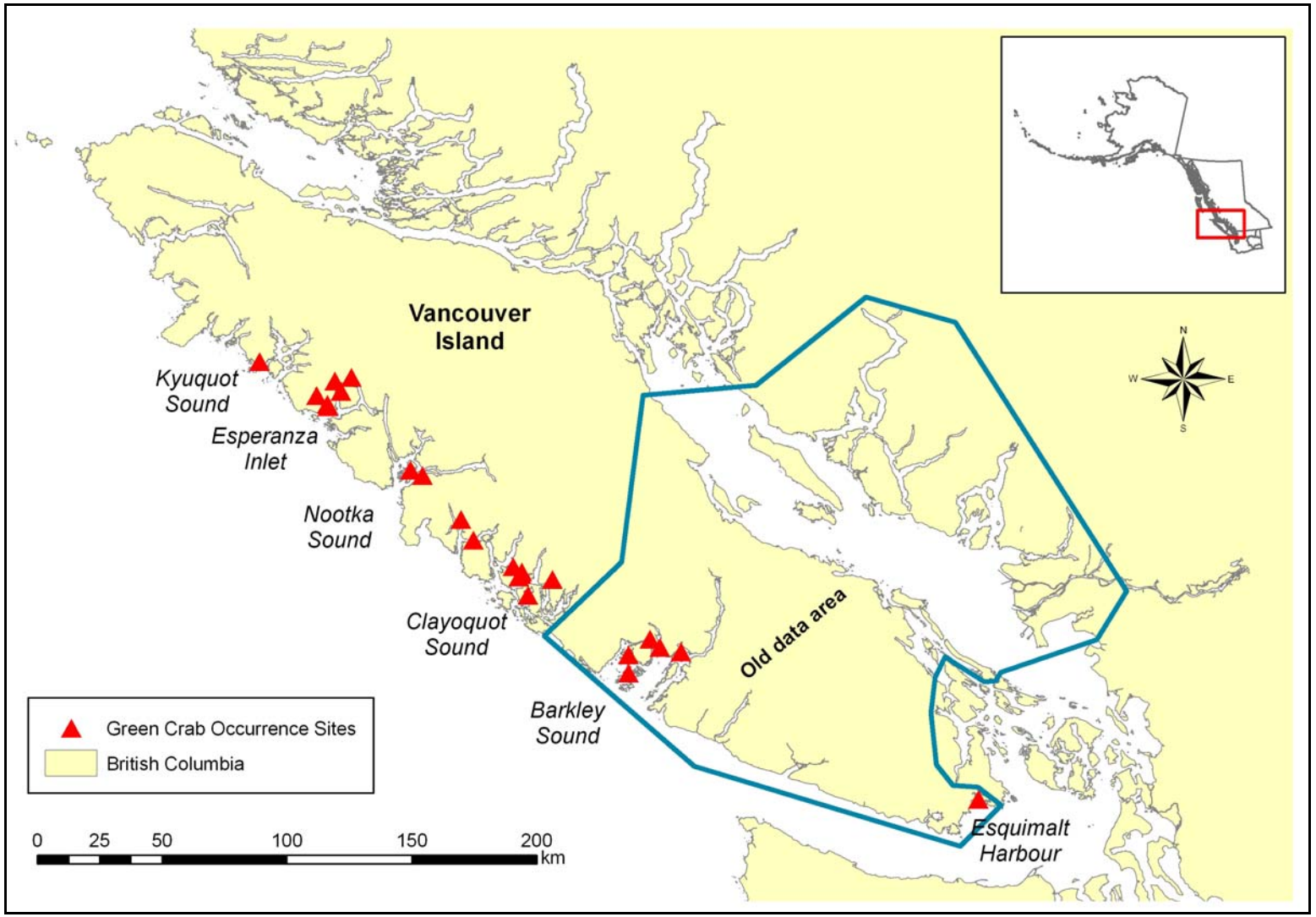

Figure 7. Green crab occurrence locations used in this study (Gillespie et al. 2007; summarized in Table 1). The polygon shows the location of limited ShoreZone data (see text).

RESULTS AND DISCUSSION

Habitat attributes at the 15 green crab occurrence sites with complete ShoreZone data are summarized in Table 2 and illustrated in Figures 8-17 in a general north to south order: Kyuqot Sound, Esperanza Inlet, Nootka Sound, and Clayoquot Sound. Attributes for the five sites in Barkley Sound with incomplete ShoreZone data are summarized in Table 3 and illustrated in Figures 18 and 19.

Shorelines that are predicted to be suitable habitat for the green crab are assigned a rating of 0-4 on the basis of the number of critical attributes the shore unit possesses. Of the 15 sites with complete ShoreZone data and the potential of four habitat attributes mapped at each site, all but one possess at least two of the four critical habitat attributes (wave exposure and one other attribute), earning a habitat model rating of 2 or better (of a possible 4). With respect to the individual habitat attributes at each of these 15 sites:

- Protected (P) or Semi-Protected (SP) wave exposure categories were mapped at all 15 sites (100%) (Figure 8).
- Sand or mud flats were mapped in 7 of the 15 sites (47%).
- Eelgrass was mapped in 7 of the 15 sites (47%).
- Salt marsh vegetation was mapped in the supratidal zone of 10 of the 15 sites (67%).

Four sites (Cypress Bay, Whitepine Cove, Mooyah Bay, and Zeballos) have a habitat rating of 4, possessing all four attributes in the same location. Three sites (Little Espinosa Inlet, Warn Bay, and Pretty Girl Cove) have a habitat rating of 3. In each case of these cases, eelgrass is the missing attribute. In Warn Bay and Pretty Girl Cove, eelgrass is mapped in nearby units (800 m and 1.5 km away from plotted sampling locations), but is not considered an attribute at the site.

Seven of the 15 sites possess only two attributes (wave exposure and one other attribute). The second attribute is eelgrass and salt marsh vegetation in equal measure, while tidal flats are absent in all seven locations. No sites have a rating less than 2.

Comparisons between occurrence locations and mapped attributes reveals that the model may under-predict habitat ratings in some uncommon conditions. For example, gravel flats and beaches are mapped at the Queen Cove Upper, Whiskey Jenny Beach, and Bligh Island sites. Each of these sites is protected and possesses either eelgrass *or* supratidal vegetation. Because sand or mud flats are lacking, the habitat rating at these sites is only 2. This suggests that, when the criteria for wave exposure is met, gravel flats and beaches that *also* contain either eelgrass or salt marsh vegetation provide suitable habitat. One explanation for this is that flats mapped as "gravel" in protected environments are likely contain a mixture of fine and coarse sediments, or a thin veneer of scattered cobbles overlying sand and mud flats. Given that the majority of "gravel flats" are dominated by coarse material and not suitable green crab habitat, inclusion of gravel flats in the nested habitat queries is not recommended.

Both *Fucus* (popweed) and *Ulva* (green algae) are also mapped as patchy (<50% cover) at the Queen Cover Upper site, but these algae are not considered critical habitat attributes (defined during the expert interview process). Green crab occurrence data suggest that these algae may

provide suitable habitat for juvenile green crabs in the lower intertidal, even if eelgrass is lacking.

At the Lemmens Inlet site in Clayoquot Sound, positional error may be the reason that only one green crab attribute (wave exposure) is noted. When plotted in GIS, the sampling site actually falls offshore, and the closest unit within 500 meters lacks eelgrass. Several other surrounding units on both sides of the inlet (700 m from the sampling location) do contain eelgrass and salt marsh vegetation. Having more precise positional data would enable the site to be matched to an exact ShoreZone unit and would allow a clearer comparison.

Five of the 21 sites (all in Barkley Sound) lack complete ShoreZone data and are more difficult to compare to model predictions, owing to the variable number of mapped attributes available at each site. Data for these sites are summarized in Table 3 and shown in Figures 18 and 19. Three sites possess two of the four critical attributes; two sites (Mayne Bay and Pacific Rim) possess only one attribute. Four of the five green crab occurrence locations in Barkley Sound are in protected or semi-protected wave exposures; Useless Inlet is mapped as very protected. Two of the five sites possess sand or mud flats. Biological data are available for the Useless Inlet and Mayne Bay sites only; of these, only Useless possesses eelgrass and salt marsh vegetation.

Table 2. Summary of critical habitat attributes at the 15 green crab occurrence sites with complete ShoreZone data (and four potential attributes).

Site #	Region	Site Name	P/SP	Flats	Eelgrass	Salt Marsh	Model Rating (0-4)
1	Kyuquot Sound	Kyuquot	P/SP		x		2
2	Esperanza Inlet	Port Eliza	P			x	2
3	Esperanza Inlet	Queen Cove Upper	P		x		2
4	Esperanza Inlet	Queen Cove Entrance	P		x		2
5	Esperanza Inlet	Espinosa Inlet	P			x	2
6	Esperanza Inlet	Little Espinosa Inlet	P	x		x	3
7	Esperanza Inlet	**Zeballos**	**P**	**x**	**x**	**x**	**4**
8	Nootka Sound	Bligh Island	P/SP			x	2
9	Nootka Sound	**Mooyah Bay**	**P**	**x**	**x**	**x**	**4**
10	Clayoquot Sound	Pretty Girl Cove	P	x		x	3
11	Clayoquot Sound	Whiskey Jenny Beach	P		x		2
12	Clayoquot Sound	**Whitepine Cove**	**P**	**x**	**x**	**x**	**4**
13	Clayoquot Sound	**Cypress Bay**	**P**	**x**	**x**	**x**	**4**
14	Clayoquot Sound	Lemmens Inlet	P/SP				1
15	Clayoquot Sound	Warn Bay	P	x		x	3
		Number of occurrences	15	7	7	10	
		% possible 15 sites	100%	47%	47%	67%	

Shown in bold are four sites that possess all four of the possible habitat attributes (protected/semi-protected wave exposure, mud or sand flats, eelgrass in the lower intertidal or shallow subtidal, and salt marsh vegetation in the supratidal). The model rating for each site is assigned on the basis of the number of critical attributes that occur at the site. Maps of locations and ShoreZone attributes for the 15 sites are shown in Figures 8-17.

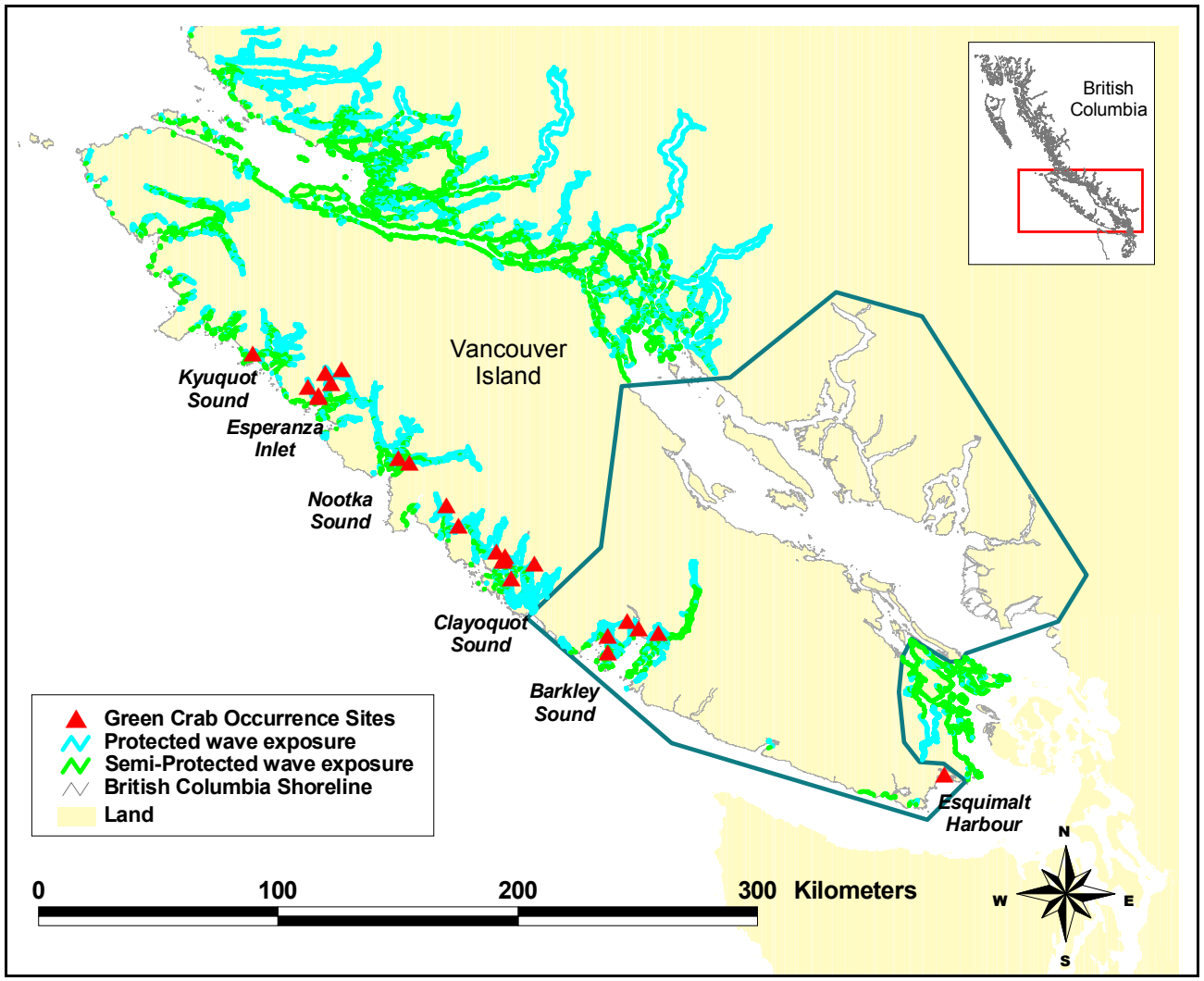

Figure 8. Sites of green crab occurrence on western Vancouver Island, plotted with wave exposure from the ShoreZone database. All sites occur in protected and semi-protected wave exposures as the habitat suitability model predicts. The polygon shows the location of limited ShoreZone data (see text). Overview maps for each inlet and detail maps for each site are illustrated in Figures 9-17.

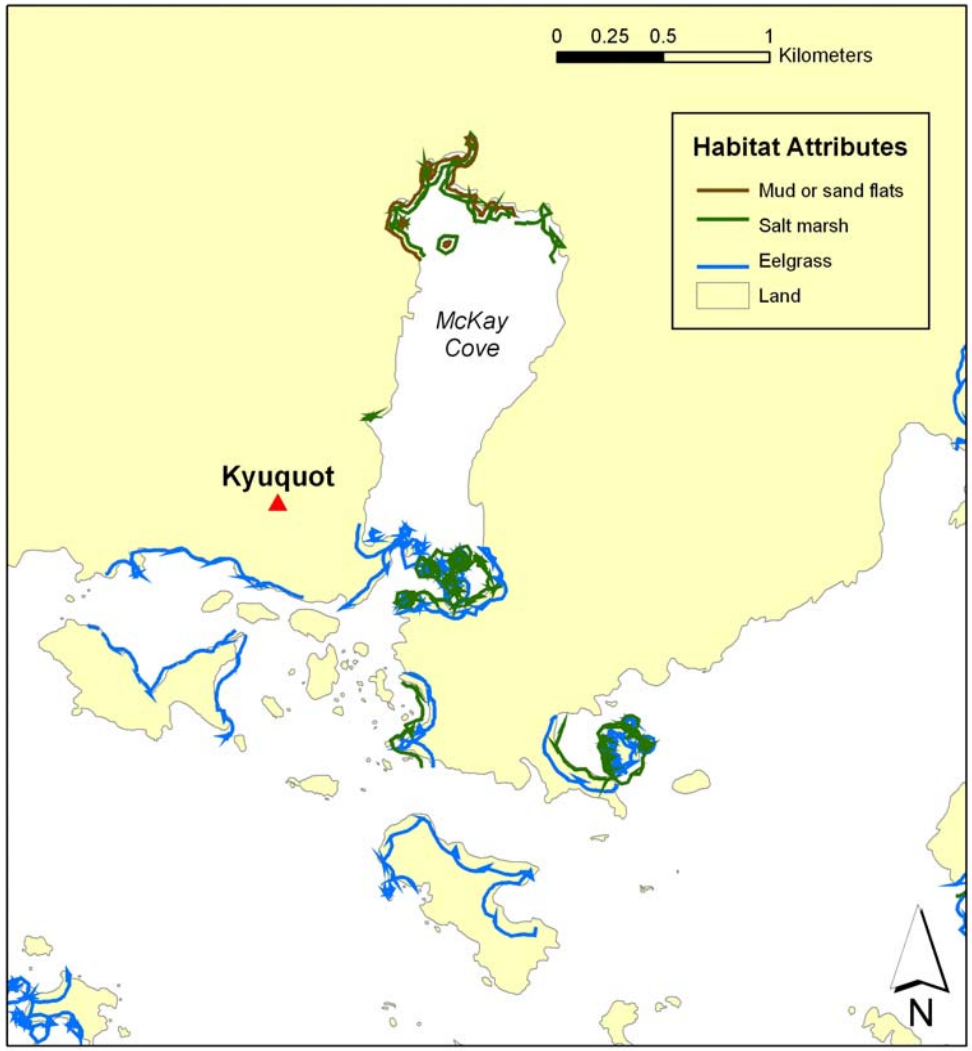

Figure 9. The Kyuquot site possesses only two critical habitat attributes (wave exposure and eelgrass). Although the site plots landward of the shoreline, the nearest unit (within 500 meters) contains eelgrass, which is considered an attribute at the site. Salt marsh vegetation is present at the southeast corner of McKay Cove but is not within 500 meters of the plotted sampling site and is thus not considered an attribute at the site.

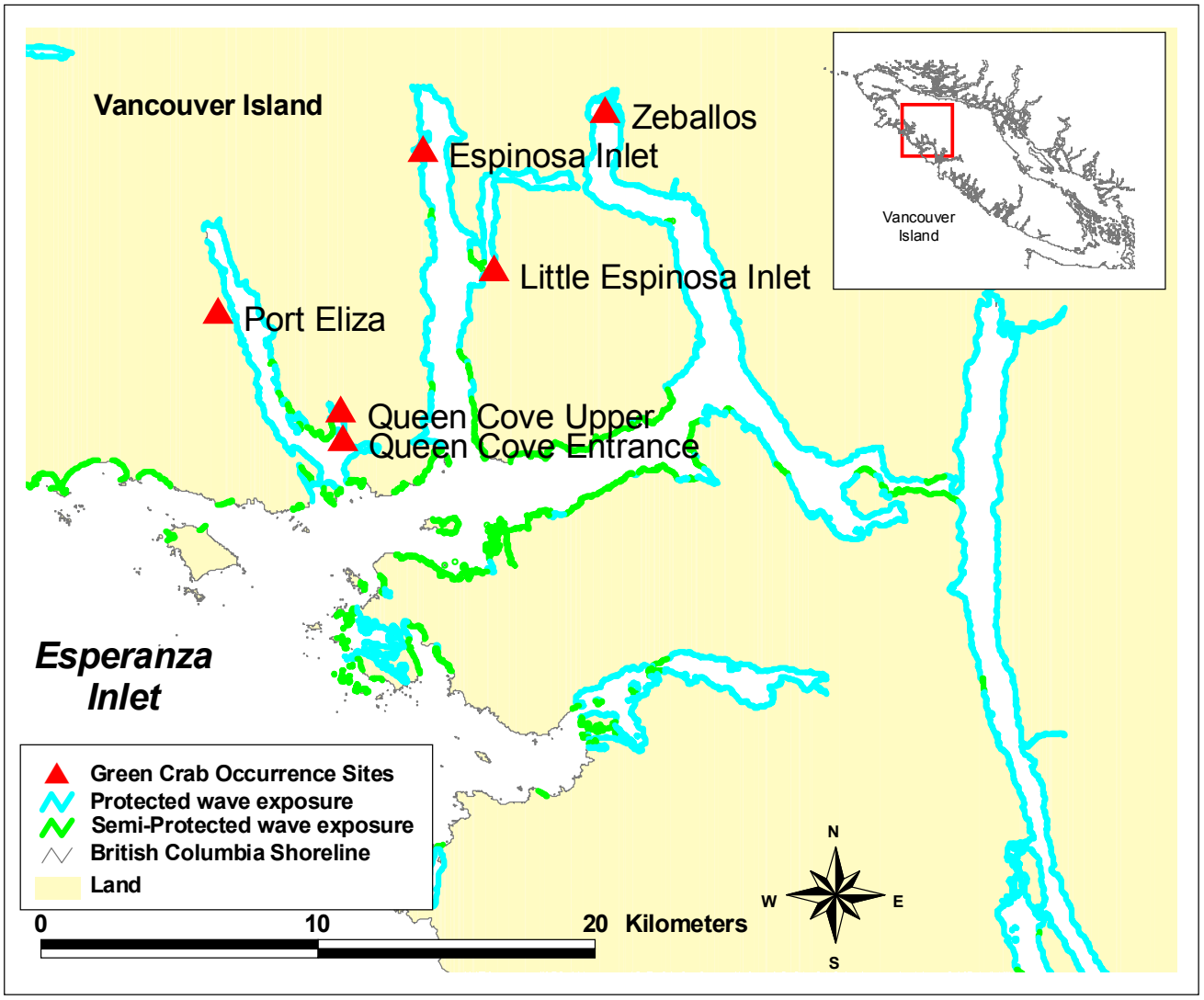

Figure 10. Sites of green crab occurrence in Esperanza Inlet. All sites occur in protected and semi-protected wave exposures. Site detail maps are shown in Figures 11 and 12.

Figure 11. In Esperanza Inlet, the Port Eliza site (A) possesses two green crab habitat attributes (protected/semi-protected wave exposure and supratidal salt marsh vegetation) occur. The head of Port Eliza possesses all four critical attributes but is not within 500 meters of the plotted sampling location. At the Queen Cove Upper site (B), salt marsh vegetation is within 500 meters of the plotted sampling location and is considered the second of two attributes, along with protected/semi-protected wave exposure. A gravel flat is also mapped at the head of Queen Cove Upper but is not included as a critical attribute (flats must be sand or mud). Two attributes are mapped at the Queen Cove Entrance site (eelgrass and protected/semi-protected wave exposure).

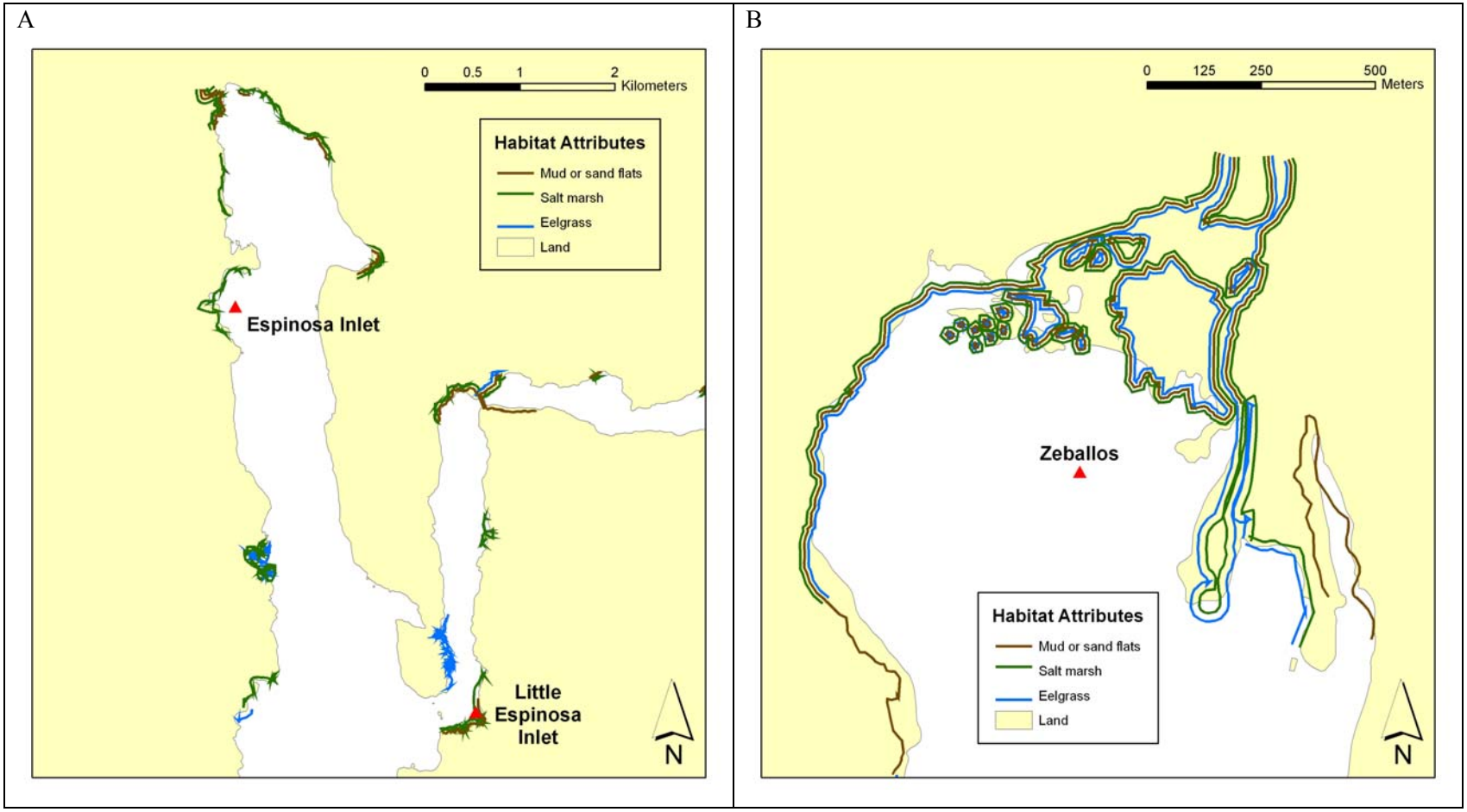

Figure 12. In Esperanza Inlet, the Espinosa Inlet site (A) possesses two of the four attributes (protected/semi-protected wave exposure and salt marsh vegetation in the supratidal). Although mud/sand flats are mapped at the head of Espinosa, they are more than 500 meters from the sampling location and are not included as attributes of the site. The Little Espinosa Inlet site (A, lower right) possesses three attributes (protected/semi-protected wave exposure, mud/sand flats, and salt marsh vegetation in the supratidal); the eelgrass mapped across the narrow inlet from Little Espinosa is more than 500 meters from the site and is not included as an attribute at the site. The Zeballos site (B) possesses all four critical habitat attributes within 500 meters of the sampling location.

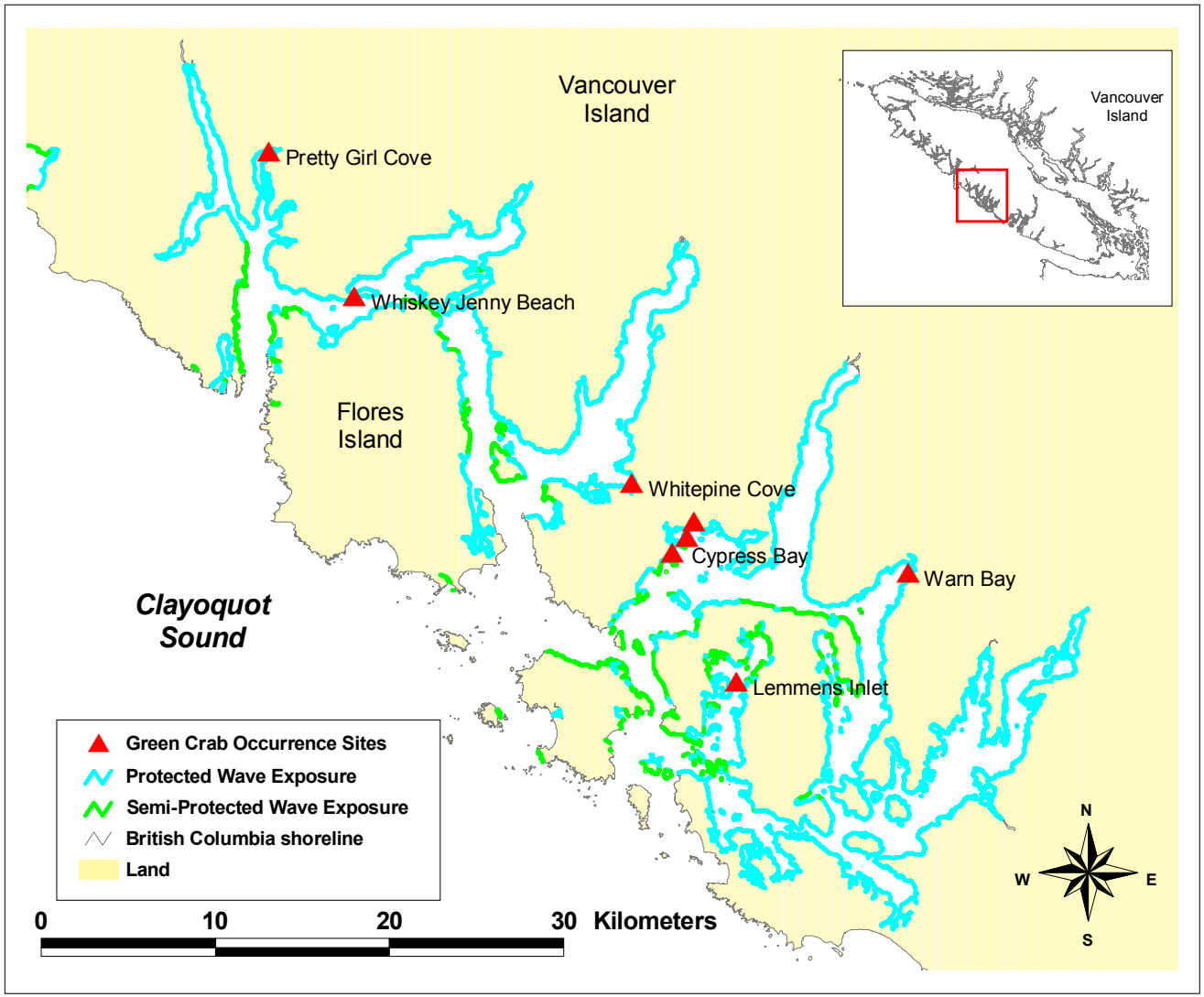

Figure 13. Sites of green crab occurrence in Clayoquot Sound. All sites occur in protected and semi-protected wave exposures. Detail maps are shown in Figures 14 and 15.

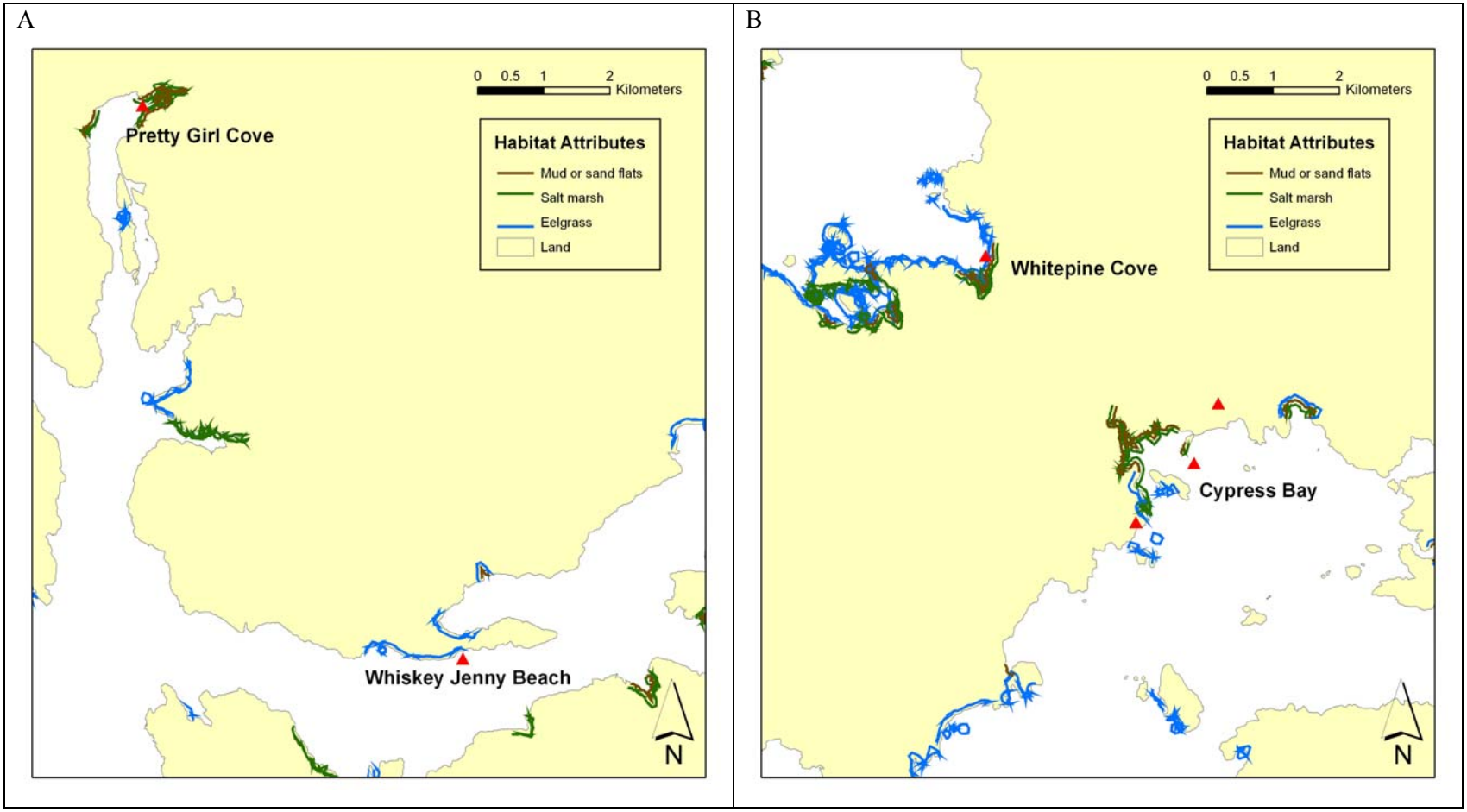

Figure 14. In Clayoquot Sound, the Pretty Girl Cove site (A, upper left) possesses three critical attributes (wave exposure, flats, and salt marsh vegetation), while the Whiskey Jenny Beach site (A, lower right) has two (wave exposure and eelgrass). Whitepine Cove and Cypress Bay (B) both possess all four attributes (wave exposure, flats, eelgrass, and salt marsh vegetation). Note that the three locations for Cypress Bay are considered one site.

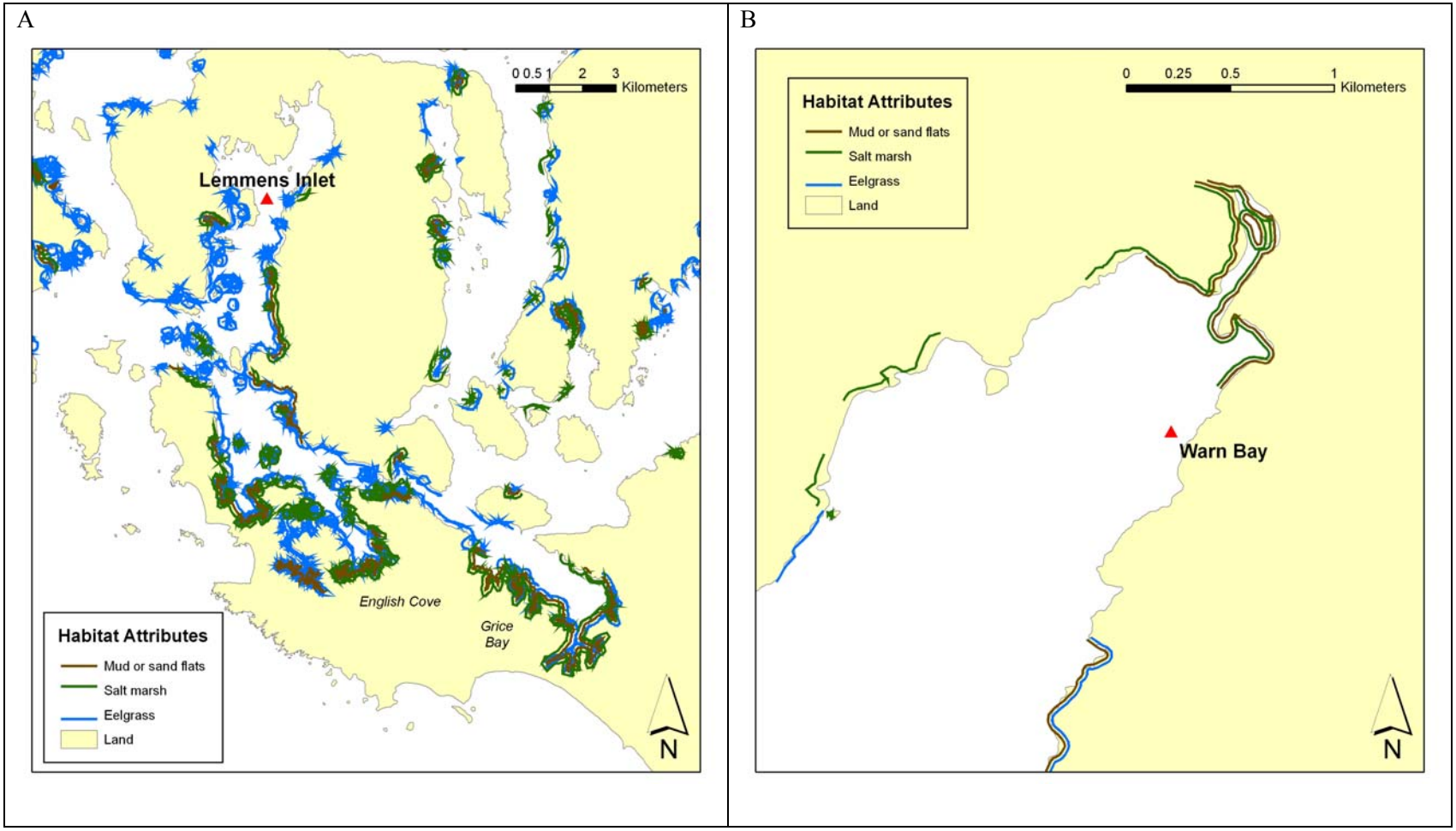

Figure 15. In Clayoquot Sound, the Lemmens Inlet site (A, upper left) possesses only one critical habitat attribute (protected/semi-protected wave exposure). Although flats, eelgrass, and salt marsh vegetation occur near the Lemmens site, they are >500 m from the sampling location and are not included as attributes of the site. South of Lemmens Inlet (English Cove and Grice Bay), highly-suitable green crab habitat is predicted by the model. The Warn Bay site (B) in Clayoquot Sound possesses three attributes (all but eelgrass).

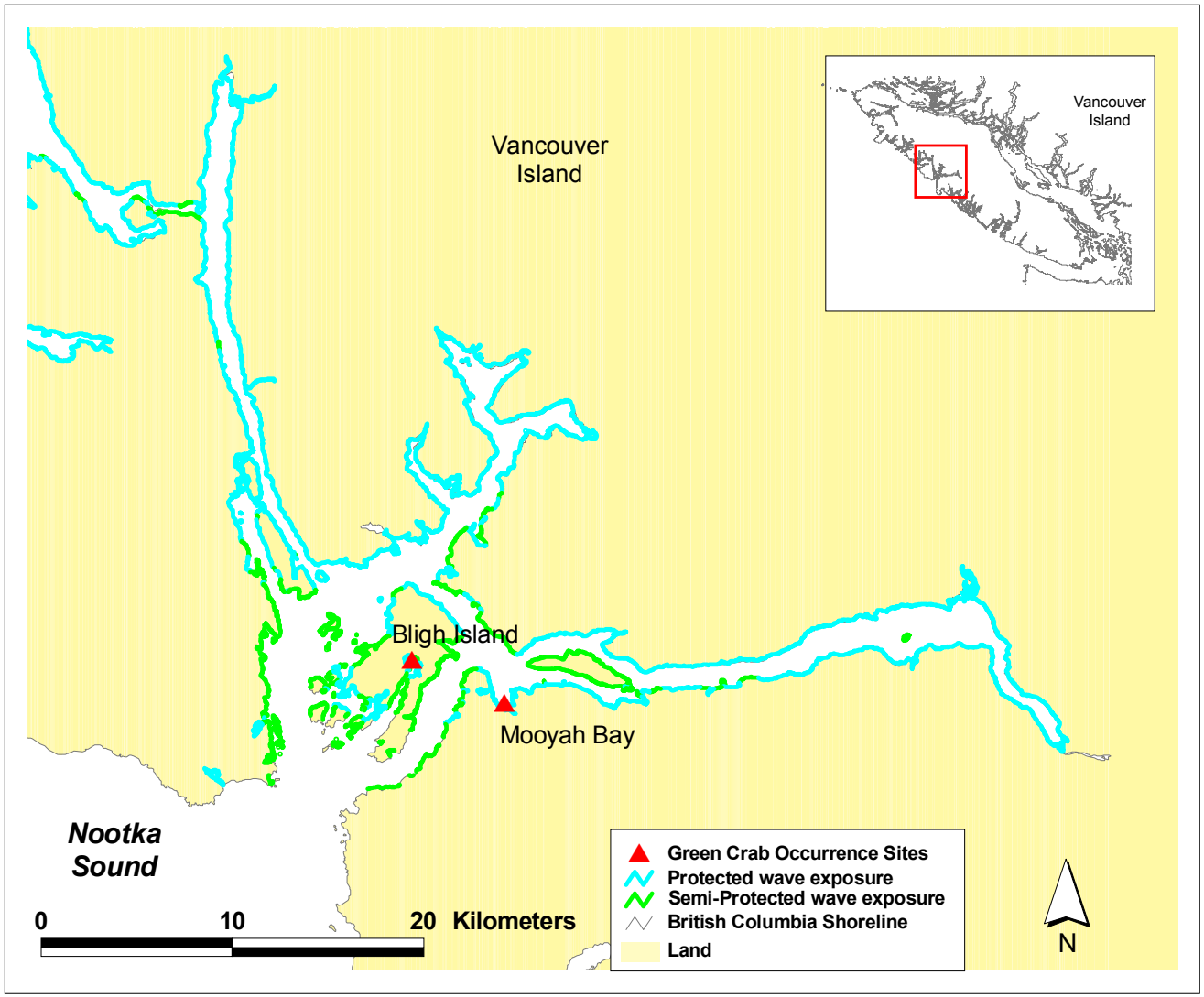

Figure 16. Sites of green crab occurrence in Nootka Sound. All sites shown occur in protected and semi-protected wave exposures. Detail maps are shown in Figure 17.

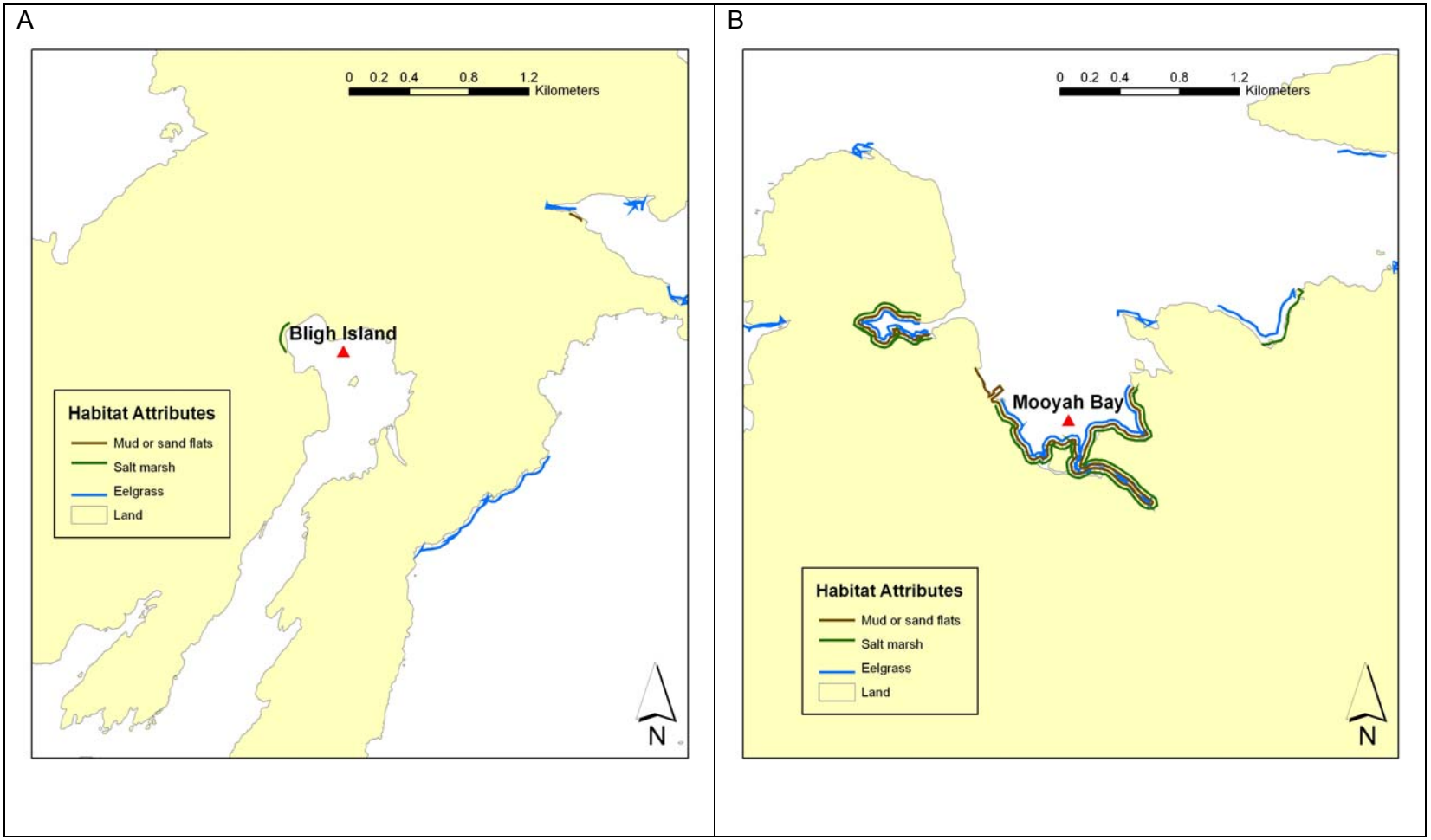

Figure 17. In Nootka Sound, the Bligh Island site (A) possesses only two attributes (wave exposure and salt marsh vegetation). A gravel beach is mapped at this site but is not considered a critical habitat attribute. The Mooyah Bay site (B) has the highest suitability rating, with all four critical attributes mapped at the green crab occurrence location.

Table 3. Summary of critical habitat attributes at the five green crab occurrence sites in Barkley Sound.

Site #	Region	Site Name	P/SP	Flats	Eelgrass	Salt Marsh	# attributes
16	Barkley Sound	Pipestem Inlet	P	x	no data	no data	2
17	Barkley Sound	Vernon Bay	P	x	no data	no data	2
18	Barkley Sound	Useless Inlet	VP		x	x	2
19	Barkley Sound	Mayne Bay	P/SP				1
20	Barkley Sound	Pacific Rim National Park	P/SP		no data	no data	1
		Number of occurrences	4	2	1	1	
		Number of possible	5	5	3	4	
		% of possible attributes	80%	40%	33%	25%	

ShoreZone data are incomplete in this region, thus not all potential attributes can be compared. The number of attributes at each site is listed rather than a habitat rating. The number of occurrences of each attribute (bottom of table) is compared to the possible number of attributes to calculate the percentage of potential sites with at which the critical attributes were mapped. Biological data in this region were retrofitted after image collection, thus the quality is not comparable to post-1992 data (see text). A location map is shown in Figure 18.

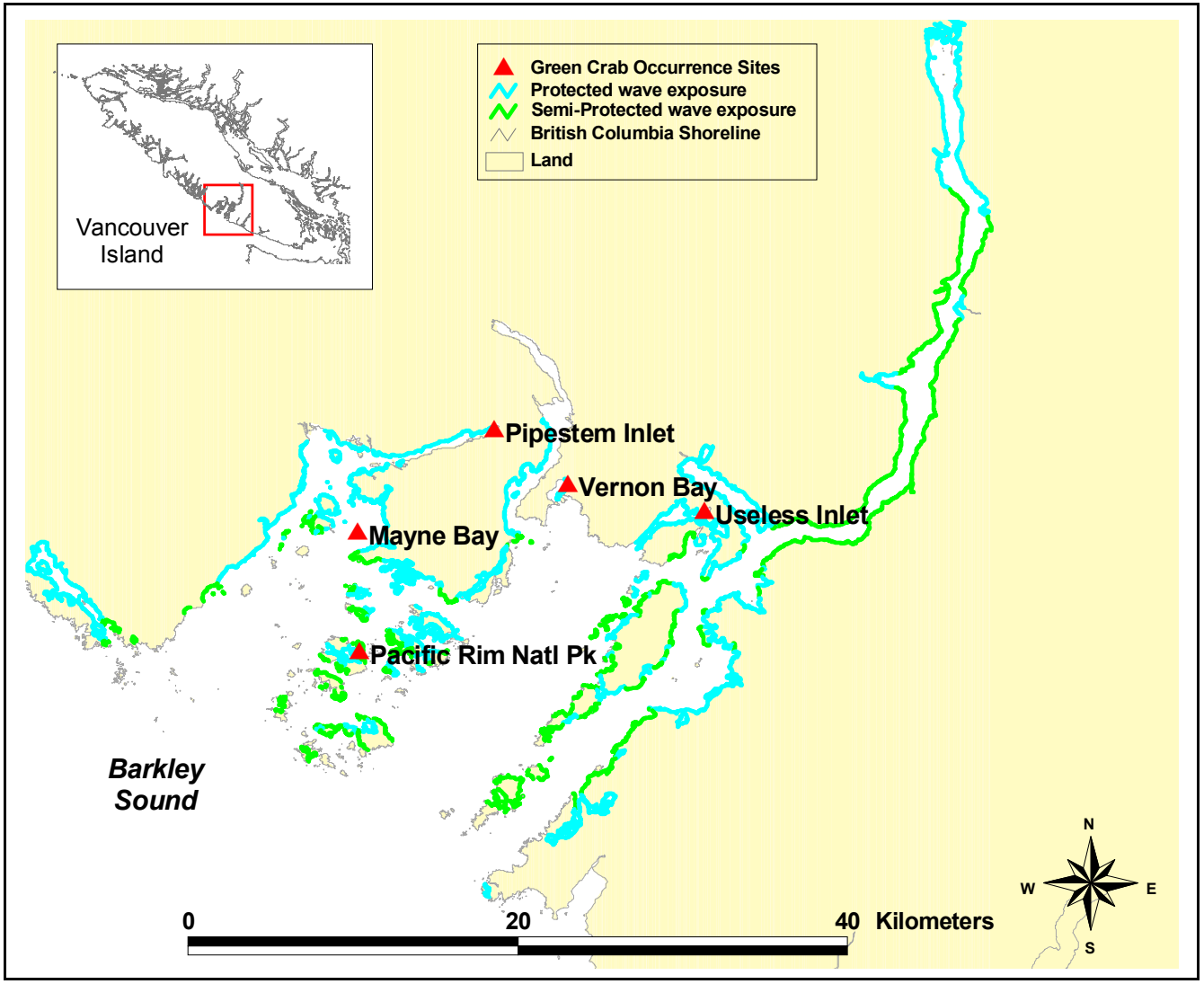

Figure 18. Sites of green crab occurrence in Barkley Sound where ShoreZone data is incomplete. Habitat detail is shown in Figure 19.

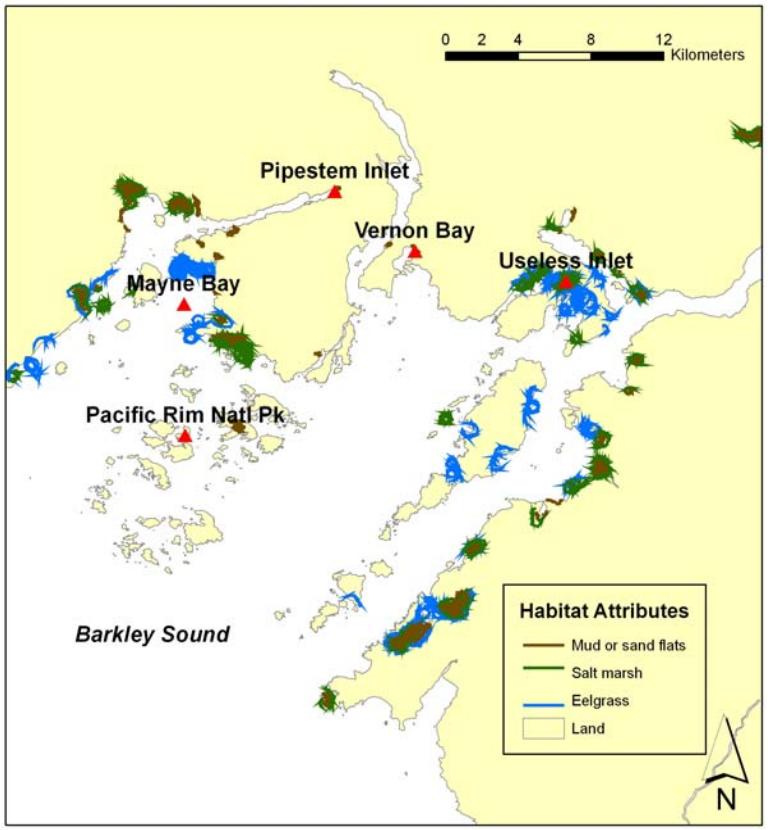

Figure 19. The five sites in Barkley Sound lack complete ShoreZone data. Four of the five green crab occurrence locations are in protected or semi-protected wave exposures. Useless Inlet is mapped as very protected but possesses eelgrass and salt marsh vegetation. Biological data are lacking for the Pipestem Inlet, Vernon Bay, and Pacific Rim sites. Sand flats occur at Pipestem and Vernon Bay but not elsewhere. The actual location of the Mayne Bay site is difficult to discern owing to positional accuracy. Sand flats, eelgrass, and salt marsh vegetation are mapped nearby but not within 500 meters, thus only wave exposure is a mapped attribute at that site.

CONCLUSIONS

All 15 green crab occurrence sites have a rating of at least 2 of 4 (wave exposure and at last one other attribute), suggesting that the model is able to predict suitable green crab habitat from mapped ShoreZone attributes, even in the absence of other data or information.

The most selective use of the green crab habitat suitability model involves a fully-nested query of all four critical habitat attributes:

- Protected or semi-protected wave exposures
- Sand or mud flats (fine sediment in the lower intertidal)
- Eelgrass in the lower intertidal or shallow subtidal zones
- Salt marsh vegetation in the supratidal zone.

Shorelines are rated with respect to habitat suitability on the basis of the number of critical habitat attributes that co-occur with a single along-shore unit (0-4). The highest rating of 4 is assigned to along-shore units in which all four attributes co-occur, suggesting these locations are highly suitable green crab habitat and potential "hot spots" for colonization. Of the 15 green crab occurrence locations examined in this study, only four meet that stringent criteria.

Protected and semi-protected wave exposures are attributes at all 15 green crab occurrence sites. Protected exposures account for 80% of the sites.

Eelgrass was mapped in 7 of the 15 sites (47%). Salt marsh vegetation was mapped in the supratidal zone of 10 of the 15 sites (67%). A portion of Useless Inlet is mapped as very protected but is one of the 5 sites in the "old data" area with incomplete or pre-1992 ShoreZone data.

Sand or mud flats are mapped in 7 of the 15 sites (47%). When flats are present, eelgrass also occurs 50% of the time. When flats are present, salt marsh vegetation also occurs 70% of the time. Bare tidal flats lacking either eelgrass or salt marsh vegetation do not occur at any of the green crab occurrence locations.

In the green crab habitat suitability model, nested queries of critical attributes are performed with the intention of identifying the most suitable habitat, in order to recommend a potential monitoring sites from thousands of kilometers of shoreline. However, applying highly-specific queries may cause the exclusion of some potential habitats. This comparison study elucidates aspects of the habitat suitability model that may be adjusted to avoid such exclusions and to improve the accuracy of predictions.

- Estuaries are identified as critical habitat for the green crab. The habitat suitability model uses the occurrence of supratidal salt marsh biobands (mapped in across-shore data tables) as indicators of estuarine habitats. This approach assumes that salt marsh biobands are *observed and mapped* in all estuarine units. An alternate approach involves querying unit-level habitat classifications to identify those units classified entirely as estuaries and organic shorelines. This approach yields fewer results, because the entire unit must meet the criteria of an organic shoreline classification (see ShoreZone Protocol for more

information; Harney et al. 2007). Use of either approach may result in the exclusion of some potential habitats. This suggests the model may be improved by employing both approaches: query the *across-shore* occurrence of salt marsh biobands then run an additional, non-nested query to add those *along-shore* units that are classified as estuaries, whether or not a specific bioband is observed and mapped in those units. Each unit would be counted only once and would capture more units than either approach alone.

- Expand model predictions to include more than one ShoreZone unit (average length ~250 meters) to better represent an area's suitability for green crab colonization and establishment (e.g. two units (~1,000 m) or three units (~1,500 m).

An understanding of data quality is necessary when interpreting model predictions. Incomplete data or that collected prior to 1992 may not reflect current protocols. This is particularly true with respect to biological mapping (across-shore bioband observation and biological wave exposure), which was not initially performed in British Columbia and was retrofitted in some locations.

This comparison study reveals several habitat attributes that are not components of the habitat suitability model but that are mapped attributes at some green crab occurrence sites. The addition of these uncommon attributes to the suitability model would not improve predictions when examining thousands of kilometers of shoreline, but may be useful on smaller scales when fewer potential sites are available.

- Gravel flats in protected environments likely contain a mixture of fine and coarse sediments, or a thin veneer of scattered cobbles overlying sand and mud flats. Given that the majority of "gravel flats" are dominated by coarse material and not suitable green crab habitat, inclusion of gravel flats in the nested habitat queries is not recommended.
- Portions of Useless Inlet are mapped with protected wave exposure, while the very head of the inlet (nearest the sampling site) is mapped as very protected. On smaller spatial scales, this attribute could be a useful predictor of suitable habitat. However, inclusion of very protected wave exposures in the model is not recommended, owing to the need for tidal influence in highly-suitable green crab habitat.
- *Fucus* and *Ulva* are ubiquitous denizens of intertidal zones. While these algae may be beneficial to green crabs in some cases, inclusion of these biobands in nested queries to identify suitable green crab habitat in Washington, BC, and Southeast Alaska is not recommended.

REFERENCES AND ACKNOWLEDGMENTS

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Gillespie, G.E., Phillips, A.C., Paltzat, D.L., and Therriault, T.W. 2007. Status of the European Green Crab, *Carcinus maenas*, in British Columbia – 2006. Canadian Technical Report of Fisheries and Aquatic Sciences 2700. 49 p.

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.

Harney, J.N., Morris, M., and Harper, J.R. 2007. ShoreZone Coastal Habitat Mapping: Protocol for the Gulf of Alaska. 138 p. Available online at www.coastalandoceans.com and at www.coastalaska.net.

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

Model development and application was dependent on the contributions and expertise of many individuals, including: Sylvia Yamada, Linda Shaw, P. Sean McDonald, Graham Gillespie, Tom Therriault, Mattias Herborg, Catherine de Rivera, Greg Ruiz, Ted Grosholz, Kevin See, Blake Feist, Erik Hansen, John Darling, John Harper, Mary Morris, Mandy Lindeberg, Joe Banta, Roger Green, Helen Berry, and Jim Brennan.

APPENDIX A

"Hot Spot" Site Locations

Shorelines predicted as suitable habitat for the green crab are assigned a rating of 0-4 on the basis of the number of critical attributes the unit possesses. For example, the highest rating of 4 is assigned to along-shore units in which all the attributes co-occur, suggesting these locations are highly suitable green crab habitat and potential "hot spots" for colonization. Ten example hot spot locations in British Columbia and Southeast Alaska predicted by the green crab habitat suitability model are listed in Table A-1 and shown in the following figures. These example sites have a habitat rating of 4 and possess all four critical green crab habitat attributes:

- Protected or semi-protected wave exposures
- Sand and mud flats (fine sediment in the lower intertidal)
- Eelgrass in the lower intertidal or shallow subtidal zones
- Salt marsh vegetation in the supratidal zone.

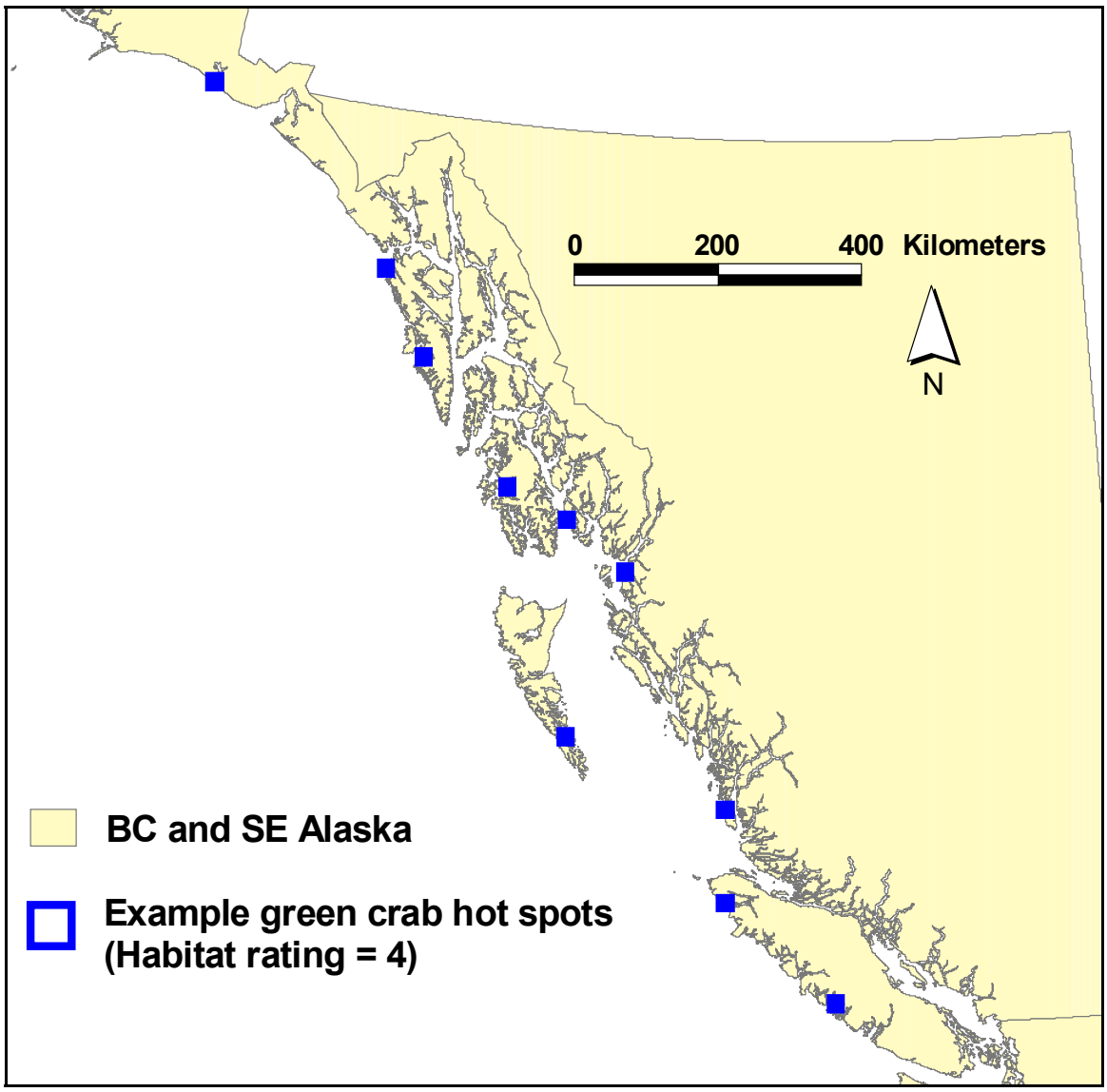
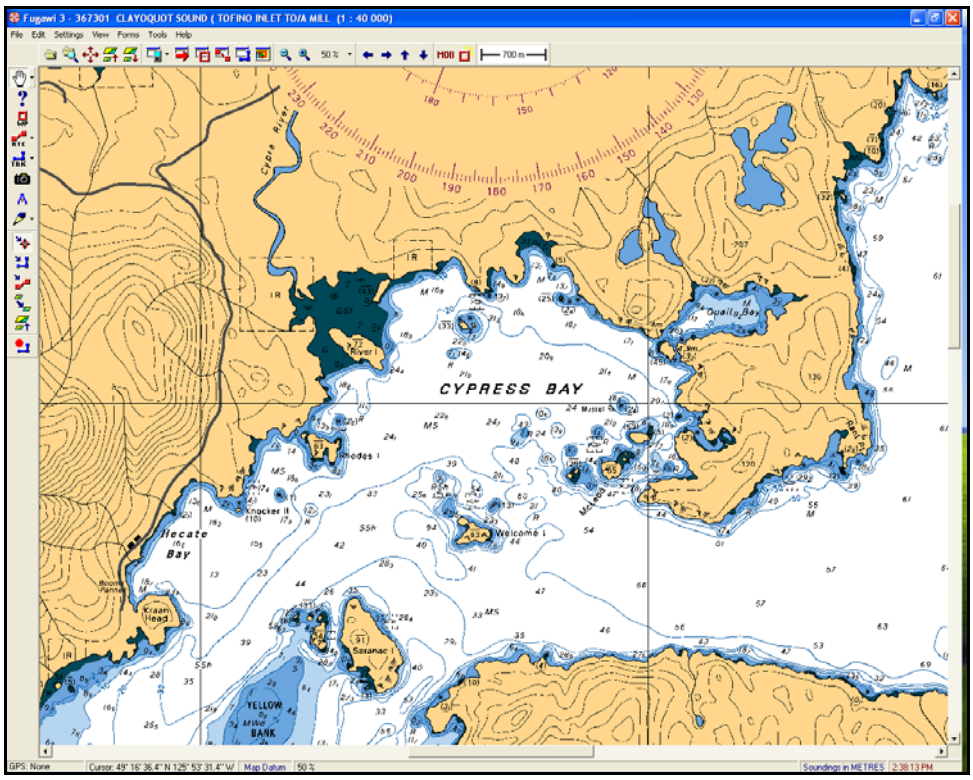


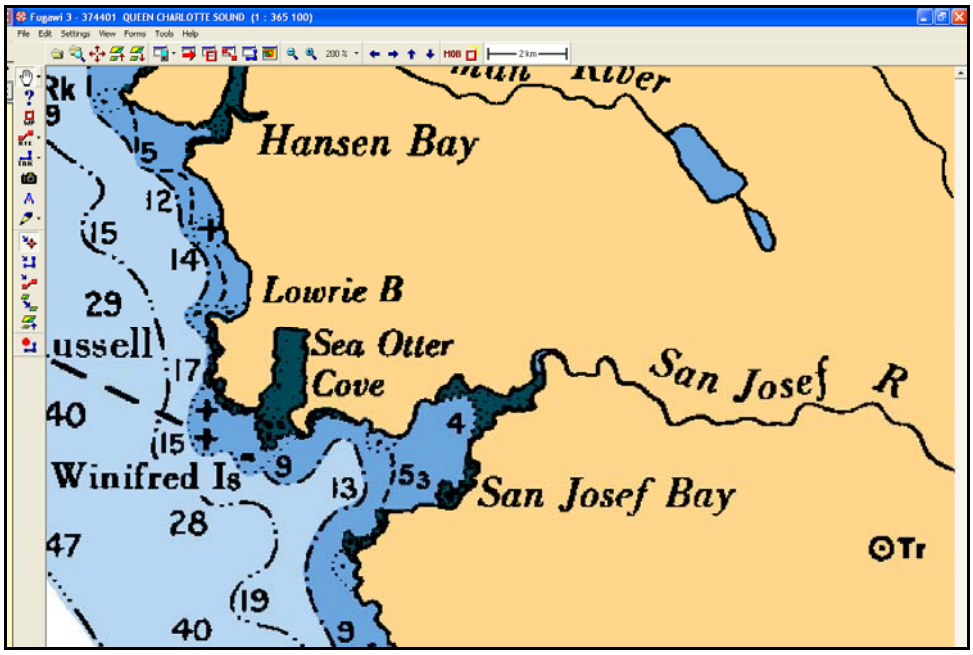
Figure A-1. Example locations of potential green crab habitat "hot spots" in British Columbia and Southeast Alaska. Each of these sites possess all four critical habitat attributes. Site names and positions are listed in Table A-1.

Table A-1. Example locations of potential green crab habitat "hot spots" in British Columbia and Southeast Alaska. Each of these sites possess the habitat suitability rating of 4. Sites 1-10 progress from south to north between Vancouver Island and the northern extent of mapping data in Southeast Alaska. The Cypress Bay position is from Gillespie et al. 2007. All other positions are extracted from GIS locations and navigational software. Sites 11 and 12 are additional sites in SE Alaska that are highly suitable habitat. Site maps from charts are provided for each site.

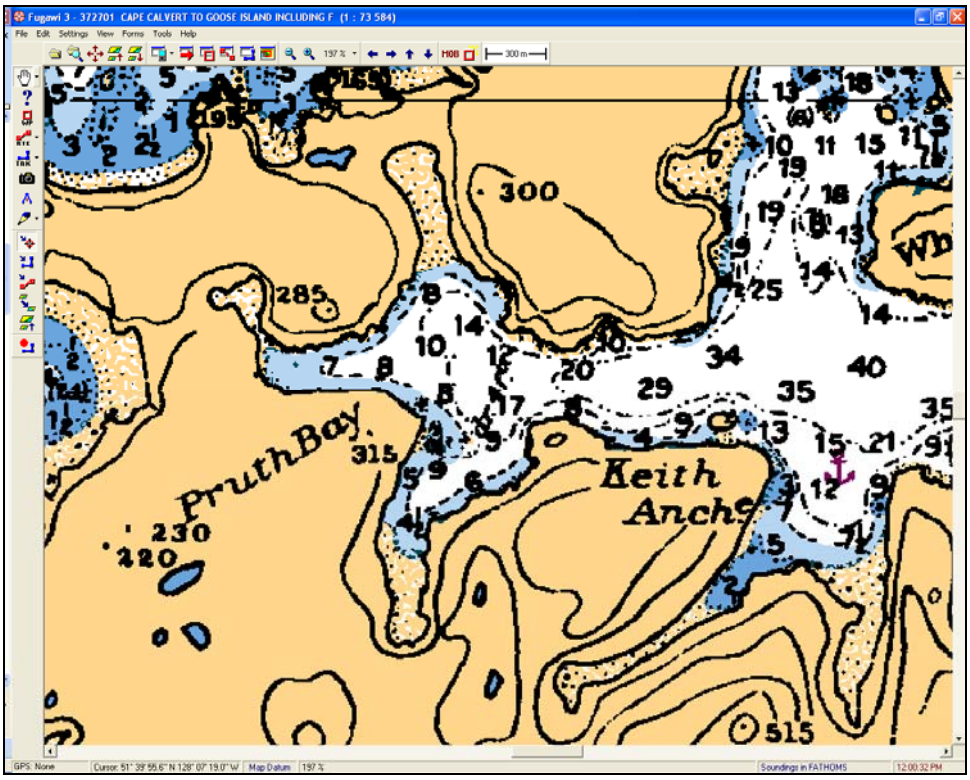
Area	Site #	Site Name	General Location	LAT	LON
British Columbia	1	Cypress Bay	West Vancouver Island	49.27500000	-125.90500000
	2	San Josef Bay	North Vancouver Island	50d 40' 11.2"	128d 17' 02.3"
	3	Pruth Bay	North Calvert Island	51d 39' 19.5"	128d 07' 48.5"
	4	Matheson Inlet (Moresby Island, Juan Perez Sound)	Southern Queen Charlotte Islands	52d 26' 53.41"	131d 28' 41.90"
	5	Port Simpson	Mainland Border BC	54d 33' 41.02"	130d 25' 59.84"
SE Alaska	6	Fish Egg Island (Klawock)	Prince of Wales Island	55d 29' 09.0"	133d 10' 30.6"
	7	Nehenta Bay, south Gravina Island	Revillagigedo Island, near Ketchikan	55d 09' 29.2"	131d 47' 07.7"
	8	Three Entrance Bay	Sitka Sound	56d 58' 38.16"	135d 21' 33.56"
	9	Surge Bay	Yakobi Island	58d 00' 57.65"	136d 33' 09.26"
	10	Riou Bay	Icy Bay	59d 53' 28.31"	141d 26' 45.84"
	11	St. James Bay	Lynn Canal	58d 37' 06.18"	135d 10' 52.03"
	12	Dundas Bay	West of Glacier Bay	58d 22' 09.68"	136d 20' 18.66"



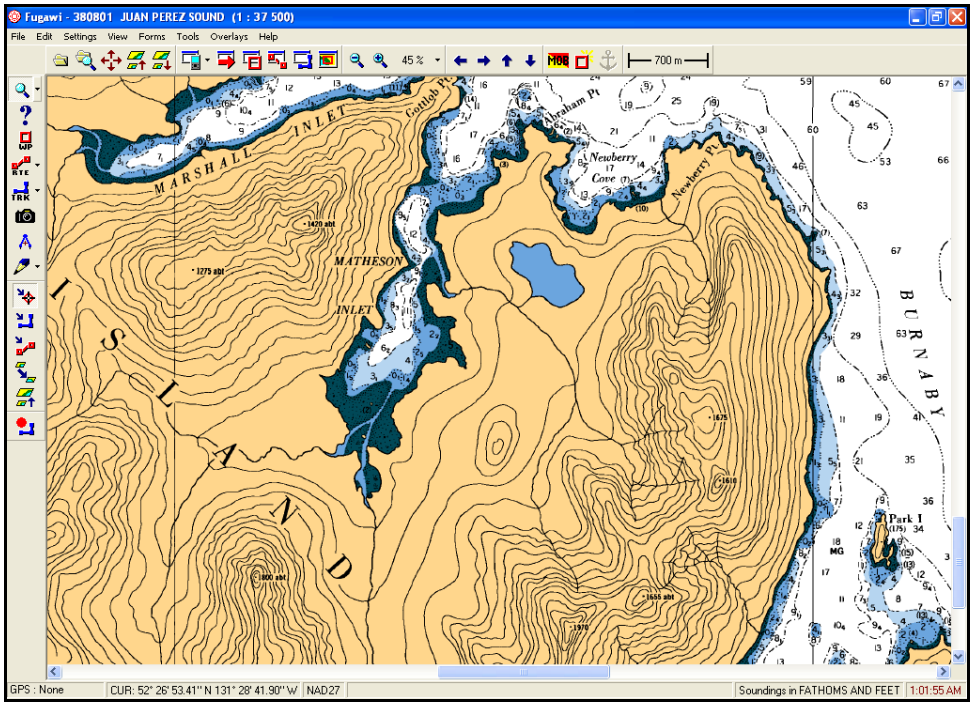
(1) Cypress Bay, West Vancouver Island



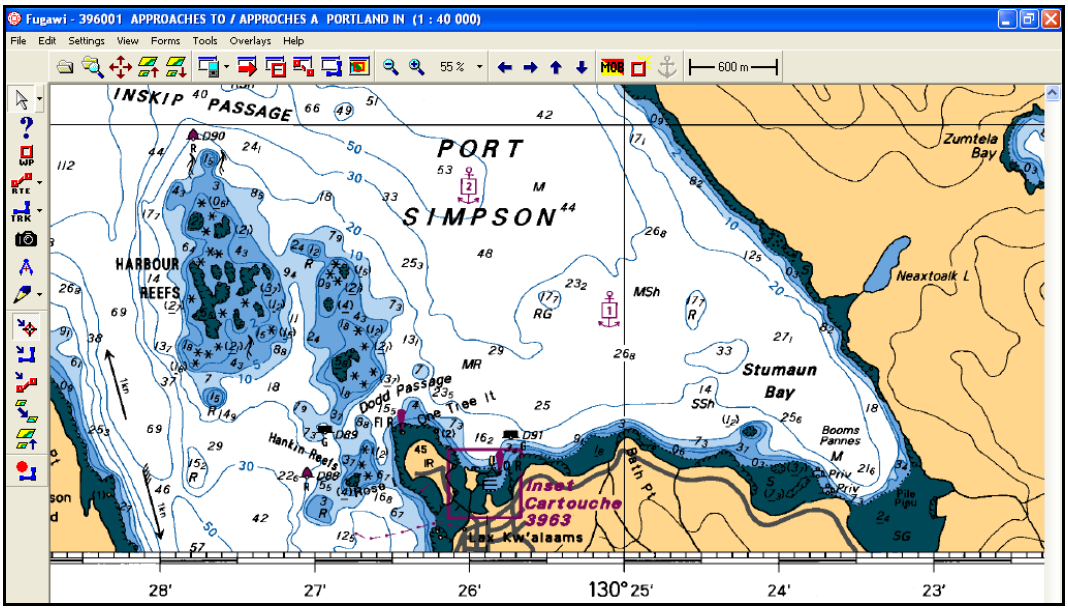
(2) San Josef Bay, North Vancouver Island



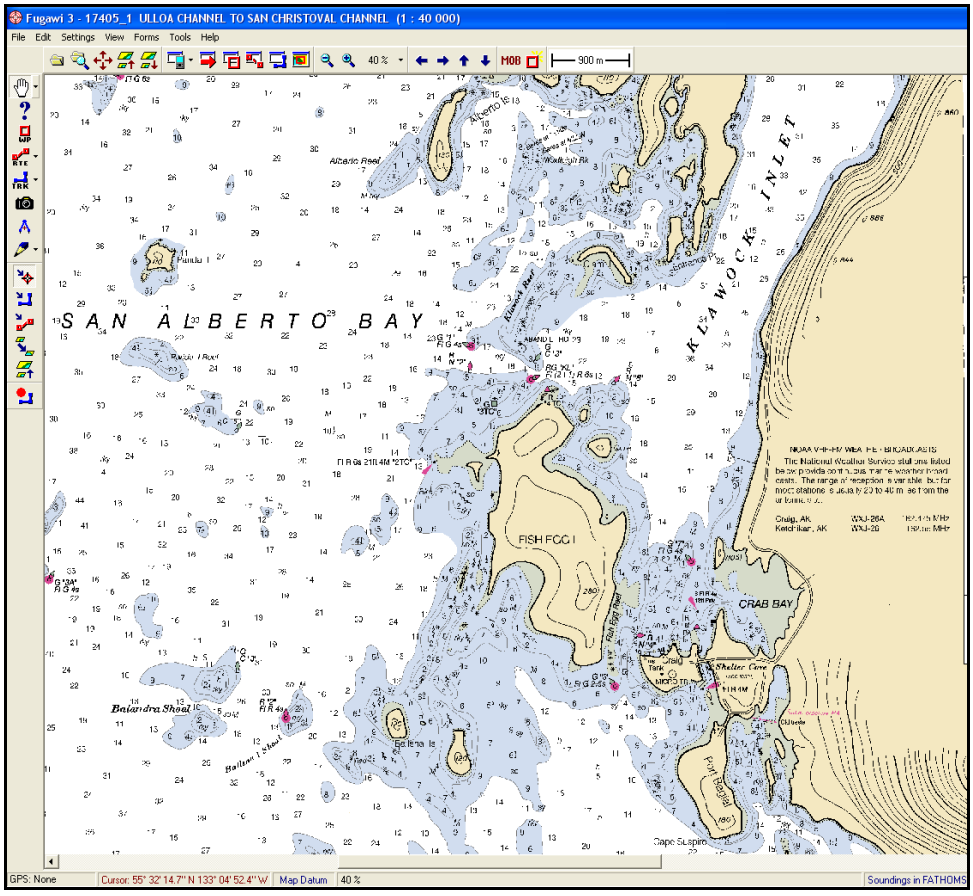
(3) Pruth Bay, North Calvert Island



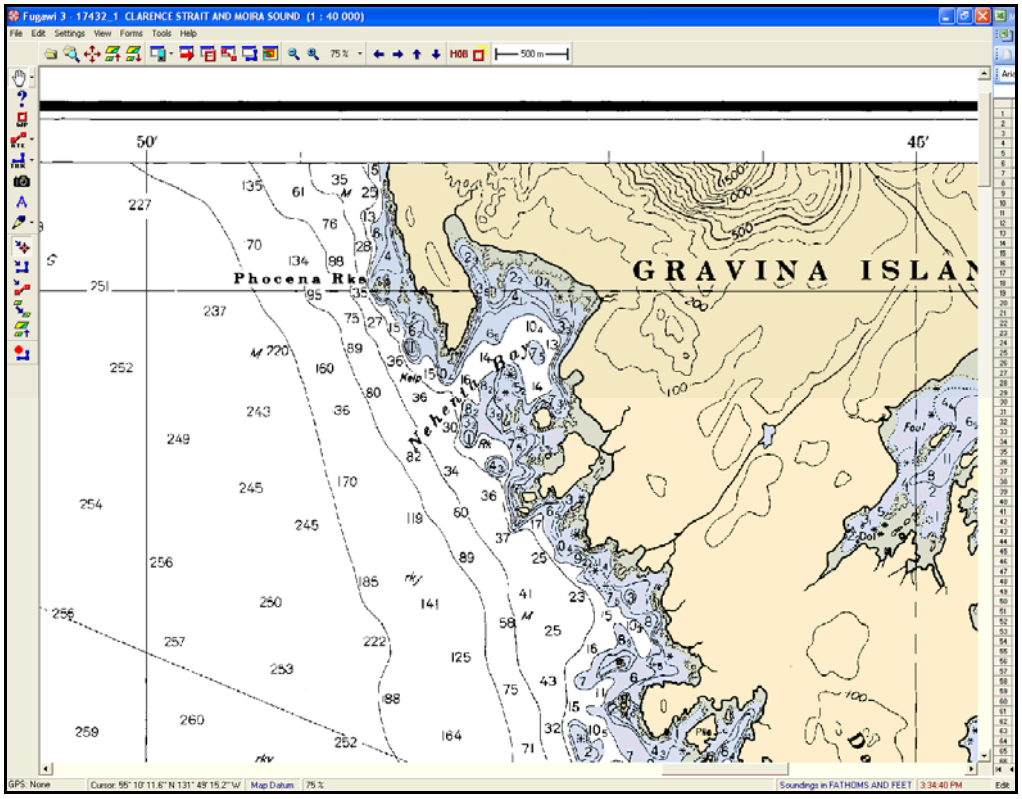
(4) Matheson Inlet Moresby Island, Juan Perez Sound (Southern Queen Charlottes)



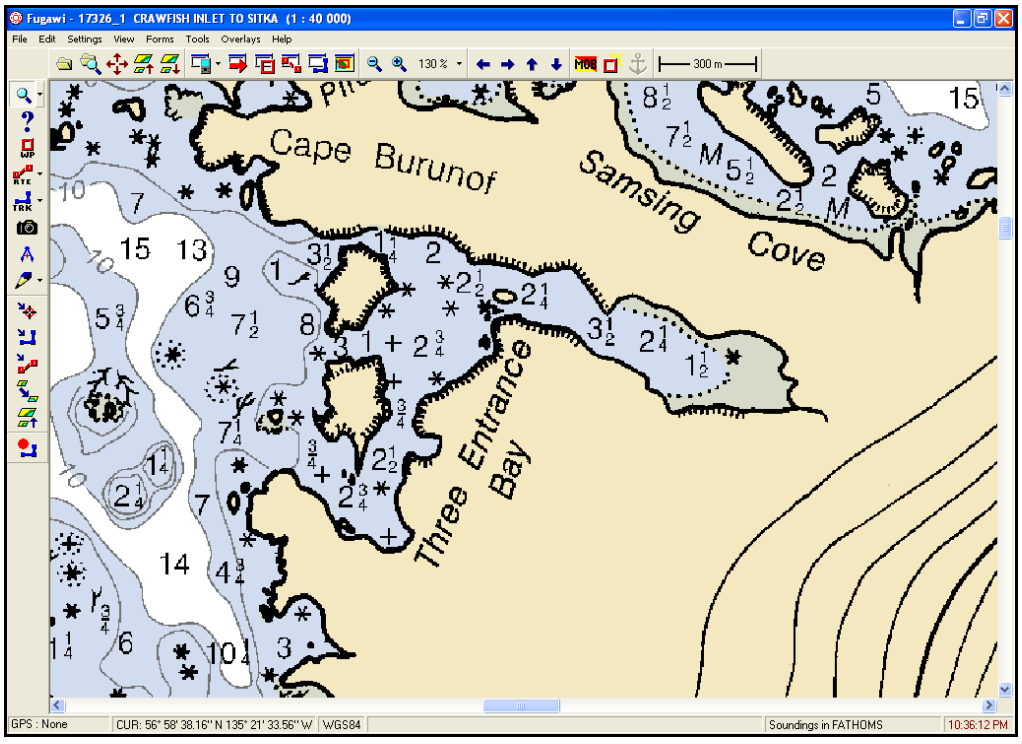
(5) Port Simpson, northern mainland British Columbia



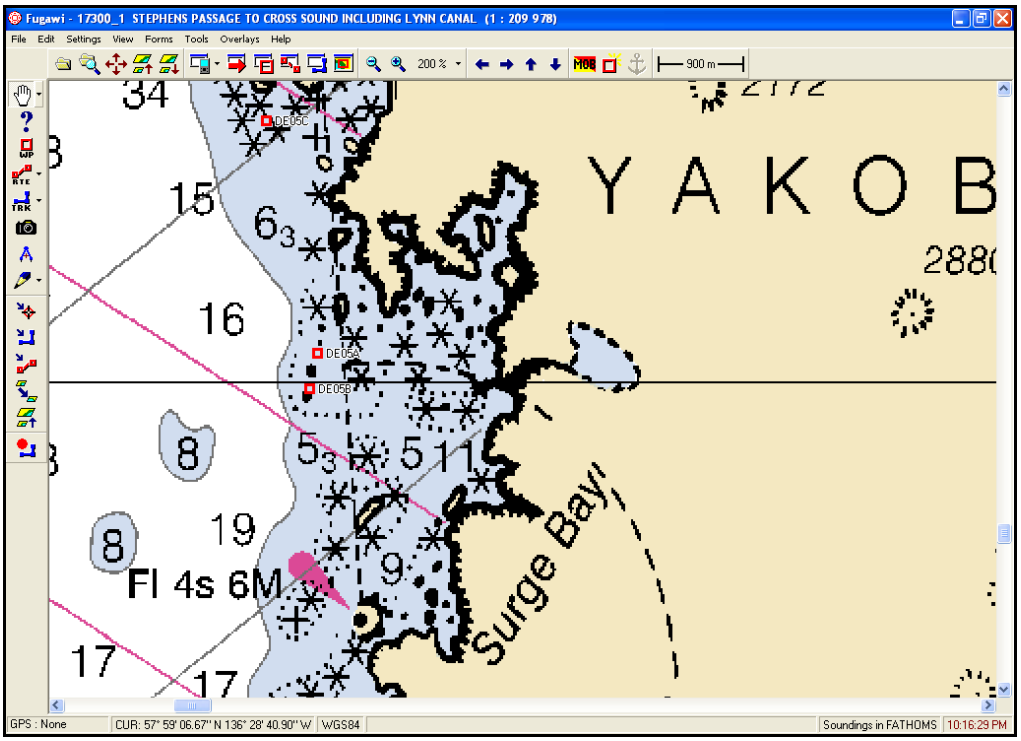
(6) Fish Egg Island (Klawock), Prince of Wales Island, SE Alaska



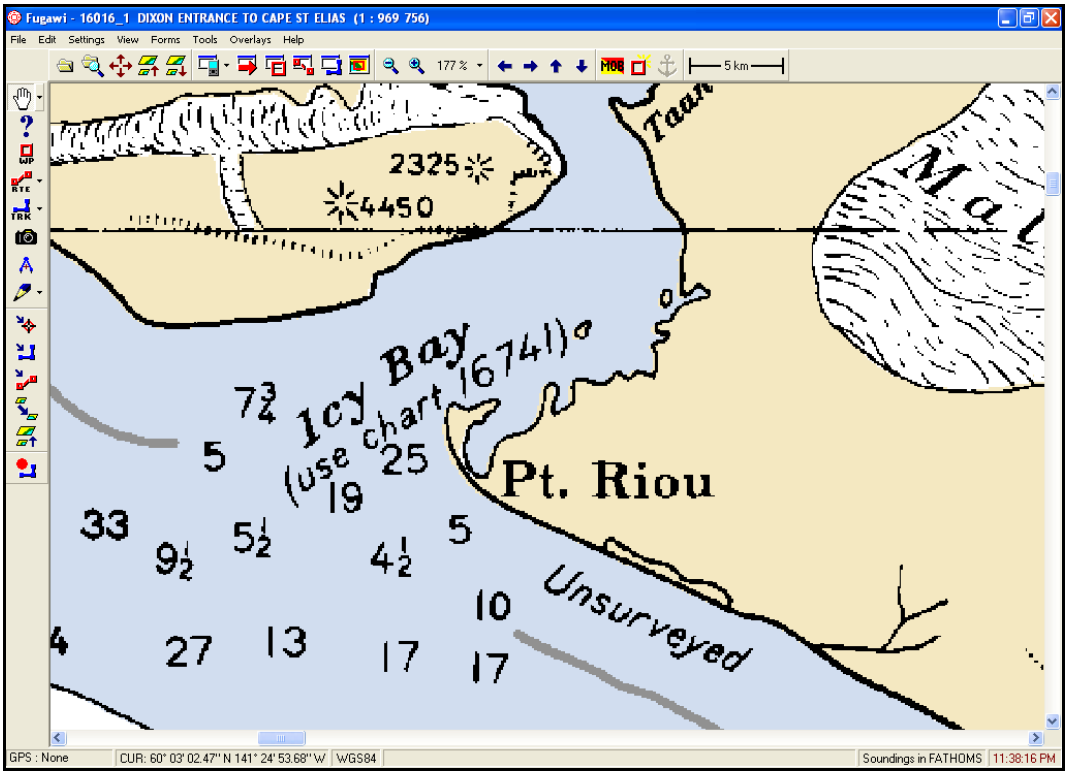
(7) Nehenta Bay, Gravina Island



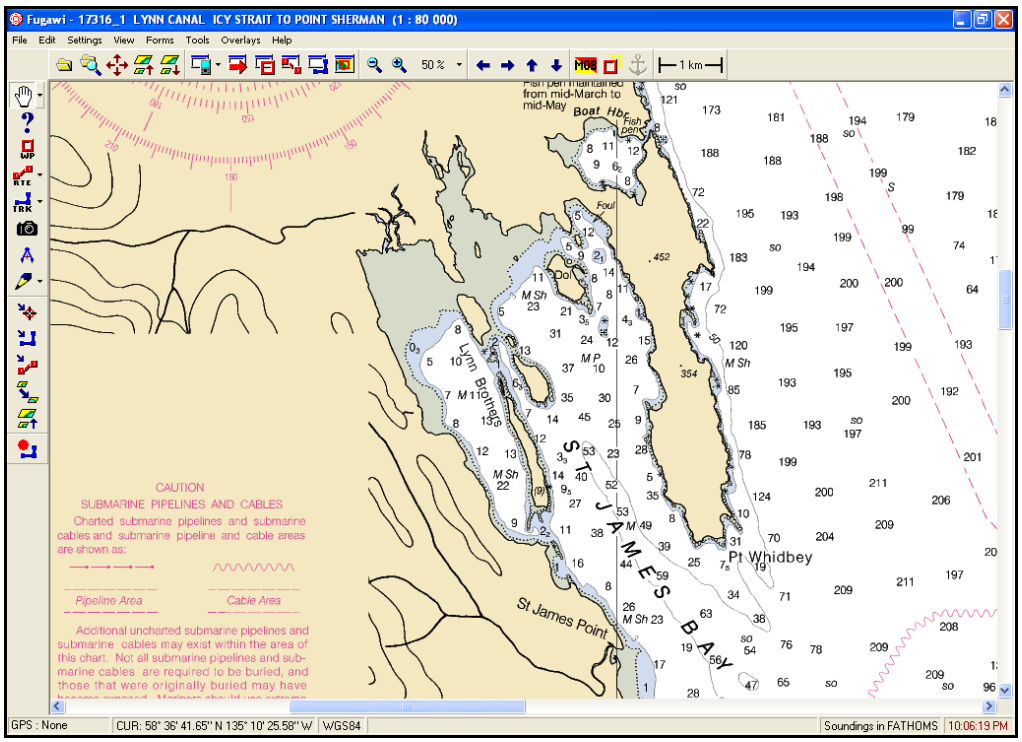
(8) Three Entrance Bay, Sitka Sound



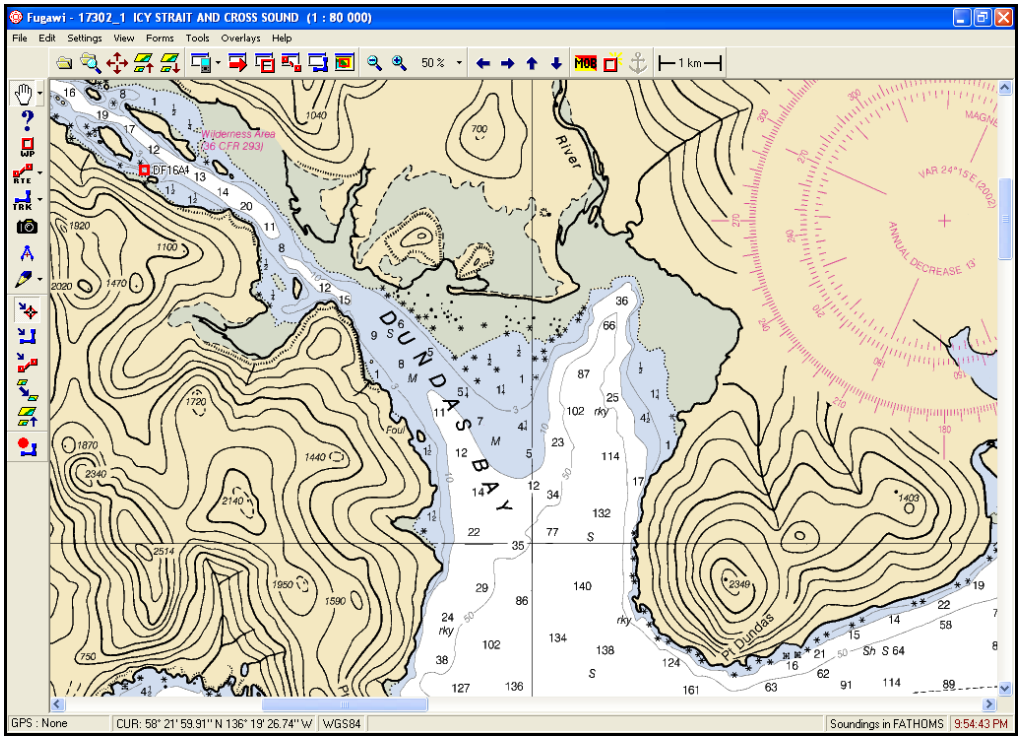
(9) Surge Bay, Yakobi Island



(10) Riou Bay, Icy Bay, north of Yakutat



(11) St. James Bay, Lynn Canal



(12) Dundas Bay, west of Glacier Bay in Icy Strait

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.

Description	File Name	km	Figure	Map
Arc Map 9.3 Project File	BC_GreenCrab_ModelTest_14Jul08.mxd	--	--	--
ShoreZone Shapefiles:				
BC ShoreZone Data (including Gulf Islands)	bc_gi_shorezone.shp	37,605	1A, 1B	--
Protected or Semi-Protected Wave Exposure	bc_exposure_p_sp.shp	25,179	1A	bc_wave_exposure.jpg
Mud or Sand Flats	bc_mudflats_sandflats.shp	1,780	1B	bc_flats.jpg
Eelgrass	bc_eelgrass.shp	5,469	2A	bc_eelgrass.jpg
Salt Marsh	bc_saltmarsh.shp	6,608	2B	bc_saltmarsh.jpg
Rating 2 (exposure, flats)	rating2_flat_sp_p.shp	1,699	3	bc_rating2_psp_flats.wmf
Rating 3 (exposure, flats, eelgrass)	rating3_flat_sp_p_zos.shp	498	4	bc_rating3_psp_flats_eelgrass.wmf
Rating 3 (exposure, flats, saltmarsh)	rating3_flat_sp_p_sal.shp	1,471	5	bc_rating3_psp_flats_saltmarsh.wmf
Rating 4 (exposure, flats, eelgrass, saltmarsh)	rating4_flat_sp_p_zos_sal.shp	434	6	bc_rating4_psp_flats_eelgrass_saltmarsh.wmf
Green crab occurrence sites (from Gillespie et al. 2007)	bc_green_crab_locations.shp	--	7	bc_green_crab_sites.jpg
Shoreline Basemaps:				
Alaska, Washington, BC map (for display only)	ak_bc_wash_bcalbers.shp	--	--	--
Canadian Hydrographic Service high-water shoreline	CHS_highwaterpoly_BCAlbers.shp	--	--	--
Additional Maps:				
West Vancouver Island green crab occurrence sites and mapped wave exposure (overview)		--	8	west_van_site_exposure_overview.wmf
Kyuquot green crab occurrence site and mapped attributes		--	9	kyuquot.jpg
Esperanza Inlet green crab occurrence sites and mapped wave exposure (overview)		--	10	esperanza_overview.wmf
Port Eliza green crab occurrence site and mapped attributes		--	11A	eliza.jpg
Queen Cove green crab occurrence sites and mapped attributes		--	11B	queencove.jpg
Espinosa Inlet sites and mapped attributes		--	12A	espinosa.jpg
Zeballos site and mapped attributes		--	12B	zeballos.jpg
Clayoquot Sound green crab occurrence sites and mapped wave exposure (overview)		--	13	clayoquot_overview.wmf
Pretty Girl Cove and Whiskey Jenny Beach green crab occurrence sites and mapped attributes		--	14A	prettygirl_whiskeyjenny.jpg
Whitepine Cove and Cypress Bay green crab occurrence sites and mapped attributes		--	14B	whitepinecove_cypressbay.jpg
Lemmens Inlet green crab occurrence site and mapped attributes		--	15A	lemmens.jpg
Warn Bay green crab occurrence site and mapped attributes		--	15B	warnbay.jpg
Nootka Sound green crab occurrence sites and mapped wave exposure (overview)		--	16	nootka_overview.wmf
Bligh Island green crab occurrence site and mapped attributes		--	17A	blighisland.jpg
Mooyah Bay green crab occurrence site and mapped attributes		--	17B	mooyahbay.jpg
Barkley Sound green crab occurrence sites and mapped wave exposure (overview)		--	18	barkleysound_overview.wmf
Barkley Sound green crab occurrence sites and mapped attributes		--	19	barkleysound_allsites.jpg
Green crab habitat example hot spots[3]		--	A-1	BC_SEAlaska_hotspot_sitemap.wmf
Reports and Reference Materials:				
Alaska ShoreZone Program Map (July 2008)				Alaska_ShoreZone_Jul08.jpg
Green Crab Habitat Modeling Report (2007)	Harney_GreenCrabReport_Aug07.pdf	--	--	--
ShoreZone Fact Sheet (2007)	ShoreZone_FactSheet_Oct07.pdf	--	--	--
ShoreZone Protocol for the Gulf of Alaska (2007)	ShoreZone_GOA_Protocol_2007.pdf	--	--	--