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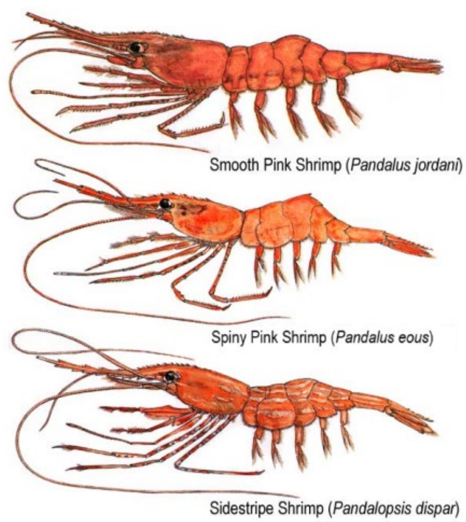
Canadian Science Advisory Secretariat
Science Advisory Report 2025/056

REVIEW OF THE STOCK DEFINITION AND DESIGN OF THE SHRIMP TRAWL SURVEY FOR STOCK MONITORING IN BRITISH COLUMBIA



Illustrations courtesy of A. Denbigh.

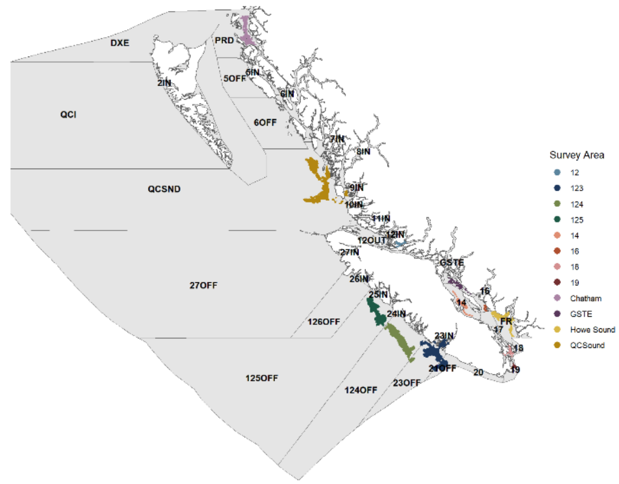


Figure 1. Map of Shrimp Management Areas (Southey et al. 1998) and Science Survey Areas (Boutillier et al. 1999).

CONTEXT

The current stock assessment framework for shrimp species targeted in the British Columbia (B.C.) shrimp trawl fishery has been in place since 1998 and is based on a series of fishery-independent surveys. Building on previous field studies, surveys began in 1998 with implementation of fixed survey stations across Survey Areas that currently cover portions of 13 of the 36 Shrimp Management Areas (SMAs).

The population structure of shrimp in B.C. is not well-defined, creating additional challenges when designing surveys to generate unbiased estimates of biomass indices. The current biomass index estimation procedure uses survey data to generate annual predictions of the broader distribution of shrimp biomass using a GIS-based spatial interpolation procedure. To date, there has been no evaluation of available information to support a biological stock definition for key Pacific shrimp stocks, nor an assessment of the accuracy and reliability of the current survey design or biomass index estimation method.

Fisheries and Oceans Canada (DFO) Fisheries Management has requested that DFO Science evaluate the accuracy and precision of candidate survey designs and index estimation methods for monitoring Smooth Pink (*Pandalus jordani*), Spiny Pink (*P. eous*), and Sidestripe Shrimp (*Pandalopsis dispar*) stocks in B.C. to provide the basis for a recommended survey design and index estimation method, as well as an evaluation of spatial stock definitions consistent with the Fish Stocks provisions of the *Fisheries Act*.

This Science Advisory Report is from the regional peer review April 1-3, 2025 on the Review of the Current Shrimp Trawl Biomass Survey Assessment Methodology for the BC Shrimp Trawl Fishery. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- The shrimp trawl fishery in British Columbia (B.C.) primarily targets three shrimp species (Smooth Pink, Spiny Pink, and Sidestripe Shrimp). For these species, stock size was indexed through annual, swept-area, fishery-independent surveys conducted within Survey Areas, which cover portions of a subset of the 36 Shrimp Management Areas (SMAs) along the B.C. coast. A biomass index estimation method employing a spatial interpolation procedure was used to estimate shrimp biomass for the entirety of each surveyed SMA based on the surveyed portion.
- To date, the survey design and biomass index estimation method have not been evaluated for their effectiveness in monitoring and estimating the status of these shrimp stocks. Furthermore, these stocks are expected to be proposed for prescription under the *Fisheries Act* Fish Stocks provisions and will therefore require a spatial stock definition and assessment of stock status relative to a biologically-defined limit reference point.
- A suite of analytical approaches was used to evaluate available data to provide recommendations on spatial stock definition, survey area, sampling design, and biomass index estimation methods to support future assessments of stock status for Smooth Pink, Spiny Pink, and Sidestripe Shrimp. Performance of indices based on simulated data was tested at a regional level (Strait of Georgia, West Coast Vancouver Island and Northern Shelf) and/or at the level of the Survey Area (i.e., surveyed portion of SMAs), depending on the method.
- Based on the available data and information, there is currently no consistent evidence to support the presence of multiple shrimp stocks for each species in B.C. waters. Accordingly, the recommended biological spatial stock definition for Smooth Pink, Spiny Pink, and Sidestripe Shrimp is a single, coastwide stock for each species. Based on the geography and ocean dynamics of the Pacific coast, stock structure may exist that could not be discerned with the tools and data currently available. Additional research and data collection are required to investigate this hypothesis.
- The total recommended survey area is 70,421 km^2, based on predicted shrimp habitat minus areas that are currently understood to be untrawlable (e.g., due to obstructions, bottom type, and area closures). Simulation analyses demonstrated that increasing the number of tows within the survey area increases the precision of biomass index estimates, as indicated by a reduction in the coefficient of variation with larger sample sizes, thus potentially improving the quality of management advice.
- The number of survey stations to be conducted within this newly defined survey area is expected to be constrained by available resources (e.g., ship time and sampling effort). It is recommended that opportunities for collaboration with stakeholders be pursued to increase the collection of comparable survey data.
- Continuing with the current fixed-station survey sampling scheme is not recommended, as simulation results yielded lower accuracy and biased estimates relative to alternative sampling schemes when tested at the regional and/or surveyed portion of SMA level. Among sampling schemes considered operationally feasible, systematic sampling schemes

generally performed marginally better than alternatives in terms of accuracy, bias, and precision, and are therefore recommended for informing coastwide stock status.

- For biomass index estimation, it is recommended that a spatiotemporal model is used, provided that sufficient annual tows with shrimp encounters are available (i.e., at least 10 shrimp-positive tows coastwide per year). If this criterion is not met, use of a design-based biomass index estimation method is recommended.
- The current approved DFO precautionary approach management framework and reference points for these stocks, which relies on generating biomass indices within 13 of the 36 SMAs, cannot be supported by the proposed survey design. The proposed survey design will be able to provide information relevant to coastwide stock status and does not preclude the use of management measures at smaller scales.
- Several uncertainties in the data and associated analyses were noted, including assumptions about model structure, spatial-scale mismatch, limited spatial and temporal coverage, limited information on genetic and population connectivity, potential changes in spatial distributions (due to climate or other environmental drivers), and potential observation error in both survey and logbook data.
- It is recommended that questions pertaining to subsequent operationalization of the new survey design (i.e., logistics and implementation specifications), as well as alternative methods for providing science advice to management at suitable spatial scales, be investigated with input from fishery participants and stakeholders. Furthermore, it is recognized that as information accrues under the new survey scheme, both the survey and management frameworks should be re-evaluated at regular intervals and re-aligned as needed.
- Future research is recommended to address key uncertainties related to suitable shrimp habitat, population connectivity (e.g., larval dispersal, genetics, and life-history parameters), and potential impacts of climate change on shrimp distribution and population dynamics.

INTRODUCTION

The shrimp trawl fishery in British Columbia (B.C.) targets seven commercially harvested species, although Smooth Pink Shrimp (*Pandalus jordani*), Spiny Pink Shrimp (*P. eous*), and Sidestripe Shrimp (*Pandalopsis dispar*) are the main species targeted. These species are characterized by protandric hermaphroditism (i.e., a reproductive strategy where individuals first mature as males and then change sex to females as they grow larger) and are distributed across a range of habitats from California to the Bering Sea. Shrimp Management Areas (SMAs) were established using historical catch data rather than biological or genetic stock delineation, creating a mismatch that potentially undermines the objectives for science assessments and effective management. Without accounting for population structure or connectivity, such misalignment may lead to localized overexploitation or underutilization. Given the Fish Stocks provisions under Canada's *Fisheries Act*, which require spatial stock definitions and sustainable management of major stocks, and the expectation that these stocks will eventually be proposed for prescription, there is a need to review the assessment framework and stock definitions for these shrimp stocks.

Current Assessment Framework

The current stock assessment framework for these species has been in place since 1998 and is based on findings from an initial series of fishery-independent surveys (Boutillier et al. 1999). Surveys (as described in Boutillier et al. 1999) began in 1998 under the new management framework with implementation of additional survey stations outside of the WCVI, currently covering portions of 13 of the 36 SMAs that comprise the B.C. coast (Figure 2, Figure 3).

Presently, an index of abundance is estimated primarily through spatial interpolation procedures applied to the fishery-independent survey data collected at predetermined (“fixed station”) sampling stations. The indices are estimated using kriging in ArcGIS, a geostatistical method that extrapolates biomass density to unsampled locations based on a spatial autocorrelation function. However, this method is computationally intensive and lacks transparency and reproducibility.

The population structure of shrimp in B.C. is not well-defined, which creates additional challenges when designing surveys that can produce unbiased estimates of biomass. To date, there has been no evaluation of available information to support a biological stock definition for key Pacific shrimp stocks, or the accuracy and reliability of the current survey design and biomass index estimation method.

ASSESSMENT

Data

Data were obtained from fishery-independent surveys (i.e., small-mesh multispecies surveys (SMMS), inshore shrimp trawl surveys, and synoptic groundfish surveys). For all surveys, data prior to 1996 were removed since they are sparse for all species.

Relevant environmental data were obtained from Canada’s Open Data portal and/or published reports (Davies et al. 2019; Peña et al. 2019Table 1) and used in the encounter models described below (Table 1). Lunar phase was calculated from the suncalc R package (Thieurmel and Elmarhraoui 2022).

Logbook data (1987-2023) from the commercial shrimp trawl fishery were used to provide an estimate of the commercial fishery footprint and to ground truth results from the encounter models described below.

A spatiotemporal Operating Model (OM) was developed with SMMS and inshore trawl survey data to generate simulated observations of coastwide shrimp biomass using sdmTMB (Anderson et al. 2025). Data outputs from the OM were also used in subsequent analyses of spatial stock definition, and similar models were developed to identify the survey area (i.e., encounter models) and as a biomass index estimation method.

Methods

Table 2 summarizes the methods used for each component of the analysis.

Spatial Stock Definition

To evaluate spatial stock definitions for Smooth Pink, Spiny Pink, and Sidestripe Shrimp stocks in B.C. consistent with the *Fisheries Act* Fish Stocks provisions, three methods were employed: hierarchical clustering of relative biomass indices; binomial mixed-effects models for length-at-stage; and, a visualization of spatial differences in length distributions. Additionally, a literature review of available information on genetics and timing differences by stage across regions was conducted.

Encounter Models to Define Survey Area

Encounter models for each of the species were developed using shrimp presence/absence data from SMMS, inshore shrimp trawl surveys, and synoptic groundfish surveys, and a suite of environmental and survey covariates (Table 1). The approach was based on Nephin et al. (2023). The models accounted for spatial autocorrelation in the data and probability of encounter was predicted over a coastwide grid. Predicted habitat was compared to the commercial fishery footprint obtained from logbook data to help ground truth the output. To arrive at a habitat-based survey area definition, untrawlable areas were removed from the predicted shrimp habitat area determined by the encounter model at varying probability thresholds (ranging from 0.3 to 0.8 predicted probability of encounter). Areas were identified as 'untrawlable' if they were deemed to be unsuitable habitat for trawling (e.g., rocky), within a high traffic corridor, or part of a protected area closure.

Survey Sampling Schemes

The OM was used to generate annual maps of shrimp distribution within each of three hypothetical survey regions: Strait of Georgia (SOG), Northern Shelf (NS), and West Coast Vancouver Island (WCVI). Six sampling schemes were then used to generate simulated survey data, and the design-based estimate (i.e., a mean or stratified mean density multiplied by survey area) at the regional level was compared with the "true" biomass indices from the OM to evaluate the performance of each sampling scheme. In addition to the current fixed-station scheme, a systematic regular grid, systematic hexagonal grid, simple random, depth-stratified random, survey area-stratified random, and depth-stratified random with Neyman allocation schemes were also tested. Performance of the different sampling schemes was compared using relative root mean square error (RRMSE) and relative bias (RB).

Biomass Index Estimation Methods

Four biomass index estimation methods were tested at the Survey Area level: a design-based approach, two spatial interpolation methods—ordinary kriging (OK) and fixed rank kriging (FRK)—and a spatiotemporal modelling approach (sdmTMB).

The design-based approach followed the same method as the design-based estimate described above; this method incorporates the least complexity of the four tested. Spatial interpolation methods estimate values at locations without observations. Both methods, OK and FRK, use spatial autocorrelation to do that spatial interpolation but differ in the way the autocorrelation is described. OK, which is the most similar to the current method, uses a semi-variogram to describe the spatial autocorrelation, while FRK uses a spatial random effects model. The spatiotemporal modelling approach, using the R package sdmTMB, was similar to the operating model and encounter models in that the models could account for spatial and spatiotemporal autocorrelation in the data through a method approximating Gaussian random fields (Lindgren et al. 2011). sdmTMB is a flexible modelling framework that allows varying levels of model complexity.

Each method was used to estimate biomass indices from simulated data at the existing Survey Area level for each of the three species. The estimated biomass index was then compared to the true biomass index values generated by the OM. Accuracy of the various methods was compared using median absolute relative error (MARE), precision was compared using the coefficient of variation (CV), and bias was evaluated using relative error (RE).

Results

Spatial stock definition

The methods employed, including hierarchical clustering of relative biomass indices, binomial generalized mixed effects models to assess variability in length at stage across Survey Areas, and visualizations of length distributions, suggested no consistent evidence for the presence of multiple spatially distinct stocks in B.C. waters for Smooth Pink, Spiny Pink, and Sidestripe Shrimp.

Encounter model

The range of estimated survey areas observed under different encounter thresholds ranging from 0.3 to 0.8—both before and after trawlable areas are removed—is provided in Table 3. As an example, Figure 4 shows the habitat-based survey area using a predicted encounter probability threshold of 0.3 and with untrawlable areas removed (which corresponds to 76,040 km^2 of survey area coastwide).

Survey sampling schemes

Systematic sampling designs generally showed improved performance relative to other schemes in terms of accuracy and precision (Figure 5, Figure 6). Simulation analyses demonstrated that increasing the number of tows within the survey area increases the precision of biomass index estimates, as indicated by a reduction in the coefficient of variation with larger sample sizes (Figure 6). The current fixed-station sampling approach produced lower accuracy and greater bias compared to other sampling configurations tested at the coastwide level.

Biomass index estimation method

Spatiotemporal models fitted with sdmTMB generally produced the highest accuracy and lowest bias. However, when the average number of tows with encounters per year fell below approximately ten, the design-based method tended to exhibit lower bias and better worst-case accuracy across iterations, even though sdmTMB still maintained higher average accuracy (Figure 7).

Sources of Uncertainty

Several uncertainties in the data and associated analyses were noted, including assumptions about model structure, spatial scale mismatch, limited spatial and temporal data, limited information on genetic and population connectivity, potential changes in spatial distributions (due to climate or environmental drivers), and potential observation error in both survey and logbook data.

Based on the geography and ocean dynamics of the Pacific coast, stock structure may exist that could not be discerned with the tools used and data currently available. Further research (e.g., genetic studies and analyses of data arising from the broader survey coverage proposed under the new survey design) to improve understanding of stock structure for these species is recommended.

CONCLUSION

- At this time, the recommended biological spatial stock definition for Smooth Pink, Spiny Pink, and Sidestripe Shrimp is a single, coastwide stock for each species. These definitions will facilitate future implementation of the Fish Stocks provisions for these stocks.
- The total recommended survey area is 70,421 km^2 based on predicted shrimp habitat threshold of 0.3 minus areas that are currently understood to be untrawlable (Figure 4). Two hundred stations per year, which is thought to be achievable given current survey resources, would result in a station approximately every 19 km across this survey area (Figure 8).
- The number of survey stations to be conducted within the newly defined survey area is expected to be constrained by available resources (e.g., ship time and sampling effort). It is

recommended that opportunities for collaborations with fishery participants and stakeholders be pursued to increase the collection of comparable survey data.

- Continuing with the current fixed-station survey sampling scheme is not recommended, as simulation results yielded lower accuracy and biased estimates relative to alternative sampling schemes when tested at the regional and/or surveyed portion of SMA level. Among sampling schemes considered operationally feasible, systematic sampling schemes generally performed marginally better than alternatives in terms of accuracy, bias, and precision, and are therefore recommended for informing coastwide stock status.
- The recommended approach for coastwide survey biomass index estimation is to use a spatiotemporal model (i.e., sdmTMB) provided there are at least 10 tows with shrimp encounters within the modeled area in each year surveyed. In all other cases, the design-based method for index estimation is recommended. When the spatiotemporal model is used, the scale of the model- and design-based estimates should be compared. If the index estimates are not similar in scale, consider simplifying the spatiotemporal model or using the design-based estimate. With the new larger survey area and one index, the number of positive tows is expected to be much greater than ten, which supports the use of sdmTMB for index estimation.
- It is recommended that questions pertaining to subsequent operationalization of the new survey design (i.e., logistics and implementation specifications), as well as alternative methods for providing science advice to management at suitable spatial scales be investigated with input from fishery participants and stakeholders. Furthermore, it is recognized that as information accrues under the new survey scheme, both the survey and management frameworks should be re-evaluated at regular intervals and re-aligned as needed.
- To maintain continuity in the biomass index time series, additional analytical work would be required to bridge data from the old and new survey designs.
- Future research is recommended to address key uncertainties related to suitable shrimp habitat, population connectivity (e.g., larval dispersal, genetics, and life-history parameters), and potential impacts of climate change on shrimp distribution and population dynamics.

OTHER CONSIDERATIONS

Industry participants provided valuable contributions at the peer review meeting about stock dynamics and species distributions based on their many years of experience in the B.C. shrimp trawl fishery. Two of these participants recused themselves from the decision about the acceptability of the working paper and subsequent development of this Science Advisory Report because it was unclear how the recommended changes to the survey design and index estimation method will impact future management recommendations (intended to be the subject of future discussions), thus preventing these participants from making informed contributions to the discussion.

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APPENDIX

Table 1. Covariates included in the encounter models and their source. Blue (x) indicates the covariate was included in the encounter model for a given species. White indicates the covariate was not included in the encounter model for a given species.

Covariate	Source	Smooth Pink	Spiny Pink	Sidestripe
Depth	Davies et al. 2019; Open Maps	x	x	x
Slope	raster R package (Hijmans 2023)	x	-	x
Mean Bottom Temperature	Peña et al. 2019	x	-	x
Lunar Phase	suncalc R package (Thieurmel and Elmarhraoui 2022)	x	-	-
Substrate (factor)	Open Maps	-	-	x
Month (spline)	Survey data	x	-	-
Tow Speed	Survey data	x	x	-
Tow Length	Survey data	x	x	x
Survey Type (factor)	Survey data	x	x	x
Year (spline)	Survey data	x	x	x

Table 2. Summary of analytical approaches used to meet each of the Terms of Reference objectives.

Objective	Analytical Approach
Stock definition	• Hierarchical clustering of relative biomass indices • Mixed-Effects Model of length-at-stage across areas • Visualization of spatial differences in length distributions • Literature review on genetics and timing of life stages
Survey area	• Evaluated using habitat predictions from an encounter model based on survey and environmental data. Logbook data from the commercial fishery used to ground truth the output.

Objective	Analytical Approach
Sampling schemes	• Tested using a simulation-based methodology (based on the operating model), including the current fixed-station approach.
Survey Index estimation method	• Four methods compared: • Design-based • Ordinary kriging • Fixed rank kriging • Spatiotemporal models – sdmTMB

Table 3. Coastwide survey area before and after the removal of untrawlable areas under each probability of encounter threshold. Areas were identified as untrawlable if they were deemed to be unsuitable habitat for trawling (e.g., rocky), within a high traffic corridor, or part of a protected area closure. Probability of encounter is used to delineate shrimp habitat throughout B.C. waters (e.g., the 0.3 threshold defines the area of the B.C. coast where the probability of encountering shrimp is 0.3 or greater as shrimp habitat).

Probability of encounter threshold	Survey area (km^2, prior to removal of untrawlable areas)	Survey area (km^2, after removal of untrawlable areas)
0.3	94,630	76,421
0.4	89,458	66,550
0.5	84,797	69,076
0.6	80,660	60,083
0.7	76,833	57,380
0.8	72,653	54,397

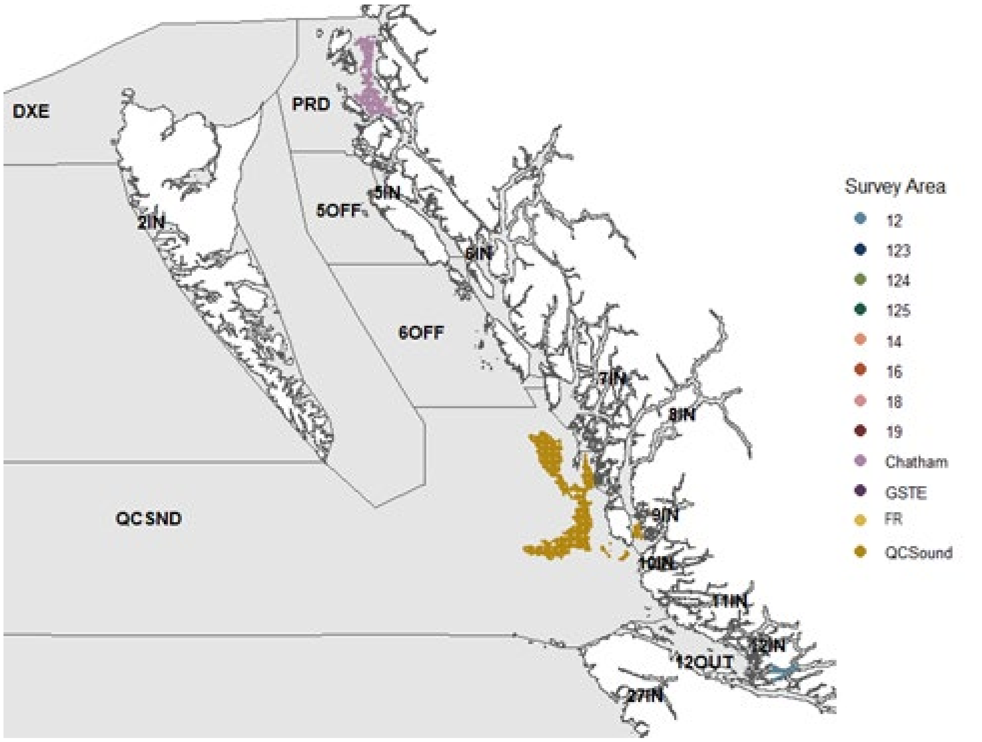

Figure 2. Current Shrimp Management Areas (SMAs; black bold text and grey lines) and associated Survey Areas (clusters of coloured dots) along the north and central coasts of B.C. (Note that the SMA names are based on Pacific Fishery Management Areas with some exceptions.)

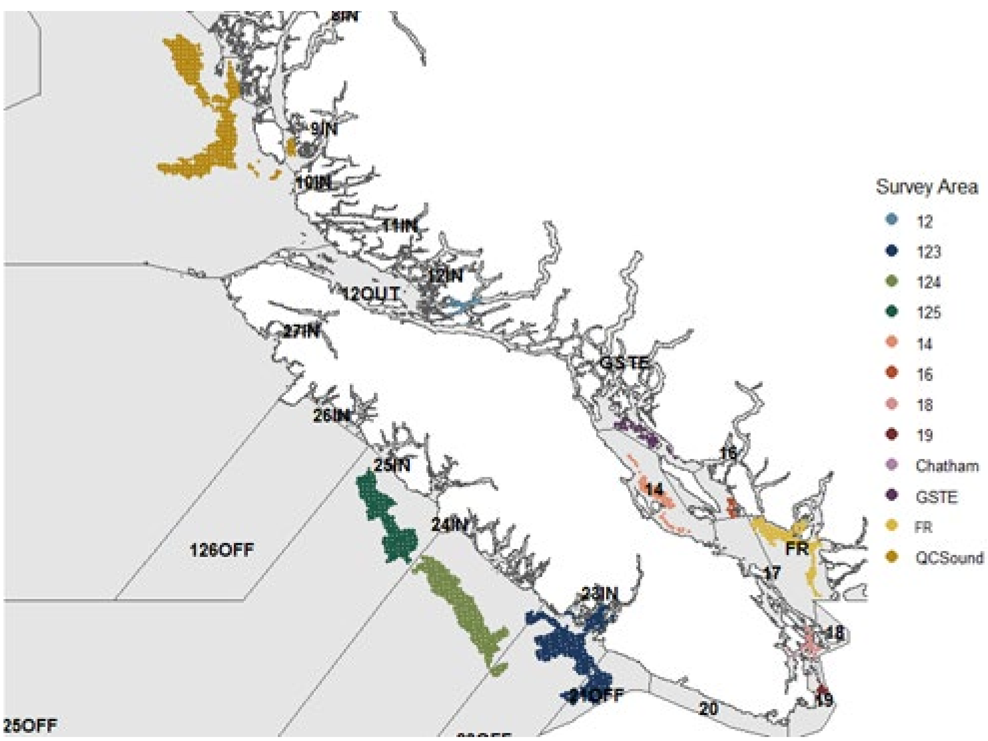

Figure 3. Current Shrimp Management Areas (SMAs; black bold text and grey lines) and associated Survey Areas (clusters of coloured dots) along the south and central coasts of B.C. (Note that the SMA names are based on Pacific Fishery Management Areas with some exceptions.)

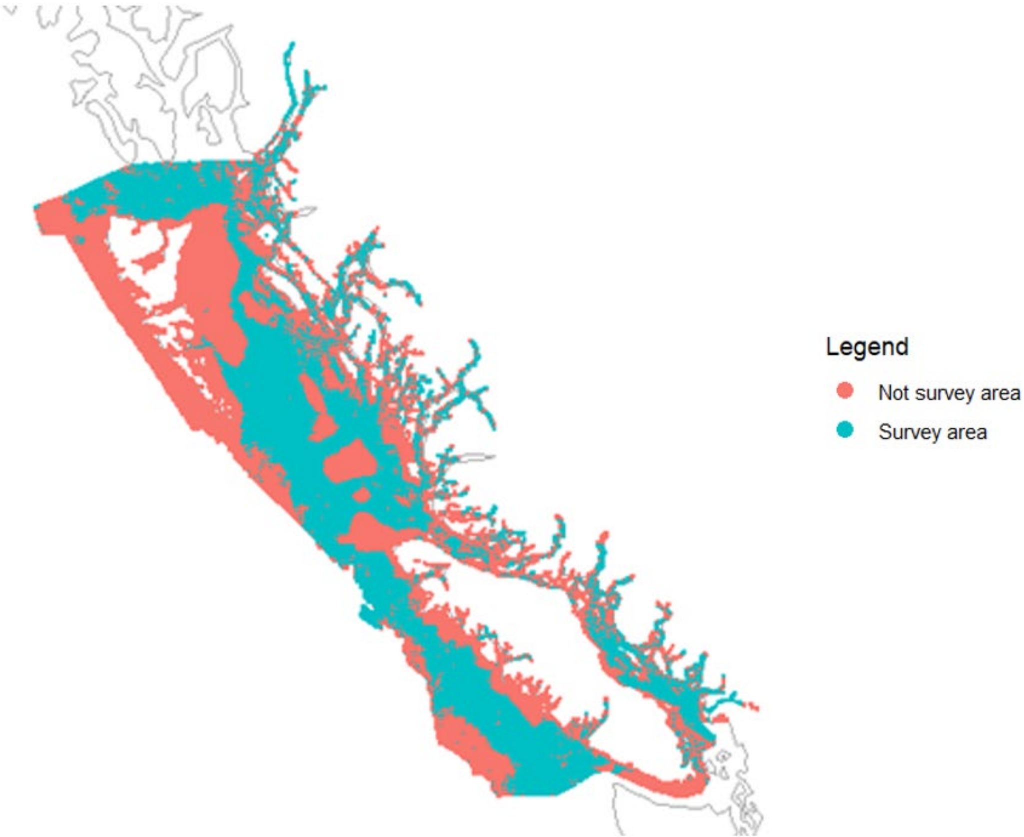

Figure 4. Habitat-based survey area for the Shrimp Trawl fishery along the coast of B.C. (turquoise = survey area, red = not survey area) with untrawlable areas removed based on a threshold of 0.3 (i.e., areas with a predicted encounter probability of shrimp above 0.3 are considered to be shrimp habitat).

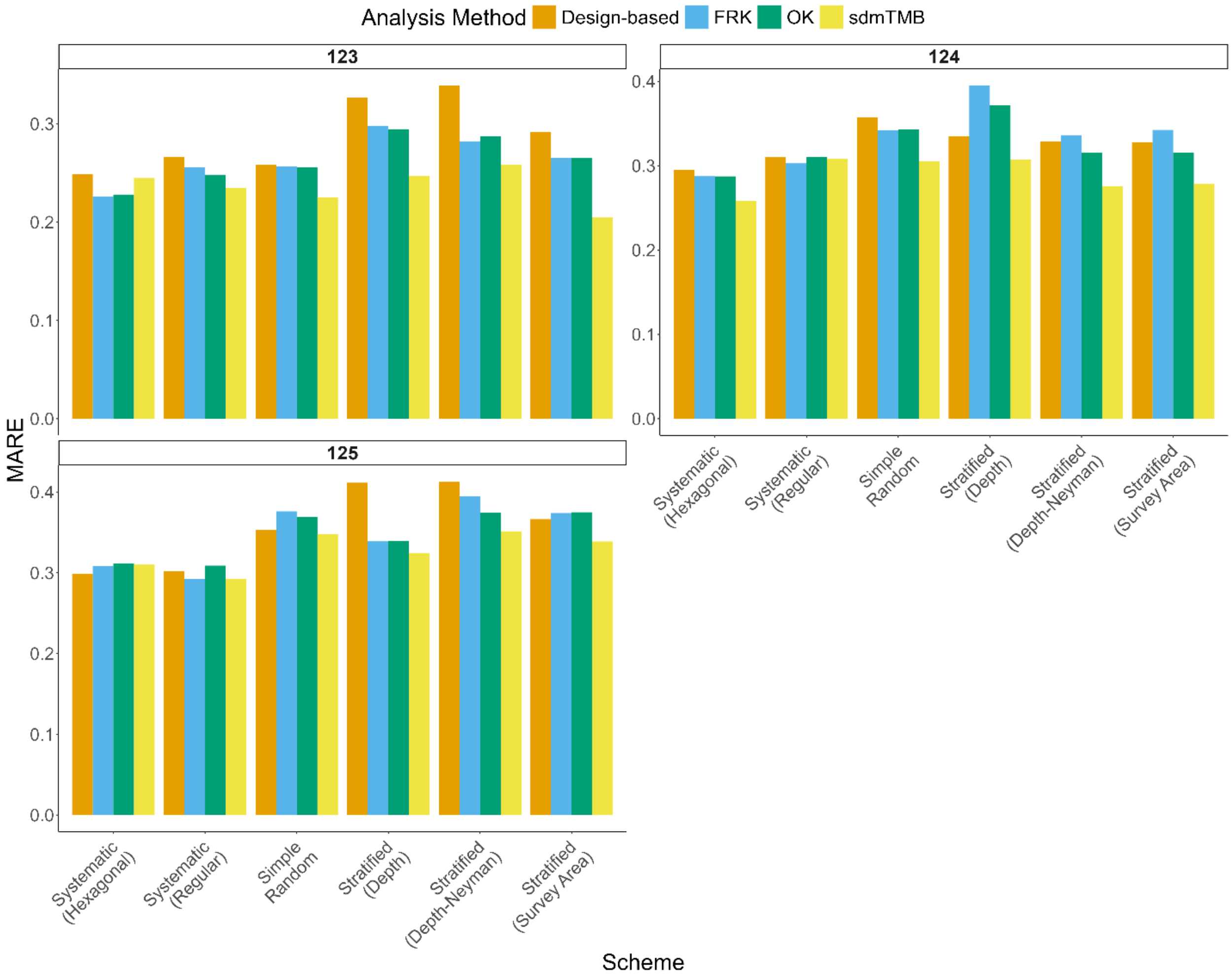

Figure 5. Median absolute relative error (MARE) for seven of the 100 iterations of Smooth Pink Shrimp in West Coast Vancouver Island (i.e., Survey Areas 123, 124 and 125) with all years, for each sampling scheme, and a sample size (number of tows) of 100 that were run with Fixed Rank Kriging (FRK). Only the simulations that converged across all methods are included here. Analysis methods are design-based (orange bars), Fixed Rank Kriging (FRK) (turquoise bars), Ordinary Kriging (OK) (green bars), and spatiotemporal models (sdmTMB) (yellow bars).

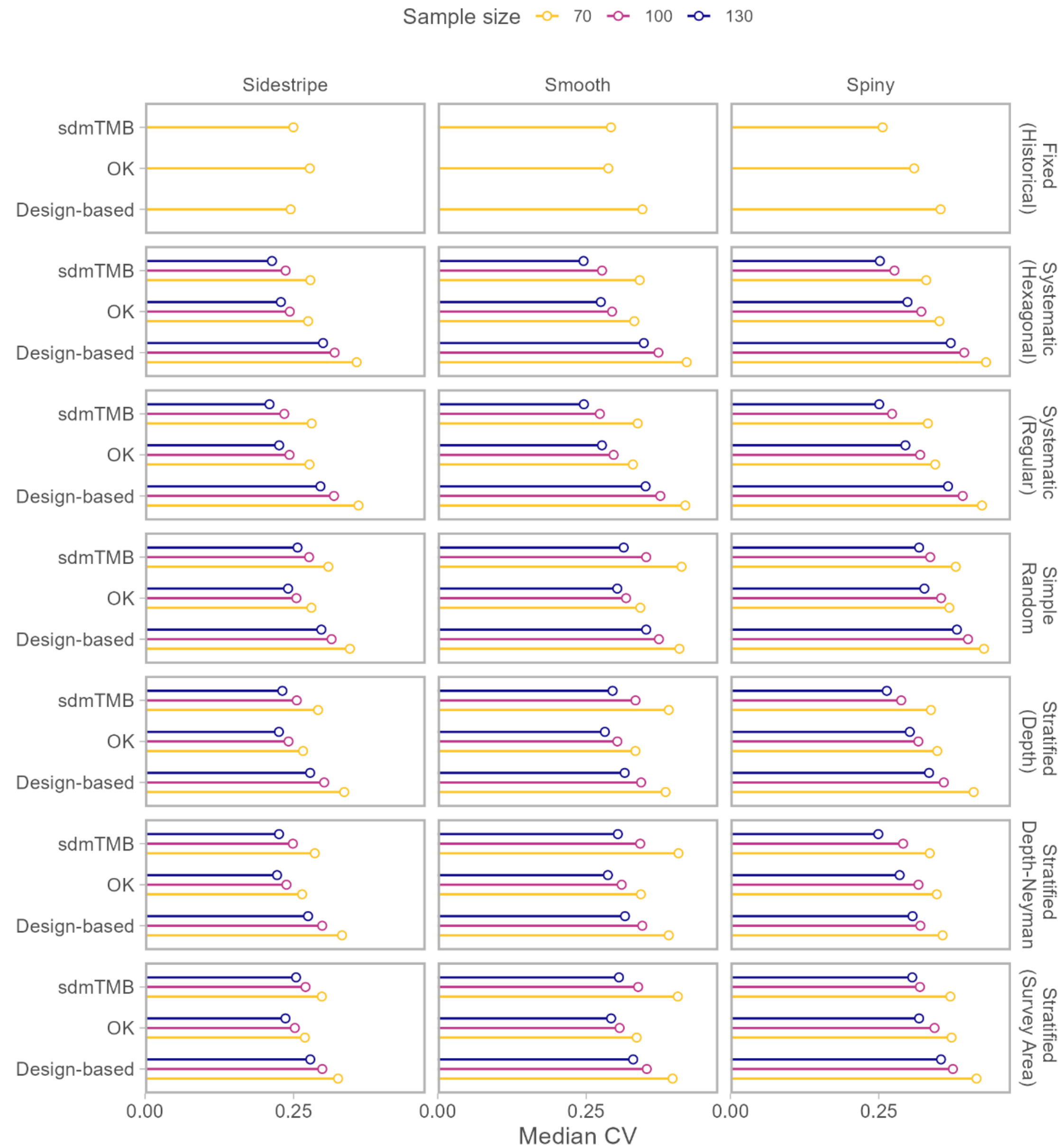

Figure 6. Effect of sample size (number of tows) and analysis method on median coefficient of variation (CV) across sampling schemes for Smooth Pink, Spiny Pink, and Sidestripe Shrimp species. Analysis methods are design-based, Ordinary Kriging (OK) and spatiotemporal models (sdmTMB).

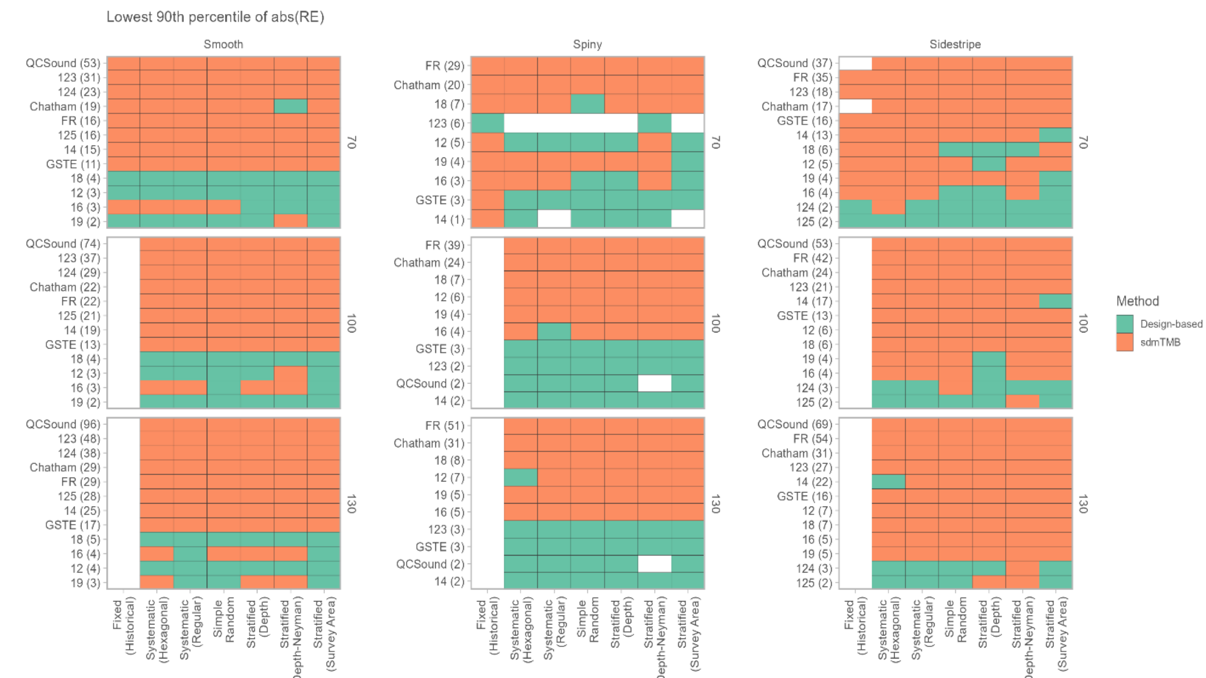

Figure 7. The index estimation method with the lowest 90th percentile of absolute relative error (RE) (i.e., identifies which method is least wrong in a worst-case (90th percentile) iteration) by Shrimp Management Area for Smooth Pink, Spiny Pink and Sidestripe Shrimp species at three sample sizes (i.e., number of tows). Only design-based and sdmTMB analysis methods are shown.

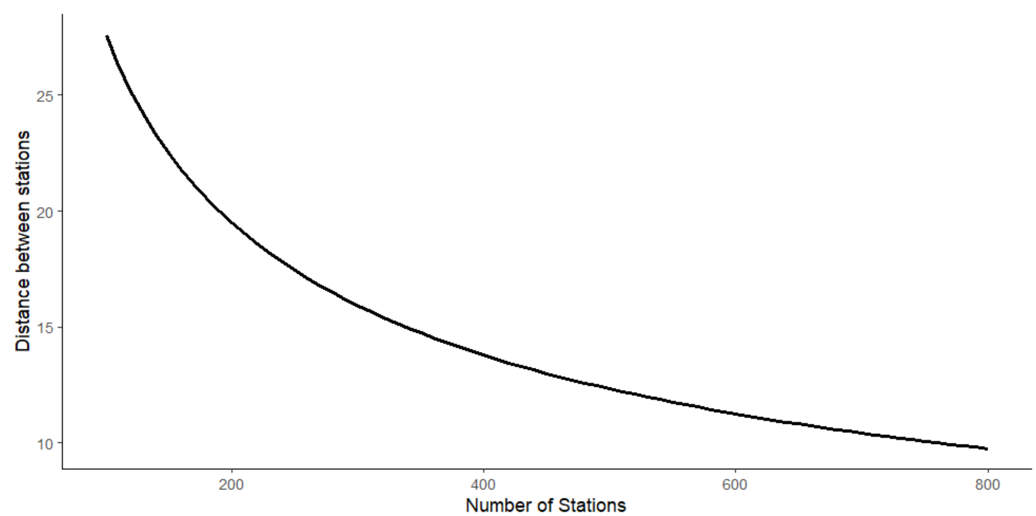

Figure 8. Approximate shortest distance between stations (in kilometres) versus number of stations in the recommended survey area of 76,040 km^2.

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