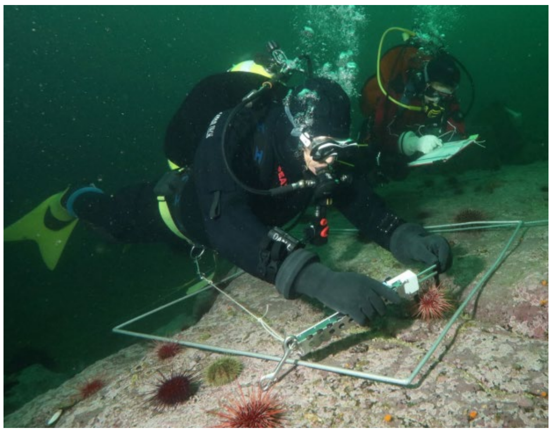
Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2023/003

RECOMMENDATIONS ON THE DESIGN OF A MULTISPECIES BENTHIC MARINE INVERTEBRATE DIVE SURVEY PROGRAM FOR STOCK MONITORING



Divers conducting a multispecies survey. Photo: D. Bureau, DFO.

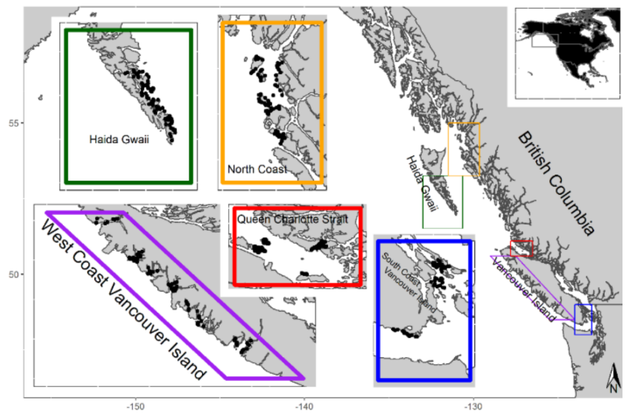


Figure 1. Map of pilot survey regions and transect locations, 2016-2021.

Context:

Stock assessment dive surveys for benthic marine invertebrates (Northern Abalone, Green and Red Sea Urchins, Giant Red Sea Cucumbers and Geoducks) in British Columbia (BC) have historically been conducted as single-species surveys that estimate density and/or biomass in different portions of the BC coast in different years. The data collected through these surveys have been used to estimate biomass and/or provide advice on harvest options for their respective commercial fisheries and are generally not suitable for coast wide stock status monitoring.

Since 2016, Fisheries and Oceans Canada (DFO) Science has been working to develop a multispecies monitoring program to determine stock status of benthic marine invertebrates to ensure dive fisheries are compliant with the Department's Precautionary Approach Policy (DFO 2009), including the legislated requirements of the amended Fisheries Act (RSC 1985, c. F-14), and specifically, the regulations pertaining to the Fish Stocks Provisions. This new multispecies monitoring program is intended to provide fishery-independent, quantitative monitoring of benthic invertebrate stocks over time, on the BC coast.

DFO Science has requested that Science Branch review and provide recommendations on optimal survey design for the multispecies benthic invertebrate monitoring program to ensure the surveys collect the data necessary to meet the objectives of the program.

This Science Advisory Report is from the July 13-14, 2022, regional peer review on Recommendations on the design of a multispecies benthic marine invertebrates dive survey program for stock monitoring. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule] as they become available.

SUMMARY

- DFO Science has designed a multispecies dive survey protocol to provide unbiased, coast wide monitoring of benthic invertebrate stocks (as may be required under the updated *Fisheries Act*) and associated habitat information for a suite of benthic marine invertebrate species (Green (*Strongylocentrotus droebachiensis*), Purple (*S. purpuratus*) and Red Sea Urchin (*Mesocentrotus franciscanus*), Geoduck (*Panopea generosa*), Giant Red Sea Cucumber (*Apostichopus californicus*), Northern Abalone (*Haliotis kamtschatkana*), and Sunflower Sea Star (*Pycnopodia helianthoides*)). Based on information available at this time, the proposed survey design can provide estimates of coast wide stock status for Red Sea Urchin and Giant Red Sea Cucumber, and relative abundance indices for Geoduck, Green Sea Urchin, Purple Sea Urchin, Northern Abalone and Sunflower Sea Star.
- The new protocol was tested through a series of pilot surveys conducted on a subset of areas of the BC coast each September from 2016-2021. Design of the pilot surveys was based on previous dive survey data and experience and demonstrated the practical feasibility of the protocol, while also gathering preliminary information to guide the following recommendations about the statistical design of the survey:
  - Use the dive survey protocol described in Appendix 12.1 of the Research Document, including the quadrat skipping sampling scheme that is dependent on transect length, a target depth range of -2 m to 12.2 m relative to chart datum, and a maximum transect length of 125 m.
  - Exclude sections of shoreline with fetch values lower than 20,000 m or higher than 2.52 million m when randomly placing transects to ensure sampling effort is focused on suitable habitat while also avoiding potentially unsafe areas for diving.
  - Ensure surveys occur at the same time of year to avoid introducing seasonal variation to the data.
  - Use the common (across species) coast wide standard deviation-to-mean ratio of density (animals/m^2) equal to 1.27 (i.e., $\sigma/\mu = 1.27$) derived from the pilot surveys in calculations to determine the initial target number of transects to be sampled. The number of transects to be sampled may change if the *in situ* standard deviation-to-mean ratio of density differs substantially from this coast wide estimate.
  - Conduct at least 240 transects coast wide to estimate stock status to adequately manage the risks of making incorrect stock status determinations. This target number of transects is based on an Acceptance Sampling analysis and uses the current reference points for Red Sea Cucumber (RSU) (Lochead et al. 2019) and Giant Red Sea Cucumbers (Hajas et al. In press), predetermined risk tolerances, and field-derived estimates of variability from the pilot surveys. The target number of transects could change in the future as new data become available or if reference points, observed variability in the data, and/or risk tolerances change.
  - Implement a two-stage, random sampling design that minimizes the time required to cover the entire BC coast and optimizes the efficient use of available resources. Ideally, the entire coast would be covered in a single year (roughly 42 days of ship time required). A realistic alternative would be to divide the coast in two or three sections and rotate through the sections over two or three years (requiring roughly 23 days or 18 days of ship time per year, respectively). Should the available resources (such as ship time, etc.) dictate a rotation longer than two years, then it is recommended that a panel design be considered.
  - Continue to explore pre- or post-stratification variables to improve survey precision, as data become available. Although there is insufficient evidence from the present analyses to suggest that stratification by fetch, Sea Otter occupancy, substrate type, or depth

improve survey precision at this time, the dynamic ecosystem occupied by these species implies that these or other variables could become relevant to the survey design in the future.

- Areas for future work were identified and include: incorporation of relevant information from species distribution and/or habitat suitability models as they become available, more explicit consideration of climate change impacts, feasibility of collecting environmental data (i.e., ocean climate data) on future dive surveys, improved understanding of larval dispersal (source/sink dynamics), Sea Otter range expansion, and inclusion of invertebrate density estimates from areas at non-diveable depths (i.e., areas with depths greater than approximately 18 m).

BACKGROUND

Stock assessment dive surveys for commercially fished benthic marine invertebrates (Northern Abalone[1], Green and Red Sea Urchins, Giant Red Sea Cucumbers and Geoducks) in British Columbia (BC) have historically been conducted as single-species dive surveys that estimate density and/or biomass in different portions of the BC coast in different years. The data collected through these surveys have been used to estimate biomass and/or harvest options for their respective commercial fisheries and are generally not suitable for coast wide stock status monitoring. The biomass estimates or harvest options are used by Fisheries Management for setting quotas.

Since 2016, DFO Science has been developing a multispecies monitoring program to determine stock status for a suite of benthic marine invertebrates to ensure dive fisheries are compliant with the Department's Precautionary Approach (PA) Framework (DFO 2009), including the legislated requirements of the amended *Fisheries Act* (RSC 1985, c. F-14), and specifically, the regulations pertaining to the Fish Stocks Provisions. This new multispecies monitoring program is intended to provide fishery-independent, quantitative monitoring of benthic invertebrate stocks (i.e., density and/or size) over time in both fished and unfished regions of the BC coast. In addition to achieving the requirements of the Fish Stocks Provisions, the multispecies monitoring program will help work towards an ecosystem-based approach to stock assessment and fishery management, which is a Departmental priority (DFO 2007). Furthermore, since single-species dive survey protocols are similar between species, using a multispecies survey approach results in a more efficient use of resources available for field work.

The species of interest for the survey at this time include Green Sea Urchin, Red Sea Urchin, Giant Red Sea Cucumber, Geoducks (i.e., the four species targeted by BC commercial dive fisheries), the Purple Sea Urchin (whose abundance and distribution has shown dramatic shifts in California in recent years; Rogers-Bennett and Catton 2019), the endangered Northern Abalone (which was also previously subject to historically important fisheries) and the Sunflower Star (an important mesopredator whose population on the BC coast nearly collapsed between 2014 and 2015 due to sea star wasting disease; Burt et al. 2018; Hewson et al. 2014) (Table 1). The survey also collects information on substrate types and algae observed on survey transects.

The results from this monitoring program are intended to be useful to Fisheries Managers for incorporating the Precautionary Approach and ecosystem considerations into their decision making. The data may also be used to inform habitat mapping, species distribution modeling,

[1] All fisheries for Northern Abalone in BC were closed in 1990 due to conservation concerns. Northern Abalone are currently listed as Endangered by COSEWIC and *SARA* (Obradovich et al. 2021) and are monitored using single-species dive surveys that began in the late 1970s and are ongoing.

and emergency response, as well as Marine Protected Area planning and monitoring programs along the BC coast.

ANALYSIS

Pilot Surveys

Pilot surveys were used to demonstrate that the proposed field protocol was logistically feasible and to provide data to estimate variability in density across transects for the species of interest. This information was then used to inform the recommended statistical design of the proposed coast wide multispecies survey.

Overall Survey Design Strategy

The dive survey protocol was designed using past dive survey experience and data, including data from single-species surveys for Giant Red Sea Cucumber, Geoduck and Red Sea Urchin, and Habitat Mapping surveys. The pilot surveys used a two-stage design with randomly selected transect locations and systematically spaced quadrats sampled along transects. Sampled quadrats were censused for the species of interest (counts for Giant Red Sea Cucumbers and Geoducks; measurements for urchins, Northern Abalone and Sunflower Star) along with depth, substrate type and algae (species identification and percent cover). Species densities were computed at the transect level, making transects the sampling unit for the survey.

Pilot surveys were conducted from 2016-2021 in September of each year, which aligned with a window of available ship time, provided good conditions for diving (visibility and temperature), and did not conflict with other dive surveys (to ensure availability of divers). Although this time of year is not ideal for observing Geoducks, it would still be possible to establish an index of relative abundance for this species based on the data collected. In the future, if it were desirable to combine multiple survey time series, consideration would need to be given to establishing comparability between them. For example, a correction factor could be applied to account for the suboptimal survey timing and correction factors may be needed for other species too (e.g., detectability of juvenile sea cucumbers is likely higher on the multispecies survey than on the single species sea cucumber surveys because the multispecies surveys use a smaller quadrat size and are searched more thoroughly).

Each year, the pilot surveys targeted a different region of the BC coast to provide data from a range of habitats and regions, namely north-eastern Vancouver Island, south-eastern Vancouver Island, the mainland North Coast, south-east Haida Gwaii and the West Coast of Vancouver Island. Surveys were conducted in areas both open and closed to commercial harvest for the species with commercial fisheries. In south-eastern Haida Gwaii, for example, both multi-use (open to commercial harvest) and strict protection (closed to commercial harvest) zones were surveyed within the Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site. Future multispecies surveys may be used to monitor changes in invertebrate densities over time in multi-use areas (i.e., to assess the impact of harvest on population densities through comparison with strictly protected areas).

Maximum Transect Length/Depth

Target depths for the transects were chosen in relation to chart datum so that comparable depth ranges were covered on all transects irrespective of tide height. A -2 m shallow target depth was selected to ensure the transect quadrats included Abalone habitat. A 12.2 m deep target depth was selected to ensure all transect lengths would fall within SCUBA diving safety limits and restrictions. Transect length is dependent on the slope of the seafloor but was capped at 125 m based on experience from other dive surveys and diving logistics (i.e., transects of this length can generally be completed on a single dive).

Variability in Species Density

The pilot surveys demonstrated a range of regional mean densities for each species. Overall, observed variability was proportional to the mean for all species and was similar among species, allowing a common coast wide standard deviation-to-mean ratio of density (sd:mean ratio) equal to 1.27 to be used (Figure 2). Use of a single sd:mean ratio of density simplifies subsequent calculations of required sample size (see section on Acceptance Sampling).

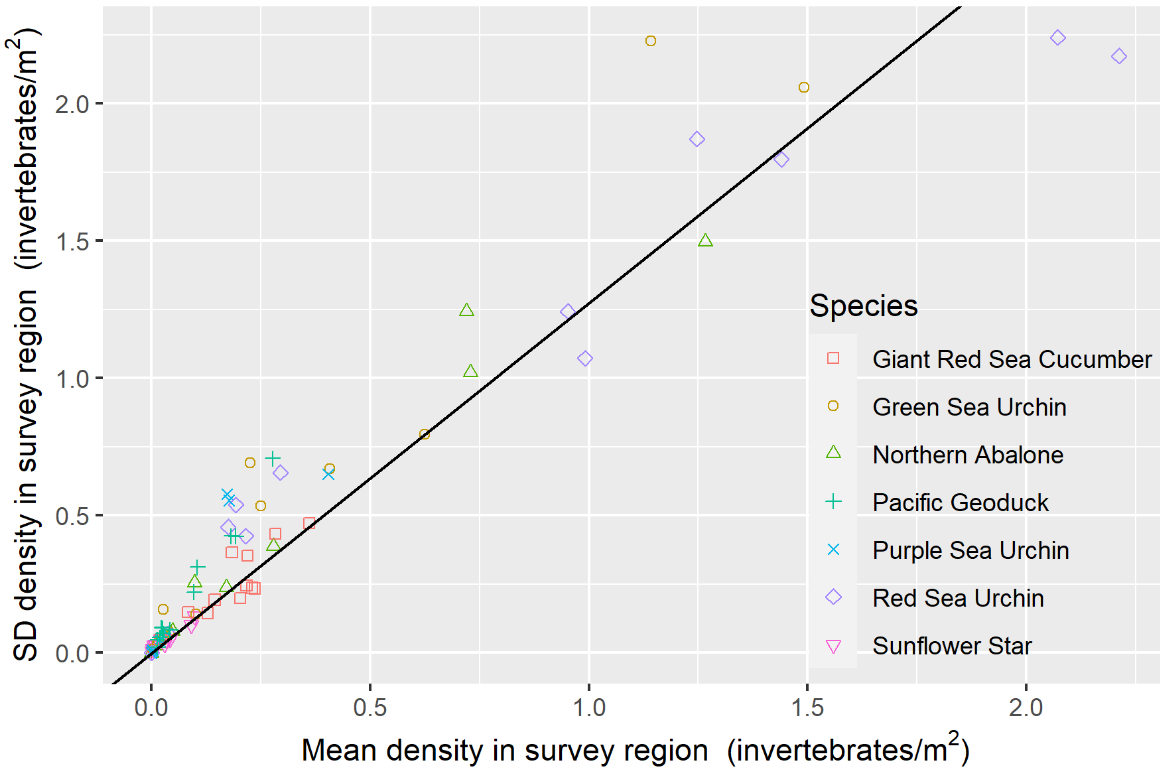


Figure 2. Relationship between density standard deviation in the survey region to mean density in survey region for all species. Black line indicates the common sd:mean ratio of density of 1.27 (i.e., σ = 1.27 μ).

Index Transects vs. Re-randomized Transects

A subset of pilot survey transects sampled precision. Assessing the impact of replicating transects to estimate long term trends is difficult because it is reasonable to expect the degree of impact could change over time (i.e., the correlation of density among replicated transects would decline as the period of time between visits increases). For example, there may be a very high correlation in the density when transects are measured 1 month apart, which could decline to a moderate correlation when the same transects are measured 2 years apart, which then could decline to 0 when the same transects are measured 5 years apart.

Based on this dataset, only moderate positive correlations between repeated density measurements were observed and there were no substantial gains in precision when compared with randomly selecting new transect positions for each survey. Furthermore, it is often difficult to return to the exact transect location on repeat visits. On the other hand, re-randomizing the selection of transect locations prior to each survey could:

- allow the collection of data from more locations over time that may contribute to improving stratification,
- enable the use of different models to estimate density (e.g., spatio-temporal models),
- lead to better knowledge about coast wide spatial and temporal variability in the populations, and
- readily incorporate additional environmental and/or ecosystem information over time.

Recommended Survey Design

Overall Survey Design Strategy

It is recommended that the multispecies dive surveys continue to use the dive survey protocol developed for the pilot surveys (i.e., a two-stage design with randomly placed transects and sampling of systematically spaced quadrats along the transect).

The transects should be capped at 125 m in length or 12.2 m chart datum depth, whichever comes first. Longer transects will subsample quadrats, resulting in a maximum of 25 quadrats sampled per transect.

A 1 m^2 quadrat size is recommended for the multispecies dive survey to be consistent with previous urchin and abalone surveys, and also as the smallest common unit of assessment across species assessed by the survey.

Sampled quadrats should be censused according to the standardized protocol described in Appendix 12.1 of the Research Document.

At this time, the protocol does not include consideration for cryptic sampling because it may not be feasible given the survey time constraints (i.e., to complete each transect on a single dive), and is complicated by the fact that cryptic sampling can only be conducted on certain substrate types (i.e., randomly placed transects may not enable unbiased cryptic sampling). However, if continuing Sea Otter range expansion impacts the survey's ability to detect some benthic marine invertebrate species due to increased predator avoidance behaviours such as crypsis, options for adopting cryptic sampling may need to be revisited.

Acceptance Sampling

Acceptance sampling is a common statistical method used in manufacturing contexts to assess if a process is operating within prespecified tolerance limits (Lawson 2021). To date, this method has not been widely used in fisheries contexts. The current work demonstrates that this method is relevant when evaluating stocks against reference criteria (i.e., Limit Reference Points [LRPs] and Upper Stock References [USRs]) in fisheries science because it uses statistical techniques to provide early detection and opportunity to avoid problems, such as controlling the probability of not detecting declining stock abundances. Despite being a relatively novel application in fisheries science, Acceptance Sampling provides the same results that would be obtained from the more traditional approach of conducting a hypothesis test with a power analysis. A key advantage of Acceptance Sampling is the lack of requirement to define Type 1 and Type 2 statistical errors (i.e., risks of false positive and false negative results, respectively), which can seem arbitrary depending on one's perspective within a fishery context.

Acceptance Sampling requires users to specify acceptable consumer and producer risk levels (defined below), and species-specific LRPs and USRs, as well as an estimate of the variability in species density (i.e., current estimate of sd:mean ratio equal to 1.27) to generate a threshold coast wide density decision-value, k, and a sample size (number of transects to be sampled), n for each species.

The consumer risk, in this context, is defined as the risk of not detecting when the density of the stock falls below the LRP. Fisheries Managers were consulted to determine an acceptable level of consumer risk in this context. A monitoring program with high power to detect if the stock falls below the LRP is highly desirable, so the consumer risk was accordingly set at 5%.

The producer risk is the risk of falsely determining that the density is below the USR when it is actually above the USR. Fisheries Managers also set the producer risk at 5% given the potential socioeconomic consequences of erroneously limiting fishing opportunity unnecessarily. For context, the likelihood scale to define DFO’s risk tolerance designates probabilities in the range of < 5% as “very low” and 5-25% as “low” (DFO 2022; 2009).

Coast wide LRPs and candidate USRs have been developed for Giant Red Sea Cucumber, and Red Sea Urchin (Table 1). Green Sea Urchin reference points were derived from fishery-independent survey data at two high density index sites, one off of north-east Vancouver Island and one off of south-east Vancouver Island (Table 1) and may therefore not be applicable coast wide. Green Sea Urchins were still included in the acceptance sampling analyses, however, in case coast wide assessments become desirable in the future. Thus, based on information available at this time, the proposed survey design can provide estimates of coast wide stock status for Red Sea Urchin and Giant Red Sea Cucumber, and relative abundance indices for Geoduck, Green Sea Urchin, Purple Sea Urchin, Northern Abalone and Sunflower Sea Star.

Table 1. Species currently monitored with the multispecies dive survey protocol.

Species	Measurement (units)	LRP	USR	Suitable Habitat – Depth Range	Suitable Habitat – Substrate type
Giant Red Sea Cucumber	Split weight (g) starting in 2020	0.029 sea cucumbers/m^2 on sea cucumber habitat[2]	0.038 sea cucumbers/ m^2 on sea cucumber habitat	0 – 250 m	Most substrates, excluding mud. Most low to moderate exposure habitats, excluding head of inlets
Green Sea Urchin (GSU)	test diameter (TD) (mm)	0.45 legal-sized (≥ 55mm TD) GSU/m^2	0.9 legal-sized (≥ 55mm TD) GSU/m^2	0-140+ m	Hard substrates (bedrock to gravel), exclude mud
Red Sea Urchin (RSU)	test diameter (TD) (mm)	0.3 mature (≥ 50mm TD) urchin/m^2 on RSU habitat[3]	0.6 mature (≥ 50mm TD) urchin/m^2 on RSU habitat	0-284 m	Substrate of gravel or larger, where mud is not the predominant substrate (Lochead 2019)
Purple Sea Urchin	test diameter (TD) (mm)	n/a	n/a	0-160m	Hard substrates (bedrock to gravel), exclude mud
Northern Abalone	shell length (mm)	n/a	n/a	-2 to 10+ m	Hard substrates
Sunflower Sea Star	maximum arm span (mm)	n/a	n/a	0-456 m	A variety of habitats, including mud, sand, gravel, cobble, boulder, and bedrock.

[2] Giant Red Sea Cucumber habitat is currently defined in Duprey et al. (2011, 2016).
[3] RSU habitat is currently defined in Lochead et al. (2019)

Species	Measurement (units)	LRP	USR	Suitable Habitat – Depth Range	Suitable Habitat – Substrate type
Pacific Geoduck	shell length (mm)	40% unfished coastwide biomass	50% unfished coastwide biomass	-1 – 110+ m	Soft substrates

A single sampling plan was developed for Giant Red Sea Cucumber, Red Sea Urchin, and Green Sea Urchin that controls the producer and consumer risks by solving for *n* and *k* such that:

$$P(\widehat{Density} < k | \text{Density} \leq \text{LRP}) = 1 - \text{Consumer risk} \quad (1)$$

$$P(\widehat{Density} < k | \text{Density} \geq \text{USR}) = \text{Producer risk} \quad (2)$$

As shown in the Research Document's supplemental material, the sample size n is "hidden" in the above equations because it affects the standard error of the estimated density which affects the two probabilities.

Under this plan, the coast wide density is estimated using a sample of *n* transects. If the estimated density is less than *k*, then the stock density is considered to be at risk of being below the LRP, corresponding to the Critical Zone of the PA Framework (DFO 2009). If the estimated density is greater than *k*, then the stock density is considered to be "acceptable", i.e., potentially above the USR, corresponding to the Healthy Zone. The decision rule is "binary", but as the estimated density approaches the LRP, there will be greater "urgency" to any management action.

A common sd:mean ratio of density of 1.27 was estimated from the pilot survey data (Figure 2). Sample sizes were assumed to be large enough that a normal approximation to the sampling distribution of $\widehat{Density}$ was applicable with the standard deviation (sd, or 'σ') used in computing the variability of the estimated density being a function of the mean (μ), i.e., $\sigma = 1.27\ \mu$.

A sensitivity analysis was also performed to assess how changing the sd:mean ratio impacts the required number of transects (Table 2). The sensitivity analysis showed that as the sd:mean ratio increases, the sample size increases.

Table 2. As the standard deviation increases (relative to the mean), the required sample size increases but the value of k remains unchanged.

Species	sd:mean	Ratio increase (%)	k	n
Green Sea Urchin	1.27	-	0.6	39
	1.39	10	0.6	47
	1.58	25	0.6	61
	1.90	50	0.6	88
Red Sea Urchin	1.27	-	0.4	39
	1.39	10	0.4	47
	1.58	25	0.4	61
	1.90	50	0.4	88
Giant Red Sea Cucumber	1.27	-	0.033	240
	1.39	10	0.033	291
	1.58	25	0.033	375
	1.90	50	0.033	540

The Acceptance Sampling analysis generated an estimated minimum number of transects required to achieve a decision on stock status relative to the reference points with the specified risk tolerances. The analysis found that 39 randomly placed transects coast wide would be needed for Green and Red Sea Urchin, and 240 would be needed for Giant Red Sea Cucumber. The same sample size for Green and Red Urchins occurs because the ratio of the USR:LRP is the same; the larger sample size for Giant Red Sea Cucumbers occurs because the two reference points are relatively closer together compared to the urchin reference points. To ensure random placement of transects will generate unbiased coast wide density estimates, additional considerations such as those outlined below are required.

Fetch Cut-offs

To help focus the allocation of randomized sampling effort on habitats associated with the species of interest while also adhering to safe diving limitations, it is recommended that fetch cut-offs be applied to the coastline prior to random transect selection. A low fetch cut-off of 20,000 m is recommended to exclude areas that are generally unfavourable habitat for the benthic marine invertebrates of interest. A high fetch cut-off of 2,520,000 m is recommended to exclude highly exposed areas that are generally unsafe for diving. It has been demonstrated that applying these cut-offs would not have excluded the vast majority of past dives (Figure 3) and also does not unduly restrict application of the diver survey protocol to the BC coast overall (Figure 4).

Stratification

Stratified sampling is one method commonly used to improve the precision of estimates from a sampling design (i.e., to target sampling in areas with higher variability). The pilot surveys provided an opportunity to assess the potential advantage of using stratification variables to improve survey precision. Candidate stratification variables included: fetch (low versus high), Sea Otter occupancy (presence versus absence), substrate type (11 categories) and depth (separated into 2 m intervals). At this point, results from the analysis using the candidate stratification variables did not show any benefit to stratification, however stratification based on these and other variables (independently or combined) may still prove to be useful in the future. For example, continued refinement of species distribution models could potentially allow stratification based on probability of presence, while also assisting in further refining the shoreline that is targeted by the survey.

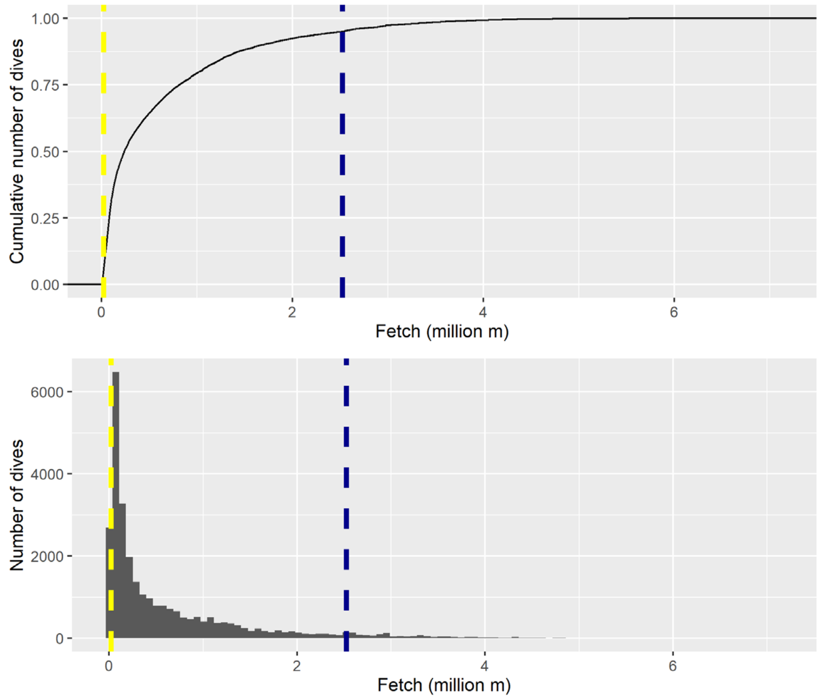


Figure 3. Distribution of density by fetch for dives from all invertebrate species surveys across all transects and years. The solid blue line is the smoothed average on the log scale and the dashed vertical lines are the recommended low (log_{10}20,000 = 4.3) and high (log_{10}2,250,000= 6.4) fetch cut-offs.

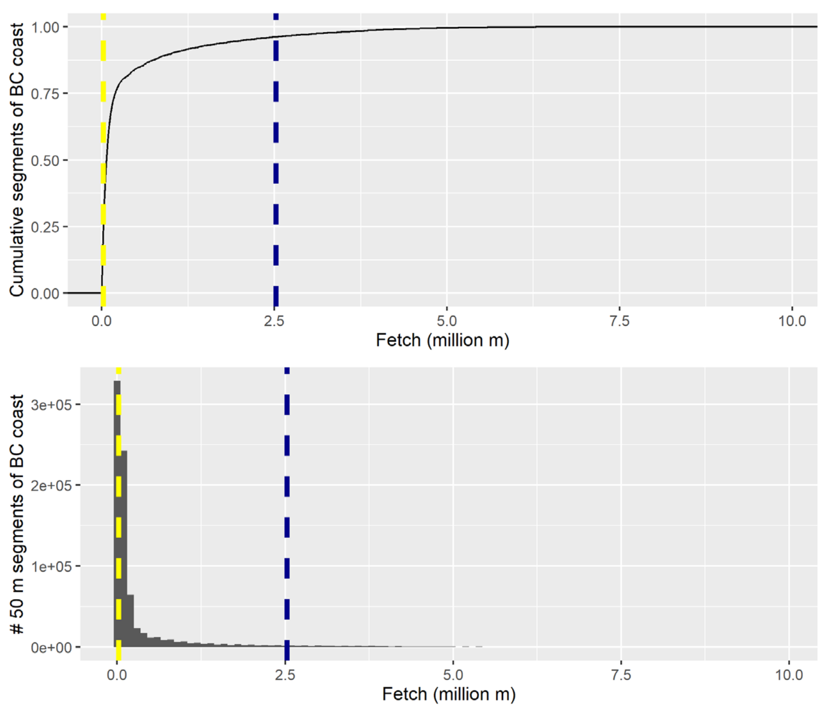


Figure 4. Cumulative number of 50 m shoreline segments along the BC coast in fetch categories from 0 to 10 million m (upper panel) and total number of 50 m shoreline segments along the BC coast in fetch categories from 0 to 10 million m (lower panel). Yellow dashed line indicates a fetch value of 20,000 m and the blue dashed line indicates the upper 95th percentile of fetch values (2.52 million m) for all dives.

Transect Placement

The objective of this survey is to generate unbiased coast wide species density estimates at meaningful intervals (e.g., every 10 years would not be often enough, while annual updates may not be logistically feasible). To a large extent, the sampling design of the survey will be limited by available resources (primarily, ship time and qualified diver capacity). It is recommended that the survey interval be as short as possible while still attaining the recommended 240 randomly placed transects coast wide.

Three scenarios for unbiased implementation of the dive survey were explored: simple random sampling, two-stage sampling, and a panel design with two-stage sampling. Simple random sampling across the entire coast was ruled out because the distance between individual transects would be large. Logistically, this would result in inefficient use of the ship time, as completing multiple transects per day would not be possible in most cases due to the travel time between transects. A more efficient method of placing the transects would be to use a two-stage sampling design (Thompson 1992). In this design, the primary (or first) stage of sampling randomly selects a fixed number of larger sampling units and then randomly places multiple smaller (secondary) sampling units within each primary unit (see Figure 5 examples). The advantage of the two-stage sample design is that it is logistically practical, as each of the randomly selected primary sampling units contains multiple (in this case, eight) transects that are close enough to each other to be completed in a single day (by minimizing travel time between transects). The third design option, a panel design with two-stage sampling, is similar but also involves choosing a random sample of primary units from the previous year's sampled primary units in the second year. The advantage of the panel design is that the repeated sample locations help to determine which part of a population density change in a given year is the result of temporal processes, like recruitment or mortality events, and which portion is related to the spatial process (sampling in a new area in each year). The disadvantage of the panel design is that it is not as logistically feasible due to the large travel time to the previous year's locations.

The ideal survey rotation will involve tradeoffs between minimizing the time to survey the entire coast and logistical feasibility given current resources. Since the entire coast cannot be covered in one year, a multiyear approach will be necessary. Multiyear rotations could result in an inability to observe sudden interannual changes in population density or habitat conditions, and lagged signals to inform timely management responses. At this time, a two-year rotation is feasible, based on current resources. With a two-year rotation, lag time is minimized such that there are no real benefits of using the panel design. Therefore, a two-stage, two-year rotation is the most efficient and logistically feasible design at this time. Should available resources dictate a rotation longer than two years, then it is recommended that inclusion of the panel design be reconsidered.

An example of how to achieve 240 transects coast wide with a two-stage sampling design and a multiyear rotation is illustrated in Figure 5. For a two-year rotation, the BC coastline could be divided into two parts (north and south, for example), and 120 transects could be completed in each of the parts over 2 years (Figure 5A). In the first stage of the two-stage design, a 50 x 50 km grid could be overlaid on the BC coast in GIS; alternatively, the BC coast could be split into sections based on shoreline length. For a three-year rotation, the BC coastline could be divided into three parts, with 80 transects completed in each part over 3 years (e.g., one part per year, 10 primary sampling units per part, 8 secondary sampling units per primary sampling unit, 1 transect per secondary sampling unit) (Figure 5B). The second stage of the two-stage design would consist of randomly selecting eight transects along the coastline (the secondary sampling units) within larger 50 x 50 km grid cells (primary sampling units) (Figure 6). For the 2-year rotation, 15 primary sampling units are chosen at random and then 8 secondary sampling units are randomly chosen within each of the randomly selected primary units for a total of 120 transects per year in the northern section of the coast and 120 transects per year in the southern section.

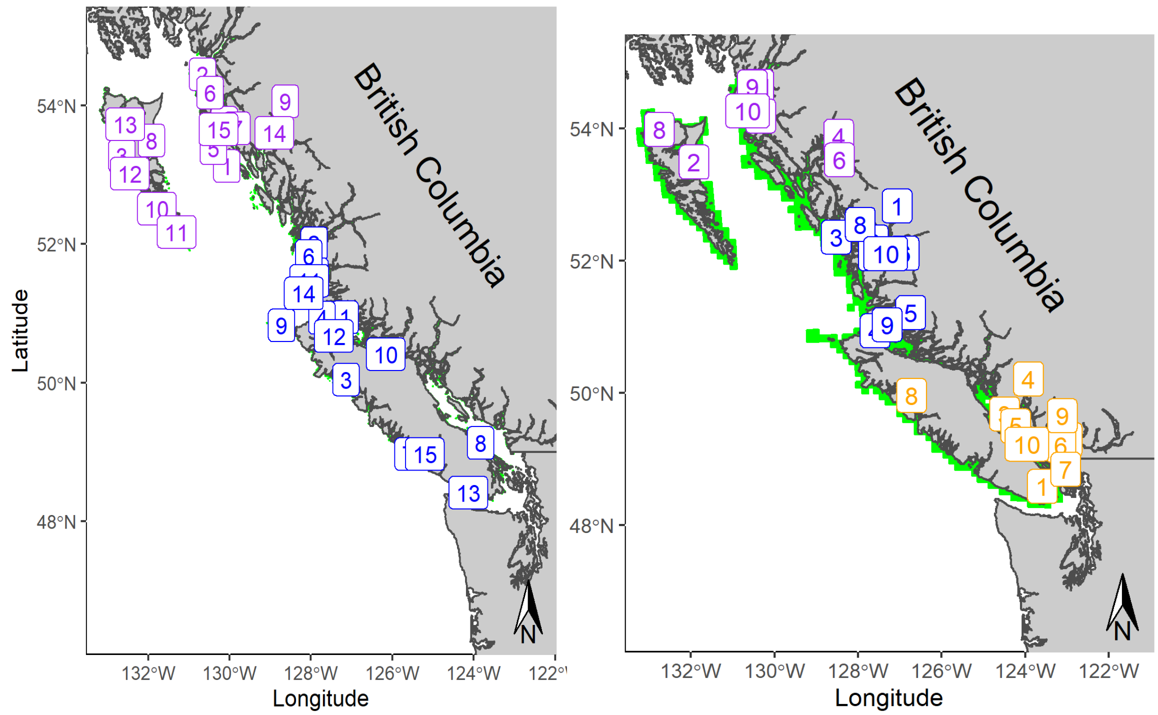


Figure 5. Examples of two-stage sampling where the primary stage randomly selects a fixed number of 50 x 50 km grids, and then randomly selects a fixed number of second stage units of coastline for placement of transects. A. Two-stage design with 2 regions (north in purple, south in blue): randomly placed primary sampling units are represented by the numbers 1-15. Within each primary sampling unit, 8 second-stage units of coastline are randomly selected for transect placement. In this example, 120 transects would be carried out each year. B. Two-stage design with 3 regions (north in purple, central in blue, south in yellow): randomly placed primary sampling units are represented by the numbers 1-10. In this case, the entire coast could be sampled on a three-year cycle with 80 transects carried out each year.

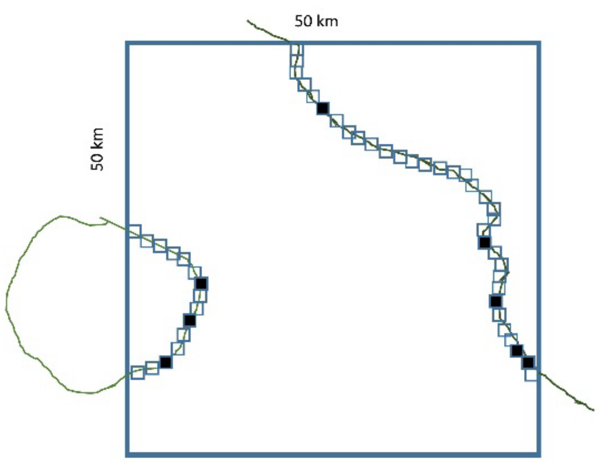


Figure 6. Example section of shoreline showing an example of a larger randomly selected primary stage sampling unit (50 km x 50 km square), with candidate second stage units (smaller 1 km x 1 km sections of shoreline) representing where dive transects would be placed. In this example, eight second stage sample units were randomly selected (small black filled squares).

Sources of Uncertainty

Geoduck show factor (the proportion of Geoducks that can be visually detected by survey divers) is known to be highest between April and July and thus, quantitative stock assessment surveys for Geoducks are typically scheduled during these months. To date, the multispecies pilot surveys have been conducted in September, which means the Geoduck data from these surveys cannot be used in current methods to estimate Geoduck biomass without inclusions of an estimate of detectability (similar to the catchability parameter commonly found in other species' stock assessments). However, Geoduck data obtained from September multispecies surveys can still be informative (i.e., by identifying locations where Geoducks are found beyond previously documented Geoduck beds and providing an additional index of Geoduck abundance).

Northern Abalone density estimates from the multispecies survey are not directly comparable to estimates obtained from the Northern Abalone index site surveys (e.g., due to different survey protocols, different target depth ranges, and lack of cryptic sampling on the multispecies survey). However, similar to Geoduck, estimates from the multispecies survey may provide a separate index of abundance for Northern Abalone and provide additional information on species distribution along the BC coast.

If the entire BC coast cannot be surveyed in a single year, careful consideration should be given to the survey schedule, recognizing that multi-year schedules will take longer to detect trends, and likely be unable to detect rapid changes in densities (such as was observed during the sea star wasting disease event). Note that once the first full coast wide rotation is complete (i.e., after the first 2 or 3 years), even a multi-year schedule could provide annual updates of species density estimates by using rolling averages of the densities.

The multispecies survey does not cover the full depth ranges of the species of interest. As such, it only provides an estimate of density for habitat located within diveable depths (i.e., to approximately 20 m depth). Future work could include the review of existing visual survey data and/or the development of new visual survey(s) to provide supplementary estimates of species densities at non-diveable depths (e.g., remotely operated vehicles, drop cameras, etc.).

The multispecies benthic invertebrate monitoring program, which collects detailed information on algae, will be an important tool for monitoring potential climate change impacts to this important benthic marine invertebrate food source. Going forward, being able to monitor additional environmental variables associated with benthic marine invertebrate habitat (e.g., ocean acidification, changes in water temperature, changing current regimes) will be important for assessing the broader impacts of climate change on these species (such as changes in species' range or depth distribution, impacts on larval dispersal, increased incidence of disease, etc.).

CONCLUSIONS AND ADVICE

To meet the regulatory requirements of the revised *Fisheries Act* and support implementation of a Precautionary Approach Framework for the benthic invertebrate species of interest, it is recommended that DFO's coast wide multispecies benthic invertebrate dive survey design should aim to:

1. Use the dive survey protocol described in Appendix 12.1 of the Research Document, including the quadrat skipping sampling scheme that is dependent on transect length, a target depth range of -2 m to 12.2 m relative to chart datum, and a maximum transect length of 125 m.

2. Exclude sections of shoreline with fetch values lower than 20,000 m or higher than 2.52 million m when randomly placing transects to ensure sampling effort is focused on suitable habitat while also avoiding potentially unsafe areas for diving.
3. Ensure surveys occur at the same time of year to avoid introducing seasonal variation to the data.
4. Use the common (across species) coast wide standard deviation-to-mean ratio of density (animals/m^2) equal to 1.27 (i.e., $\sigma/\mu = 1.27$) derived from the pilot surveys in calculations to determine the initial target number of transects to be sampled. The number of transects to be sampled may be revised if the in situ standard deviation-to-mean ratio of density differs substantially from this coast wide estimate.
5. Conduct at least 240 transects coast wide to estimate stock status to adequately manage the risks of making incorrect stock status determinations. This target number of transects is based on an Acceptance Sampling analysis and uses the current reference points for Red Sea Cucumber (RSU) (Lochead et al. 2019) and Giant Red Sea Cucumbers (Hajas et al. In press), predetermined risk tolerances, and field-derived estimates of variability from the pilot surveys. The target number of transects could change in the future as new data become available or if reference points, observed variability in the data, and/or risk tolerances change.
6. Implement a two-stage, random sampling design that minimizes the time required to cover the entire BC coast and optimizes the efficient use of available resources. Ideally, the entire coast would be covered in a single year (roughly 42 days of ship time required). A realistic alternative would be to divide the coast in two or three sections and rotate through the sections over two or three years (requiring roughly 23 days or 18 days of ship time per year, respectively). Should the available resources (such as ship time, etc.) dictate a rotation longer than two years, then it is recommended that a panel design be considered.
7. Continue to explore pre- or post-stratification variables to improve survey precision, as data become available. Although there is insufficient evidence from the present analyses to suggest that stratification by fetch, Sea Otter occupancy, substrate type, or depth improve survey precision at this time, the dynamic ecosystem occupied by these species implies that these or other variables could become relevant to the survey design in the future.

OTHER CONSIDERATIONS

Further efficiencies in the survey protocol may be possible with technological improvements. For example, new underwater data logging calipers and methods to digitally record dive survey data on tablets in underwater housing are currently being developed by the Department and contract partners. This may enable real-time density estimation, making double sampling plans (as described in Appendix 12.4 in the Research Document) more feasible in the future.

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SOURCES OF INFORMATION

This Science Advisory Report is from the July 13-14, 2022, regional peer review on Recommendations on the design of a Multispecies Benthic Marine Invertebrate Dive Survey Program for Stock Monitoring. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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