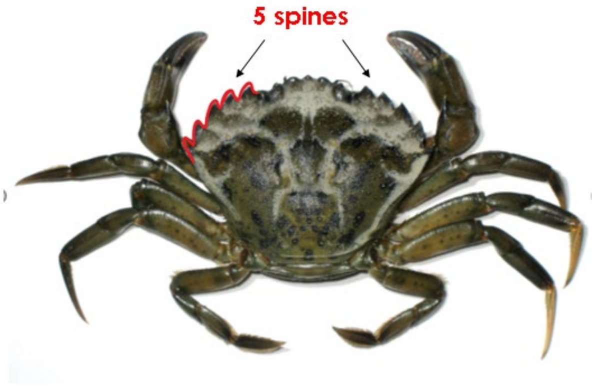
Fisheries and Oceans Canada
Pêches et Océans Canada

Ecosystems and Oceans Science
Sciences des écosystèmes et des océans

Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2022/037

EVALUATION OF METHODS FOR IDENTIFICATION OF EARLY DETECTION MONITORING SITES BASED ON HABITAT SUITABILITY FOR INVASIVE EUROPEAN GREEN CRAB IN THE SALISH SEA, BRITISH COLUMBIA



European Green Crab. Photo credit: [DFO](#).

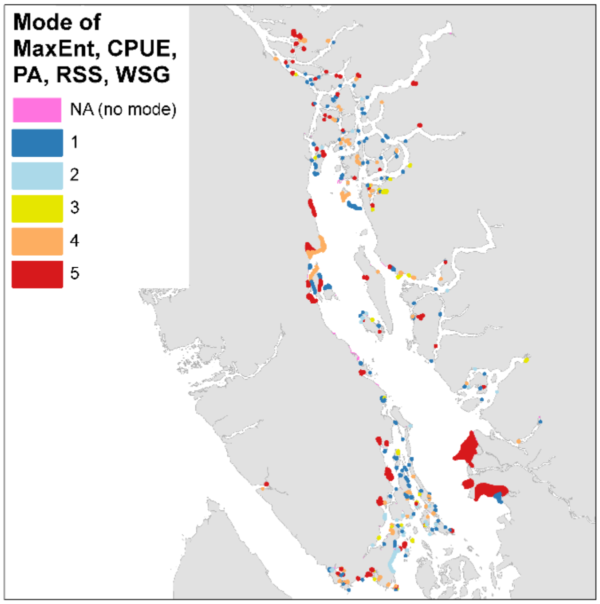


Figure 1. Potential monitoring sites for European Green Crab (EGC) in the Salish Sea. Sites were identified by calculating the mode (the most frequent value) across the five input models at each site.

Context:

The European Green Crab (EGC) is a high risk invader that is listed as a Control Species under the Aquatic Invasive Species (AIS) Regulations in the Fisheries Act. EGC can devastate aquatic ecosystems, displacing native species, degrading and disturbing native habitats (including eelgrass), and altering food webs.

To better understand the incursion of EGC into the Salish Sea, Fisheries and Oceans Canada's (DFO's) Ecosystem Management Branch (EMB) and AIS Science programs worked with the Washington Department of Fish and Wildlife, Washington Sea Grant's Crab Team, and University of Washington to develop a Salish Sea Transboundary Action Plan for Invasive European Green Crab. This plan lays out early detection (monitoring) recommendations but does not specify how to identify or prioritize intertidal sites for EGC monitoring.

Additionally, DFO's Aquatic Invasive Species National Core Program has been working to develop a monitoring program for the early detection of EGC throughout coastal BC, with a focus on the Salish Sea. Given the extreme spatial extent to be monitored, efforts must involve citizen science and

August 2022

Indigenous groups focusing on sites most likely to have EGC. Thus, prioritized monitoring sites for EGC in Canadian waters of the Salish Sea are urgently needed and the approach could be extended to other coastal areas in the future. DFO's Fish and Fish Habitat Protection Program (FFHPP - AIS) in Pacific Region has requested that Science Branch evaluate a range of models to inform their monitoring program and in particular, trap site selection for EGC.

This Science Advisory Report is from the January 31-February 2, 2022 regional peer review of the Evaluation of Methods for Identification of Early Detection Monitoring Sites for Invasive European Green Crab in the Salish Sea, British Columbia. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- European Green Crab (EGC; *Carcinus maenas*) was first detected in Sooke Basin in 2012, and in US waters of the Salish Sea in 2016. EGC is not yet known to be established in Canadian waters of the Salish Sea outside of Sooke, presenting an opportunity for early detection and management of newly invaded areas.
- AIS managers require information on where to target early detection monitoring programs. As such five existing models were evaluated based on habitat suitability using 447 sites in the Salish Sea.
- Each of the five individual models was informative at identifying sites suitable for EGC in Canadian waters of the Salish Sea but there was generally low agreement among models, likely because each model incorporates different aspects of EGC biology and habitat use. Without an independent validation dataset it was not possible to identify a single "best" model to identify early detection sites.
- An ensemble model approach can buffer uncertainty arising from individual models by combining the outputs of multiple individual models. To incorporate all of the models in an ensemble, the outputs for each model were rank-transformed into 20th percentiles (i.e., rescaled values 1-5), and the 'mode' (most frequent) value across all five models was determined for each site (n = 447). The 68 sites with a rank-transformed mode of 5 were prioritized for early detection monitoring (see Figure 1).
- While the 68 sites identified can serve as a starting point, there are other considerations beyond habitat suitability when selecting specific monitoring sites for EGC in the Salish Sea that were beyond the scope of this process. Managers may choose to add or remove sites as needed based on likelihood of arrival (e.g., through larval drift, human-mediated movements, immigration); presence of other important features (e.g., eelgrass); presence of available prey/absence of predators; ecologically, economically, or culturally important areas; site access; or partner interest.
- The ensemble model approach developed here may be applied elsewhere by using or deriving models specific for that region, based on the available data and management objectives. However, the input data does not capture all factors, including propagule pressure, that may contribute to invasion success.

INTRODUCTION

The European Green Crab (EGC) is a high risk aquatic invasive species known to devastate aquatic ecosystems, displace native species, degrade and disturb native habitats (including eelgrass), and alter food webs. This species was first introduced to the west coast of North America in San Francisco Bay around 1990 and spread north reaching British Columbia (BC) by the late 1990s. EGC expanded rapidly on the west coast of Vancouver Island, and has since been detected on the Central Coast of BC and Haida Gwaii. However, EGC did not appear in the Salish Sea until 2012, when they were introduced via human-mediated activities to Sooke Basin. In 2016, the first detection of EGC in the Salish Sea outside of the Sooke Basin occurred in US waters; it has since been detected at multiple sites on both the US and Canadian sides of the Salish Sea. It is believed the long delay in EGC range expansion into and around the Salish Sea is due to oceanographic processes limiting larval dispersal, rather than a lack of suitable habitat.

Detecting and eradicating invasive species in new areas while their numbers are still low is a crucial step in effective invasive species management. As such, Fisheries and Oceans Canada’s (DFO’s) Ecosystem Management Branch (EMB) and AIS Science programs worked with the Washington Department of Fish and Wildlife, Washington Sea Grant’s Crab Team, and University of Washington to develop a Salish Sea Transboundary Action Plan for Invasive European Green Crab (Drinkwin et al. 2019). This plan lays out early detection (monitoring) recommendations for the Salish Sea, but does not specify how to identify or prioritize intertidal sites for EGC monitoring. DFO's Aquatic Invasive Species National Core Program, along with citizen science and Indigenous groups, have been working to develop a monitoring program for the early detection of EGC throughout coastal BC, with a focus on the Salish Sea. However, given the extreme spatial extent to be monitored there was an urgent need prioritize potential monitoring sites for EGC in Canadian waters of the Salish Sea based on suitability for EGC. A prioritization approach could also be extended to other coastal areas in the future.

A variety of methods have been implemented by different users to identify suitable habitat for EGC at a range of spatial scales, but the outputs have not been evaluated in the context of EGC management nor for the Canadian portion of the Salish Sea specifically. Here, five habitat suitability models and site selection tools were evaluated to provide recommendations for EGC trapping sites in the Salish Sea. This assessment fulfils a need identified by the DFO AIS Management program and contributes to DFO’s international commitment related to the Bilateral EGC Action Plan.

The specific objectives of this review were to:

1. Evaluate the strengths/weaknesses associated with four different methods of assessing habitat suitability for EGC, for the purpose of identifying potential monitoring sites in Canadian waters of the Salish Sea. Specifically reviewing: 1) MaxEnt; 2) Stochastic gradient boosted regression models; 3) Washington Sea Grant’s Crab Team’s site assessment tool; and 4) DFO Science’s rapid site selection tool.
2. Identify uncertainties in each of the tools evaluated in Objective 1.
3. Identify sites for EGC monitoring in Canadian waters of the Salish Sea using the preferred method(s) evaluated in Objective 1.
4. Characterize the feasibility of using the preferred method(s) to identify potential monitoring sites throughout coastal BC in the future.

ANALYSIS

Five individual species distribution models or site selection tools based on habitat suitability (hereafter termed “models”; described below) were used as the main inputs for this analysis. Although each was developed independently and for different purposes, all have been validated and have the capacity to inform EGC management with respect to early detection/monitoring site selection. The functionality of these models, both individually and in combination, were evaluated to identify a reasonable number of possible early detection/monitoring sites in Canadian waters of the Salish Sea for EGC (Objective 3). Although the internal validity and accuracy of these individual models was reviewed, the focus was on how they compare to and complement each other when applied to site selection (Objective 1). There is currently insufficient data on EGC occurrence in the Salish Sea to statistically assess each models' predictive accuracy. As such, analyses here focus on the amount of agreement in the predictions among models. An important assumption is that all of the models are able to capture some of the complexity of EGC biology and factors affecting invasion success in their predictions, but none are perfect and limitations are noted (Objective 2). Finally, this approach can be used to identify additional monitoring sites based on habitat suitability either in the Salish Sea or elsewhere in British Columbia based on available data (Objective 4).

Data and methods

To facilitate comparison among models, the analysis was limited to a set of 447 discrete sites in Canadian waters of the Salish Sea. Although some of the individual models used in this analysis predict over the entire coast, it was necessary to scale down to a discrete, predetermined set of sites since several of the models require site-specific information to make predictions. The sites include all areas previously surveyed for EGC by DFO in the Salish Sea and randomly generated locations along the coastline. Random sites were added to dilute the inherent bias in previously surveyed sites, which would have been selected with some expectation of finding EGC.

Five different models have been created to help understand the possible future distribution of EGC on the west coast of North America based on habitat suitability and to support management decision making. The models were: MaxEnt, linear boosted regression tree (presence-absence, “PA”), logistic boosted regression tree (abundance/catch per unit effort, “CPUE”), rapid site selection (RSS), and a modified version of the Washington Sea Grant (WSG) tool. Table 1 provides an overview of the characteristics, inputs, and outputs of each of these five individual models.

Each of the individual models has their own strengths and weaknesses (Table 2), especially with respect to predictions. One key statistical assumption for species distribution models is that distributions are at equilibrium; however, because the range of EGC is still expanding through BC (including the Salish Sea), this assumption is clearly violated. One way to overcome potential limitations and uncertainty associated with individual models is to take a multi-model approach (e.g., ensemble models) when making predictions. Such approaches are advantageous because while individual models can be informative, few can completely capture all the complexity of a species' biology.

An additional five derived models were produced by combining the outputs of the five individual models. First, the two BRT outputs were combined. The continuous non-zero CPUE predictions (“CPUE” model) were multiplied by the probability of EGC presence (“PA” model) at each site, resulting in a conditional abundance model (CPUE*PA) that predicts the expected CPUE of EGC, if present at a site. Because the MaxEnt model output also predicts the probability of EGC presence, we produced a second derived conditional abundance model (CPUE*MaxEnt). The remaining three derived models also used MaxEnt output, multiplied by the output of the other individual models. The rationale for this was that the BRTs, RSS and modified WSG models all rely on static, site-specific habitat characteristics as their primary input variables. In contrast, MaxEnt uses environmental conditions (i.e., temperature, salinity) and incorporates seasonality into its predictions (Table 1). Thus, it was hypothesized that the product of the MaxEnt output and the other habitat-based outputs would be more likely to capture the full range of abiotic and biotic conditions affecting EGC occurrence at various sites in the Salish Sea. These derived models were annotated as: PA*MaxEnt, RSS*MaxEnt, and WSG*MaxEnt.

Table 1. Overview of the five individual models used to generate predictions of suitable habitat for EGC in Canadian waters of the Salish Sea. BRT = Boosted Regression Tree.

Model Traits	MaxEnt EGC Model	Linear BRT EGC Model (“PA”)	Logistic BRT EGC Model (“CPUE”)	Rapid Site Selection (RSS) Tool	Washington Sea Grant (WSG) Crab Team Method
General method and output	Species distribution model that predicts probability of presence (0-1) of an established EGC population.	Predictive linear regression model for relative abundance (catch-per-unit effort, 0 – ∞) of EGC for individual sites.	Predictive logistic regression model for probability of presence (0-1) of EGC for individual sites.	Automated identification and ranking (ordinal score from 0-1) of coastal areas where important abiotic habitat variables for EGC are present.	Manual scoring system to identify and rank (ordinal score from 0-1) individual sites for early detection of EGC using aerial or satellite imagery.
Spatial scale	Original model coverage available for west coast of North America.	Developed using data from the west coast of Vancouver Island.	Developed using data from the west coast of Vancouver Island.	Developed for the entire coast of BC. Implemented in the Canadian Salish Sea, Haida Gwaii, and North Coast.	Created for the Washington coast and US Salish Sea Modified and implemented in the Canadian Salish Sea.
Temporal scale	Includes seasonal climatologies for salinity and sea surface temperature.	Uses data from ongoing trapping surveys for EGC. Otherwise all input variables temporally static.	Uses data from ongoing trapping surveys for EGC. Otherwise all input variables temporally static.	All input variables temporally static.	All input variables temporally static.
Abiotic inputs	Salinity (seasonal) Sea surface temperature (seasonal)	Intertidal area Edge length Beach isolation Widest point of beach Fetch (max, min) Wave exposure (ShoreZone) Bottom type (substrate) Substrate type (ShoreZone) Sediment type (ShoreZone) Slope (ShoreZone) Width (ShoreZone)	Intertidal area Edge length Beach isolation Widest point of beach Fetch (max, min) Wave exposure (ShoreZone) Bottom type (substrate) Substrate type (ShoreZone) Sediment type (ShoreZone) Slope (ShoreZone) Width (ShoreZone)	Beach width Freshwater input Substrate type (ShoreZone)	Beach isolation Beach width Freshwater input Shelter Wave energy Tidal channels
Biotic inputs	Species occurrence data (presence-only)	Eelgrass likelihood ShoreZone biobands	Eelgrass likelihood ShoreZone biobands	–	Presence/ absence of terrestrial vegetation

Model Traits	MaxEnt EGC Model	Linear BRT EGC Model (“PA”)	Logistic BRT EGC Model (“CPUE”)	Rapid Site Selection (RSS) Tool	Washington Sea Grant (WSG) Crab Team Method
		EGC CPUE	EGC presence/ absence		

Table 2. Usability of the five individual models highlighting the data processing requirements, technical expertise and feasibility of use for new sites or new areas.

Useability Traits	MaxEnt EGC Model	Linear boosted regression tree EGC Model (“PA”)	Logistic Boosted Regression Tree EGC Model (“CPUE”)	Rapid Site Selection (RSS) Tool	Modified Washington Sea Grant (WSG) Crab Team Method
Data required	A limited number of spatial data layers that cover the study area and presence-only records for EGC.	Many spatial data layers to extract site-specific information and catch data for EGC.	Many spatial data layers to extract site-specific information and either catch data or presence/ absence data for EGC.	A limited number of spatial data layers that cover the study area.	No data requirements. High quality aerial and/or satellite imagery recommended.
Technical expertise	Statistics, coding, MaxEnt modelling techniques and GIS software.	Statistics, coding, and GIS software.	Statistics, coding, and GIS software.	GIS software.	None.
Resolution of output	Coast-wide, 0.04 degree resolution with values from multiple grid cells averaged for individual sites.	Individual, pre-defined sites of interest.	Individual, pre-defined sites of interest.	Coast-wide identification of possible sites.	Individual, pre-defined sites of interest.
Repeatability	High (mathematical model)	High (mathematical model)	High (mathematical model)	High (automated process)	Unknown, but possibly low due to subjectivity of method.
Update frequency	When new climatology data is available, or as new information on distribution of EGC is collected.	When new or improved spatial layers become available, or as new EGC trapping survey data is collected (from west coast Van. Isl.).	When new or improved spatial layers become available, or as new EGC trapping survey data is collected (from west coast Van. Isl.).	When new or improved spatial layers become available.	When new or improved aerial or satellite imagery becomes available for areas/sites of interest.
Applicability for new sites/areas	Existing model can be applied rapidly, as coast-wide raster is already available. Only requires defining areas or sites of interest.	Requires significant data collection using GIS analysis for all new sites of interest, but model itself can be run quickly.	Requires significant data collection using GIS analysis for all new sites of interest, but model itself can be run quickly.	Can be applied rapidly (1-2 days) as process is automatic and does not require sites of interest to be identified in advance.	Can be applied instantly, provided sites of interest have already been identified.

Model standardization

Each of the five individual models and five derived models represent different aspects of EGC ecology, with response values that are not directly comparable (e.g., probability of presence vs. predicted CPUE). To facilitate model comparisons, the output for each of the models was rank-transformed, except RSS and WSG, into 20% percentiles (quantiles); i.e., percentile 1-20 = 1, percentile 21-40 = 2, percentile 41-60 = 3, percentile 61-80 = 4, and percentile 81-100 = 5. Transformation of the five derived models was done in the same way, after multiplying the respective individual model outputs. Quantile transformations were not carried out for the individual RSS and modified WSG models because their outputs were already ordinal categories of suitability, not continuous values. To keep all models on the same scale, the RSS and modified WSG outputs were converted as follows: 0 = 1, 0.25 = 2, 0.50 = 3, 0.75 = 4, 1.00 = 5.

Analysis of model agreement

Since EGC have only recently been observed in the Salish Sea and this invasion is not yet considered complete, there is no independent dataset to evaluate model performance. Thus, model agreement, which is an assessment of the amount of overlap in model predictions across all 447 sites was used to identify early detection sites for EGC in Canadian waters of the Salish Sea. This analysis relies on the assumption that all the models accurately capture some aspects of EGC biology in making their predictions. Quantiles were used as a standardized metric to assess model agreement. Model agreement was first assessed between the individual and derived models by calculating the number of sites where the rank-transformed model values agreed, out of the total number of sites where both models had data (Table 3).

Relatively low agreement among the various individual and derived models was observed so it was not possible to identify a single ‘best’ model. An alternative approach to assessing agreement is by considering multiple models at the same time (i.e., an ensemble), thus buffering the uncertainty inherent in using a single model.

Table 3. Agreement between predictions made by individual models, based on the number of sites where the rank-transformed model values agree, out of the number of sites where both models have data (ranging from 444-447). Values above 50% are bolded.

Model	CPUE	PA	MaxEnt	RSS	WSG	CPUE* PA	CPUE* MaxEnt	PA* MaxEnt	RSS* MaxEnt	WSG* MaxEnt
CPUE	–	25	20	27	25	33	44	23	23	23
PA	–	–	19	24	24	**54**	23	**60**	24	24
MaxEnt	–	–	–	20	19	22	37	28	28	33
RSS	–	–	–	–	42	25	24	22	41	28
WSG	–	–	–	–	–	23	22	19	27	37
CPUE* PA	–	–	–	–	–	–	36	**51**	25	30
CPUE* MaxEnt	–	–	–	–	–	–	–	27	30	32
PA* MaxEnt	–	–	–	–	–	–	–	–	31	36
RSS* MaxEnt	–	–	–	–	–	–	–	–	–	40

Using rank-transformed values for ensemble model predictions

To create the ensemble models, combinations of 3, 4, or all 5 of the original (individual) models were generated. Derived models were not considered in the ensembles as this would over-represent the MaxEnt model outputs in the ensemble predictions, as MaxEnt is a component of 4 of the 5 derived models. For each combination of individual models, the agreement among their standardized, rank-transformed values was used to determine site suitability for EGC. ‘Suitability’ was defined as any site with a rank-transformed value of 5 (i.e., outputs above the 80th percentile or a raw score of 1.0 for models with ordinal responses). To assess the effect of using the 80th percentile when determining habitat suitability, a sensitivity analysis using outputs above the 60th percentile (rank-transformed values of 4 or 5, or values of 0.75 for the RSS and WSG models) was conducted. Using a lower threshold to indicate habitat suitability identified a greater number of potential sites than using a higher threshold.

Three levels of agreement, defined as mode, union, and intersect ensemble models (each with its own strengths and weaknesses) were evaluated (Figure 2). Intersect models had the most conservative definition of agreement, as a site would only be assigned a value of 5 (i.e., suitable for EGC) if *all* models in the combination had predicted a rank of 5 for that site (i.e., intersection = “AND”). Union models had the least conservative definition of agreement, as a site would be assigned a value of 5 if *any* model in the combination had predicted a rank of 5 for that site (i.e., union = “OR”). Finally, mode models assigned sites a value of 5 if it was the *most frequent* value across the combination of models. Sites with no model agreement (no most frequent prediction) have a mode of NA.

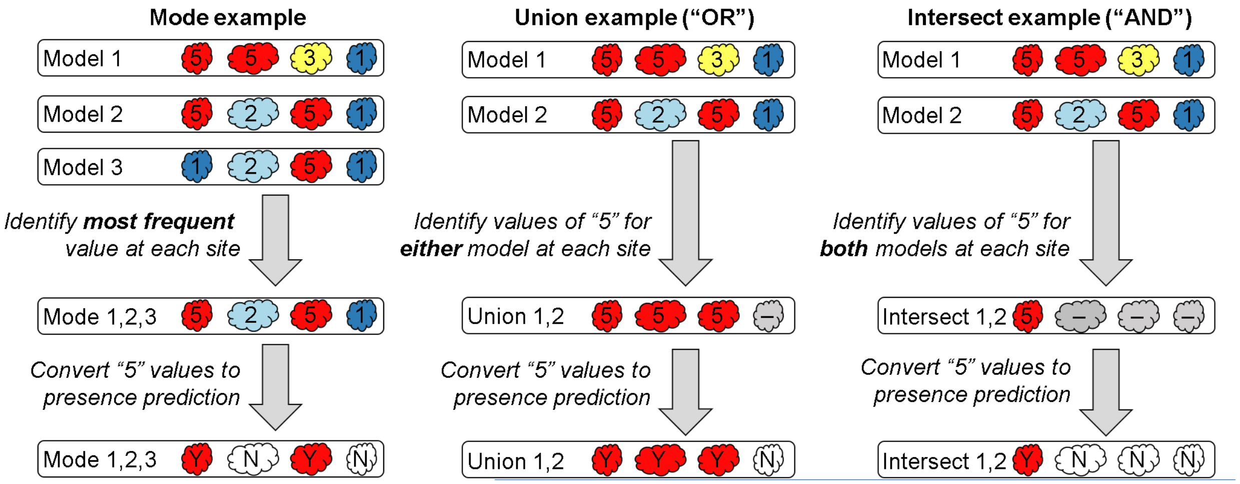


Figure 2. A hypothetical example of calculating the mode, union, and intersection from multiple models. Each colored shape represents a site, with the number indicating the rank-transformed value for each model at that site (1=1-20th percentile, 2=21-40th percentile, … 5=81-100th percentile).

Results

Sites likely to support EGC were widely distributed across the Salish Sea irrespective of model choice. Across each of the individual models, 78-90 sites were predicted to support EGC based on habitat suitability (using a threshold value of 5). The site-level, rank-transformed predictions of the five individual models are shown in Figure 3, and the list of sites with model predictions are shown in Table A 1.

Agreement of component models within each of the ensemble models depended on how restrictive the definition of ‘agreement’ was. Intersection models identified the fewest number of sites for monitoring; as few as two sites when all five original models were included in the combination. This conservative approach increases the risk of overlooking otherwise suitable sites captured by some of the individual models, but not all. Union models had the least conservative definition of agreement and therefore usually identified the greatest number of sites for monitoring (up to a maximum of 141 sites for certain combinations). In addition to generating a potentially unreasonably large number of sites to monitor, union models also had a higher likelihood of Type 1 errors (i.e., unsuitable sites erroneously considered suitable). For these reasons, the mode models were preferred as they balanced the need for agreement with the benefits of buffering the uncertainty in each of the individual models with a multi-model approach. Mode models identified an intermediate number of sites considered suitable for EGC, depending on the number and combination of models considered (range: 51 – 90 sites).

Identifying potential monitoring sites

Choosing which model(s) to use to determine potential early detection/monitoring sites based on habitat suitability for EGC in the Salish Sea is challenging, especially without an independent validation dataset to evaluate predictive performance. However, based on the results presented here, the most defensible method is to use an ensemble model approach, relying on agreement across model predictions as a means of identifying site suitability. Agreement among models reduces uncertainty by using multiple lines of evidence. In particular, by defining agreement as the most frequent value (i.e., mode) the risk of either missing suitable sites or including a lot of unsuitable ones is minimized. Although the rank-transformed outputs of three, four, and all five of the original habitat suitability models were generated, we highlight the results of the mode model that included all five of the original models, as this uses all available information, for a total of 68 potential monitoring sites (Figure 1). If managers have the capacity to survey more sites, a longer, less conservative site list can be generated either by moving to the union ensemble model, using all five individual models (113 sites), or lowering the threshold for suitability from the 80th percentile to the 60th percentile (151 sites for mode, 207 for union). Managers should use site-specific knowledge to exclude potential sites (e.g., if the information used to build the model does not reflect the actual conditions on the beach) or use independent datasets (e.g., presence of eelgrass beds, First Nation harvest sites) to further prioritize sites.

For identifying either more Salish Sea sites, beyond the 447 considered here, or predicting into new areas, an ensemble mode model is still recommended. However, complete data for all five models may not always be available and thus require managers to either generate new output or work with fewer models. It is important to note that the mode ensemble approach requires a minimum of three models be available at any site of interest. If this requirement is not met, managers can still use any of the existing models, as all of them worked reasonably well at identifying suitable habitat for EGC based on model validation using EGC data from outside the Salish Sea.

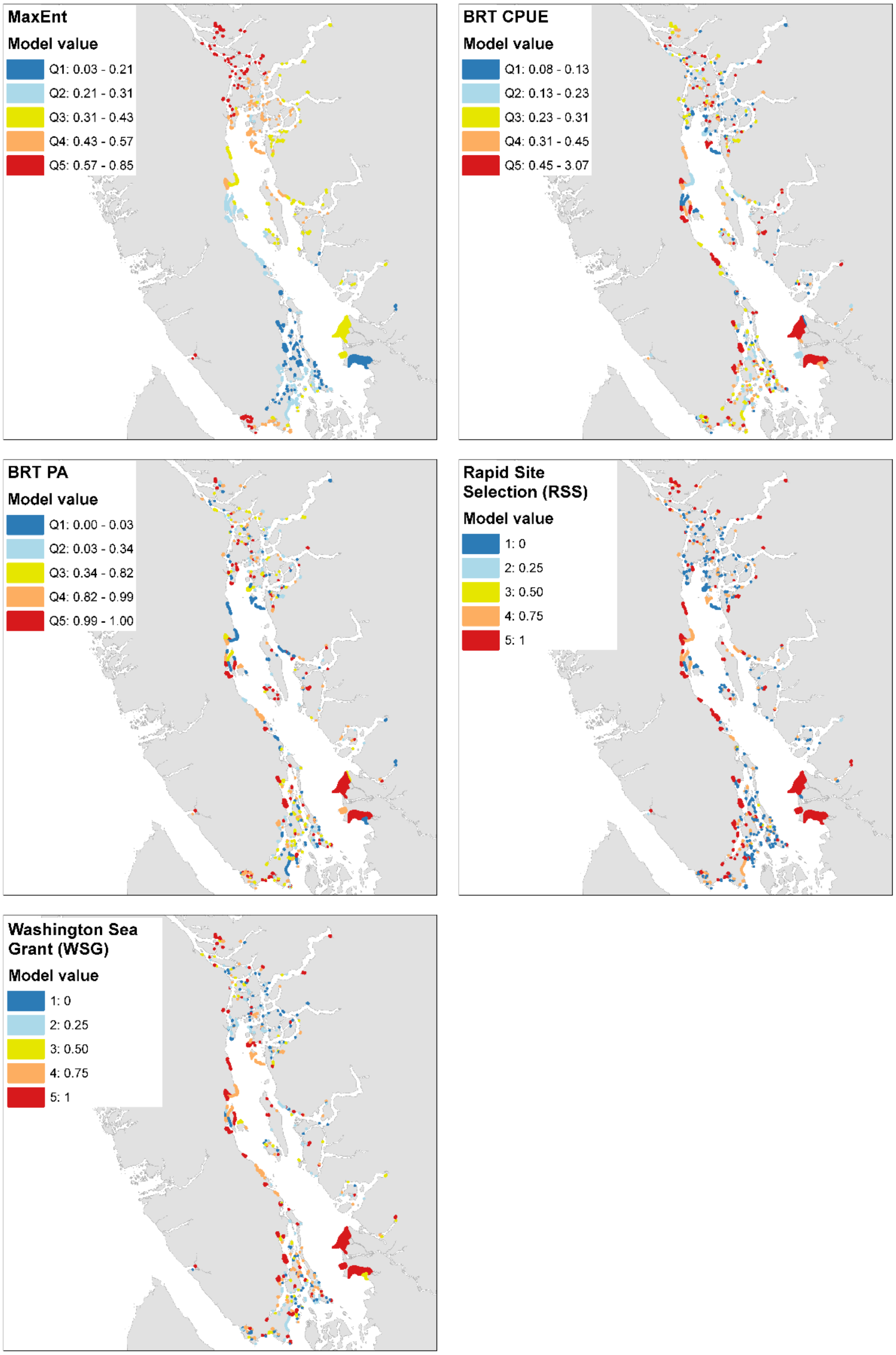


Figure 3. Outputs for each of the five individual models. Site polygons are shaded based on rank-transformed values, where 5 is considered highly suitable EGC habitat. The original values for each rank-transformed value are also given.

Sources of uncertainty

The lack of a robust, independent validation dataset limits the identification of a “preferred” model. There are a limited number of sites with confirmed EGC presence in Canadian waters of the Salish Sea, with most of these spatially aggregated around Sooke Basin. Until the invasion cycle is fully complete in space and time (i.e., sites will either be persistently occupied or not) it will not be possible to assess the accuracy of any of the individual models. However, ongoing observations will be important to refine future predictions of habitat suitability for EGC in the Salish Sea and ultimately can be used retrospectively to evaluate model accuracy.

Each of the ensemble modeling approaches (mode, union, intersect) represents a trade-off in model agreement that can substantially increase or decrease the number of potential early detection monitoring sites. Intersect ensembles are the most restrictive for site identification as all models in the ensemble must rank a site as highly suitable habitat for it to be considered, while union ensembles are the least restrictive in that a site will be included if any model in the ensemble ranks a site as highly suitable. Here, mode is the recommended approach because it requires several, but not all, models to rank a site highly. While this is interpreted as the most balanced approach, using more or less conservative methods (i.e., intercept or union ensembles) may be warranted depending on resources available and risk tolerance.

The choice of thresholds used to delineate a site as “suitable” can also influence which and how many sites are recommended for monitoring. Using a threshold of 5 to delineate suitability across the original five habitat suitability models was intended to identify those sites that had the greatest probability of being suitable for EGC. However, this does not mean that other sites are unsuitable for EGC; some lower-scoring sites are known to have EGC present. Lowering the suitability threshold results in more sites being identified for monitoring. Managers could opt for this less conservative approach if available resources allow.

Future work is needed to better assess how abiotic or biotic factors facilitate or mediate EGC invasion dynamics, and at what spatial and temporal scales. The individual habitat suitability models used here capture some, but not all, aspects related to EGC invasion dynamics. Potentially important missing components for assessing if a specific site will become invaded include biotic resistance (i.e., predation/competition) and micro-habitat suitability, but our understanding of mechanisms and data availability are limited for both. Additionally, none of the models consider larval dynamics (i.e., probability of arrival), instead all assume that propagules have the ability to reach all sites. Therefore, future analyses could incorporate particle tracking or human-mediated transport of larvae to further refine sites for EGC early detection.

Limitations on the accuracy and resolution of the input variables used in the individual models can lead to uncertainties at the site level. Models that rely on CPUE to predict EGC abundance are prone to uncertainty due to variability in catch as a consequence of gear used, seasonality, etc. Models that rely on occurrence records can be uncertain during a new invasion as absences may reflect truly unsuitable habitats, failure to detect a very small population, or a site that has yet to be invaded. Presence records are more robust, but do rely on the assumption that a single individual indicates the location is broadly suitable for an established population of the invader. Sites may also have specific characteristics that are either not reflected in large-scale environmental or habitat data layers, or are not visible in satellite imagery, particularly in intertidal habitats which are quite dynamic. Therefore, a site identified as suitable by a model might in fact be completely unsuitable for EGC occupancy (e.g., rockier or more exposed than indicated by the input data). Therefore, managers should employ their own judgement when assessing sites, especially when in the field, as it is possible that some sites that were identified as priorities from the model predictions should ultimately be de-prioritized for actual monitoring.

The availability and quality of the input data, the expertise of the user, and the spatial resolution required all potentially limit how readily these models can be applied for management purposes beyond the 447 sites considered here. Both the MaxEnt and BRT models have significant data requirements, and the BRTs are further limited in that predictions can only be made for predetermined sites, due to the site-specific nature of the input variables (i.e., high water line length, isolation, etc.). Both the RSS and modified WSG models are less demanding with respect to input data requirements and user expertise but, like the BRTs, the modified WSG requires sites of interest to be determined in advance. However, the BRTs, modified WSG, and RSS tool (to some extent) are better suited than MaxEnt when discrete sites are the preferred output for management. Ultimately, using as many of these models as possible in an ensemble approach will provide the most robust site identification.

AIS managers may opt to further prioritize sites in ways not discussed here, such as by assessing important ecosystem components known to be degraded by EGC (e.g., eelgrass meadows, Howard et al. 2019; clam beds, Grosholz et al. 2000), ease of access, or local volunteer capacity. Additionally, managers will need to apply their own expertise when determining trap placement within a site. Broadly speaking, the current best practice is to target features that may provide EGC with shelter, but what this looks like will vary widely among sites.

CONCLUSIONS AND ADVICE

Each of the individual models considered here has strengths and limitations, especially for predicting suitable habitat for an invader like EGC that has broad environmental tolerances and can survive in a range of habitats. However, by using information from an ensemble of the five separate models (the mode, or most frequent value across all models at each site), each with predictive power from different predictor and response variables, it was possible to identify specific sites based on habitat suitability for early detection/monitoring for EGC in Canadian waters of the Salish Sea (Table A 1).

An expanded set of potential monitoring sites can be obtained by reducing the threshold for “highly suitable habitat” (results shown in Research Document).

CLIMATE CHANGE CONSIDERATIONS

Although this report is intended to fill an immediate need, ecosystems are not static and climate change and seasonal variability can influence the site-specific outcomes of an invasion, which in turn affects site identification for early detection monitoring programs. Of the habitat suitability models considered here, MaxEnt has the ability to predict EGC distributions based on future oceanographic conditions (assuming the relationships between environmental predictor variables and EGC ecology do not change) whereas the other models are based more on habitat features or characteristics that are less subject to climate change effects (e.g., substrate type, inlet length, etc.).

LIST OF MEETING PARTICIPANTS

Last Name	First Name	Affiliation
Anderson	Erika	DFO Centre for Science Advice Pacific
Campbell	Jill	DFO Centre for Science Advice Pacific
Chaves	Lais	Council of the Haida Nation
Christensen	Lisa	DFO Centre for Science Advice Pacific
Davis	Alexandra	University of Alberta
Demers	Andreanne	DFO Aquatic Invasive Species Management
DiBacco	Claudio	DFO Science
Foster	Sophie	DFO Science
Francis	Fiona	DFO Science
Gale	Katie	DFO Science
Grason	Emily	Washington Sea Grant
Greene	Stephanie	University of Alberta
Howard	Brett	DFO Science
Lyons	Devon	DFO Science
McKenzie	Cynthia	DFO Science
Menning	Patty	DFO Fisheries Management
McDonald	Sean	University of Washington
Sobey	Timothy	Ka:'yu:'k't'h'/Che:k:tles7et'h' First Nations
Smith	Nicola	University of British Columbia
Talbot	Renny	DFO Aquatic Invasive Species Management
Therriault	Thomas	DFO Science

SOURCES OF INFORMATION

This Science Advisory Report is from the January 31-February 2, 2022 regional peer review on the Evaluation of Methods for Identification of Early Detection Monitoring Sites for Invasive European Green Crab in the Salish Sea, British Columbia. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Drinkwin, J., Pleus, A., Therriault, T., Talbot, R., Grason, E.W., McDonald, P.S., Adams, J., Hass, T., and Litle, K. 2019. Salish Sea Transboundary Action Plan for Invasive European Green Crab.

Grosholz, E.D., Ruiz, G.M., Dean, C.A., Shirley, K.A., Maron, J.L., and Connors, P.G. 2000. The impacts of a nonindigenous marine predator in a California bay. Ecology 81(5): 1206-1224.

Howard, B.R., Francis, F.T., Côté, I.M., and Therriault, T.W. 2019. Habitat alteration by invasive European Green Crab (*Carcinus maenas*) causes eelgrass loss in British Columbia, Canada. Biol. Invas. 21(12): 3607-3618.

APPENDIX

Table A 1. Predictions of highly suitable habitat for EGC (√) at all sites for individual models and for the mode of all five models (i.e., the most frequent value at each site), using threshold values of 5 (i.e., 80th percentile). Sites where no models predict suitable EGC habitat are not shown. Sites predicted by the mode are highlighted (blue) and denoted with an asterisk as the recommended option for initial monitoring.

Site	Latitude	Longitude	MaxEnt	CPUE	PA	RSS	WSG	Mode
agamemnon	49.71353	-124.081	–	√	√	–	–	–
albert	48.3939	-123.49	–	–	–	–	√	–
anderson1	48.35968	-123.654	√	–	–	–	√	–
anderson2	48.36	-123.66	√	√	–	–	–	–
annie	49.38944	-124.593	–	–	–	√	√	–
april	50.06135	-125.236	√	–	–	–	–	–
arnette	48.82315	-123.38	–	–	–	√	–	–
artaban*	49.476	-123.348	–	–	√	–	√	√
artificial*	50.38923	-125.519	√	√	√	–	–	√
ashworth	49.96596	-124.918	–	√	–	–	–	–
asman	50.40321	-125.147	√	√	–	–	–	–
attwood	50.30986	-124.661	–	√	√	–	–	–
baker	49.93095	-124.039	–	√	–	√	–	–
bargain	49.61179	-124.037	–	√	–	–	–	–
bear	50.36276	-125.658	√	–	–	–	–	–
becher*	48.34237	-123.589	√	–	√	–	√	√
becher1	48.33827	-123.602	√	–	–	–	–	–
becher2	48.33833	-123.599	√	–	–	–	–	–
becher3	48.33667	-123.627	√	–	–	–	–	–
becher4	48.33917	-123.596	√	–	–	–	–	–
bedwell	49.31453	-122.919	–	–	√	–	–	–
beecher1	48.33033	-123.592	√	–	–	–	–	–
beecher2	48.333	-123.591	√	–	–	–	–	–
bessborough*	50.49278	-125.771	√	–	√	√	√	√
bickley*	50.45128	-125.393	√	√	–	–	–	√
binnington	50.34114	-125.321	√	–	–	–	–	–
boatcove	49.46728	-124.243	–	–	√	√	–	–
boatswain	48.71415	-123.553	–	–	–	√	–	–
boot	48.78895	-123.2	–	–	√	–	–	–
boothbay	48.86702	-123.55	–	–	–	√	–	–
boundarybay*	49.07951	-122.898	–	√	√	√	√	√
brem*	50.43242	-124.654	–	–	√	√	–	√
bull*	49.47706	-124.21	–	√	√	–	√	√
burgess	49.44149	-123.445	–	√	–	–	–	–
burgoyne	48.78912	-123.52	–	–	–	√	–	–
cabbage*	48.797	-123.085	–	–	√	√	√	√
cadboro	48.45752	-123.288	–	√	–	–	√	–
capemudge	49.99414	-125.174	–	–	√	–	–	–
captain	49.78264	-123.994	–	√	–	–	–	–
carlson*	49.53996	-123.799	–	√	–	√	√	√
charles	48.84044	-123.381	–	√	–	–	–	–
chatham	48.42978	-123.25	–	–	√	–	–	–
chisholm	48.79221	-123.6	–	–	√	–	√	–
coghlan	48.39123	-123.485	–	–	√	–	–	–
comox1*	49.66375	-124.945	–	√	–	√	√	√
comox2*	49.66705	-124.918	–	–	√	√	√	√

Site	Latitude	Longitude	MaxEnt	CPUE	PA	RSS	WSG	Mode
conville	50.1922	-125.142	–	√	–	–	–	–
copper	50.11443	-125.297	√	–	–	–	–	–
cordero	50.4506	-125.243	√	–	–	–	–	–
cortes	50.03286	-124.976	–	–	–	–	√	–
cowichan2*	48.7516	-123.624	–	√	–	√	√	√
craig	49.31448	-124.263	–	√	–	√	–	–
crescent	49.05558	-122.889	–	–	–	√	–	–
cross*	50.05563	-124.774	–	√	√	–	–	√
cufra	49.01343	-123.685	–	–	√	–	–	–
departure	49.20292	-123.97	–	–	–	–	√	–
depbay2	49.20985	-123.954	–	√	–	–	–	–
discovery	48.42778	-123.241	–	–	–	–	√	–
dmountain	50.31414	-125.401	√	–	–	–	–	–
donop1	50.14192	-124.956	–	√	–	–	√	–
drew*	50.10345	-125.205	–	–	√	√	–	√
edith	50.37511	-125.544	√	–	–	–	–	–
egerton	50.48348	-125.252	√	–	–	–	–	–
elagoon*	48.42636	-123.463	–	–	√	√	–	√
elk*	50.28123	-125.44	√	–	–	√	√	√
esquimalt1	48.44845	-123.433	–	√	√	–	–	–
esquimalt2	48.45382	-123.443	–	–	√	–	–	–
esquimalt3*	48.4534	-123.454	–	√	√	√	–	√
evans1	50.19792	-125.063	–	√	–	–	–	–
evans2	50.19918	-125.094	–	–	√	–	–	–
evans4	50.2218	-125.069	–	√	–	√	–	–
false*	49.48942	-124.355	–	√	–	–	√	√
fanny*	49.51445	-124.826	–	√	√	√	–	√
fawn	50.08191	-125.216	√	–	–	–	–	–
finnerty	49.50353	-124.389	–	–	√	–	–	–
forbes	50.24296	-124.59	–	–	–	√	–	–
forward*	50.48935	-125.701	√	–	–	√	√	√
frederick1*	50.50439	-125.258	√	–	–	√	√	√
fulford	48.77037	-123.461	–	–	–	–	√	–
gabriola1	49.12959	-123.72	–	√	–	–	√	–
galvani	50.38197	-125.845	√	–	–	–	–	–
ganges	48.85093	-123.5	–	–	–	–	√	–
ganges1	48.8554	-123.48	–	–	–	√	–	–
gillies*	49.67966	-124.509	–	–	–	√	√	√
goldstream	48.49105	-123.553	–	–	–	√	√	–
gowlland*	50.10237	-125.257	√	√	√	√	–	√
grace1	50.04873	-124.755	–	–	√	–	–	–
granite1	49.45023	-122.862	–	–	–	√	–	–
hadley	49.49786	-124.353	–	√	√	–	–	–
hagan	48.59001	-123.465	–	–	–	√	–	–
hall1	50.4445	-125.283	√	–	–	–	–	–
hamilton	48.77403	-123.275	–	–	–	–	√	–
hay	48.74258	-123.225	–	√	–	–	–	–
heydon	50.57816	-125.572	√	–	–	√	–	–
higgins	49.49619	-124.367	–	–	√	–	–	–
hjorth1	50.18109	-125.121	–	√	–	–	–	–
hmpbck*	50.36147	-125.689	√	–	–	√	√	√
hope2	48.80136	-123.277	–	–	√	–	–	–
horton1	48.82912	-123.255	–	√	–	–	–	–
horton2	48.82388	-123.243	–	√	–	–	–	–

Site	Latitude	Longitude	MaxEnt	CPUE	PA	RSS	WSG	Mode
hotham1	49.83669	-123.995	–	√	–	–	–	–
hotham2	49.9204	-124.024	–	–	√	–	–	–
hotham3*	49.91782	-124.021	–	√	√	–	–	√
hutchinson	48.38887	-123.635	√	–	–	–	–	–
hyacinth	50.30697	-125.195	–	√	√	–	–	–
hyacinthe	50.11964	-125.229	–	–	√	–	–	–
ivanhoe	50.37084	-125.534	√	–	–	–	–	–
jackson	48.75157	-123.442	–	–	√	–	–	–
jackson1*	50.52927	-125.821	√	–	√	√	√	√
jackson2	50.51467	-125.757	√	–	–	–	–	–
james1*	48.60745	-123.348	–	√	–	√	√	√
james2	48.5945	-123.352	–	–	–	–	√	–
jelina	49.51043	-124.296	–	–	√	√	–	–
johns2	48.60376	-123.521	–	–	–	√	–	–
kanish*	50.25988	-125.325	√	–	√	–	–	√
kanish1	50.24425	-125.358	√	–	–	√	–	–
kanish2*	50.24012	-125.313	√	√	√	–	–	√
kanish3*	50.26372	-125.289	√	√	–	√	√	√
killam	49.80219	-123.912	–	–	√	–	–	–
kilpahlas	48.73842	-123.605	–	√	–	√	–	–
kingfisher1	48.7593	-123.412	–	–	–	–	√	–
komas	49.58048	-124.799	–	–	–	–	√	–
kulleet*	49.01753	-123.778	–	–	–	√	√	√
ladysmith2	49.00717	-123.814	–	–	√	–	–	–
ladysmith3*	49.01933	-123.841	–	√	√	√	√	√
lamalchi	48.94243	-123.641	–	–	√	–	–	–
lambert*	49.52695	-124.751	–	√	√	–	√	√
lancelot	50.0596	-124.7	–	√	–	–	–	–
larsons*	49.9878	-124.688	–	√	√	√	–	√
long	48.86665	-123.475	–	–	–	√	–	–
loughborough1	50.58343	-125.533	√	–	–	–	–	–
loughborough2	50.58705	-125.528	√	–	–	–	–	–
lyall	48.7959	-123.174	–	–	–	√	√	–
madrone	48.8595	-123.489	–	√	–	–	–	–
malaspina1	49.75017	-124.279	–	–	√	–	–	–
malaspina2	49.76933	-124.332	–	–	–	√	–	–
malaspina3	49.77425	-124.352	–	–	–	√	–	–
malaspina4*	49.77208	-124.366	–	–	√	√	√	√
manzanita*	50.06685	-124.908	–	–	–	√	√	√
maple	48.81689	-123.609	–	√	–	–	–	–
mcken	48.55467	-123.505	–	√	–	√	–	–
medecin*	48.76012	-123.268	–	√	–	√	√	√
menzies	50.13282	-125.392	√	–	–	–	√	–
millbay	48.65593	-123.557	–	–	–	√	–	–
miners	48.85187	-123.301	–	√	–	–	–	–
moh	50.51661	-125.038	–	–	–	√	–	–
mortimer	48.76678	-123.256	–	–	–	–	√	–
mud*	49.46923	-124.786	–	√	√	√	√	√
mudge1	49.13107	-123.803	–	–	√	–	–	–
murchinson	48.88875	-123.336	–	–	√	–	–	–
musqueam	49.22504	-123.204	–	–	–	√	√	–
nanoosebay*	49.26447	-124.18	–	–	√	√	√	√
narvaez	48.77417	-123.1	–	–	√	–	–	–
needham	50.38756	-125.601	√	–	–	–	–	–

Site	Latitude	Longitude	MaxEnt	CPUE	PA	RSS	WSG	Mode
nodales*	50.36857	-125.315	√	√	√	–	–	√
nodales1	50.36406	-125.314	√	–	–	–	–	–
okeover2	49.97452	-124.679	–	–	–	√	–	–
okeover3	49.96775	-124.678	–	–	–	√	√	–
orford*	50.59123	-124.867	–	√	–	√	√	√
paddy	48.80733	-123.587	–	√	–	–	–	–
patricia	48.65608	-123.449	–	–	–	√	–	–
pedder1	48.34873	-123.577	–	√	–	–	–	–
pender1*	49.63282	-123.998	–	√	√	√	√	√
pender2*	49.62652	-123.995	–	√	√	√	√	√
pender3*	49.62572	-124.01	–	√	√	–	–	√
pendrell1	50.26863	-124.729	–	–	√	–	–	–
pendrell3	50.27317	-124.728	–	–	–	–	√	–
pim*	48.36388	-123.662	√	–	√	–	–	√
portsj1	48.55365	-124.421	√	–	–	–	–	–
portsj2*	48.57933	-124.413	√	–	√	√	√	√
prevost	48.84008	-123.395	–	–	–	–	√	–
prideaux2	50.14185	-124.669	–	√	–	–	–	–
puget*	48.4352	-123.248	–	–	√	–	√	√
quarry	49.67632	-124.084	–	√	–	–	–	–
ramsay	50.44574	-125	–	√	–	–	–	–
read*	50.52987	-125.78	√	–	–	√	√	√
retreat	48.9416	-123.501	–	–	√	–	–	–
ripple	50.3563	-125.556	√	–	–	–	–	–
roche2*	48.37037	-123.624	√	√	√	–	–	√
rock1	50.3525	-125.488	√	√	–	–	–	–
rocky	48.31752	-123.54	√	–	–	–	–	–
roscoe*	50.15859	-124.774	–	√	√	√	–	√
roy	49.64952	-124.941	–	–	–	√	√	–
rumbottle	49.73517	-124.499	–	–	√	–	√	–
saanichton	48.59147	-123.378	–	–	–	√	√	–
saltery2	49.77962	-124.18	–	–	–	–	√	–
saltwater	50.13945	-125.337	√	–	–	–	√	–
samuel	48.81698	-123.204	–	–	–	–	√	–
saratoga*	49.85786	-125.106	–	–	–	√	√	√
sbasin1*	48.36345	-123.644	√	–	√	–	–	√
sbasin2	48.36293	-123.636	√	–	–	–	–	–
sbasin3	48.37285	-123.631	√	–	–	–	–	–
sbasin4	48.37815	-123.634	√	–	√	–	–	–
sbasin5	48.39418	-123.655	√	–	–	–	–	–
sbasin6	48.38615	-123.684	√	–	√	–	–	–
scottie	49.51916	-124.341	–	–	√	–	–	–
selby*	48.83183	-123.395	–	√	–	–	√	√
shaft	49.19761	-123.945	–	–	–	–	√	–
shannon	49.6744	-123.163	–	√	–	–	–	–
sharbour1	48.37187	-123.706	√	–	–	–	–	–
sharbour2	48.36717	-123.712	√	–	–	–	–	–
sharbour3	48.36212	-123.704	√	√	–	–	–	–
sharbour4	48.3568	-123.726	√	–	–	–	–	–
sharbour6	48.36327	-123.729	√	–	–	–	–	–
sheer	50.19966	-125.127	–	–	–	–	√	–
shoal*	48.89708	-123.651	–	√	√	√	√	√
shoalbay2*	50.45765	-125.368	√	√	–	√	√	√
shorter*	50.40918	-125.731	√	√	–	√	–	√

Site	Latitude	Longitude	MaxEnt	CPUE	PA	RSS	WSG	Mode
sidney3*	48.63111	-123.328	–	–	√	–	√	√
skerry	49.49912	-124.237	–	–	√	–	–	–
slab	50.32064	-125.443	√	–	√	–	–	–
snarrows2*	50.23791	-125.154	–	√	√	–	√	√
sooke1	48.37435	-123.719	√	–	√	–	–	–
sooke2	48.38247	-123.704	√	–	–	√	–	–
sooke3*	48.38948	-123.657	√	√	–	–	√	√
sooke5	48.3642	-123.712	√	–	–	–	–	–
southgate	50.88751	-124.801	–	–	–	√	√	–
spectacle	48.55953	-123.536	–	√	–	–	–	–
stag	50.07838	-125.218	√	–	–	–	–	–
stella	50.28677	-125.434	√	–	–	–	–	–
steveston1*	49.13027	-123.21	–	√	√	√	√	√
steveston2*	49.1207	-123.179	–	–	√	–	√	√
stoney	48.80539	-123.583	–	√	–	–	–	–
storey	50.41905	-125.331	√	–	–	–	–	–
stove	50.10282	-125.004	–	√	√	–	–	–
stuart2	50.41309	-125.14	√	–	–	–	–	–
sturt	49.76275	-124.572	–	–	–	√	√	–
suffolk	50.3555	-125.44	√	–	–	–	–	–
tallac*	50.44489	-125.471	√	√	–	√	–	√
taylor	49.19356	-123.86	–	–	–	–	√	–
tenedos	50.12529	-124.705	–	–	√	–	–	–
theodocia3	50.07864	-124.661	–	–	–	√	–	–
thunder1	49.76126	-124.269	–	–	√	–	–	–
thunder2	49.7733	-124.278	–	–	–	–	√	–
thurlow	50.40565	-125.504	√	–	–	–	–	–
thurston1	50.36236	-125.323	√	–	–	–	–	–
thurston2*	50.37688	-125.316	√	√	–	√	√	√
tilly	48.73242	-123.206	–	√	–	–	–	–
tod	48.55948	-123.465	–	–	–	√	–	–
topaze	50.52567	-125.723	√	–	–	√	–	–
tork	50.13911	-124.929	–	–	√	–	–	–
trueworthy	48.76821	-123.18	–	–	√	–	–	–
tsawassen*	49.04857	-123.113	–	–	–	√	√	√
tugboat	49.14879	-123.69	–	√	–	–	–	–
tumbo	48.79498	-123.091	–	√	–	–	–	–
twin	50.03173	-124.935	–	–	–	–	√	–
tyee	50.04937	-125.256	–	–	√	–	–	–
uganda	50.09607	-125.038	–	√	√	–	–	–
unionpoint	49.5965	-124.884	–	–	–	√	–	–
vansittart	50.37794	-125.747	√	–	–	–	–	–
vantreight	48.4391	-123.253	–	–	–	–	√	–
venture	50.30454	-125.34	√	–	–	–	–	–
vere*	50.39062	-125.771	√	√	–	–	√	√
vharbour	48.43801	-123.386	–	√	√	–	–	–
victoria1	48.42865	-123.385	–	√	–	–	–	–
victoria2	48.43548	-123.379	–	–	√	–	–	–
vondonop1	50.15233	-124.949	–	√	–	–	–	–
waiatt1	50.26242	-125.252	√	–	–	–	–	–
waiatt2	50.26224	-125.241	–	–	√	–	–	–
walkem1	50.35893	-125.522	√	–	–	–	–	–
walkers	48.89325	-123.501	–	–	–	–	√	–
walter	48.84406	-123.483	–	–	–	–	√	–

Site	Latitude	Longitude	MaxEnt	CPUE	PA	RSS	WSG	Mode
wellbore*	50.45332	-125.769	√	√	–	√	√	√
whiterock	50.25695	-125.088	–	–	–	√	–	–
wigwam	49.46464	-122.888	–	–	–	√	√	–
witty*	48.38617	-123.513	–	√	√	√	√	√
young	50.35182	-125.365	√	–	–	–	–	–

THIS REPORT IS AVAILABLE FROM THE:

Centre for Science Advice (CSA)
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

E-Mail: csap@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087
ISBN 978-0-660-44872-5 Cat No. Fs70-6/2022-037E-PDF

Correct Citation for this Publication:

DFO. 2022. Evaluation of Methods for Identification of Early Detection Monitoring Sites Based on Habitat Suitability for Invasive European Green Crab in the Salish Sea, British Columbia. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/037.

Aussi disponible en français :

MPO. 2022. Évaluation des méthodes de détermination des sites de suivi en matière de détection rapide du crabe vert, une espèce envahissante, dans la mer des Salish, en Colombie-Britannique. Secr. can. des avis. sci. du MPO. Avis sci. 2022/037.