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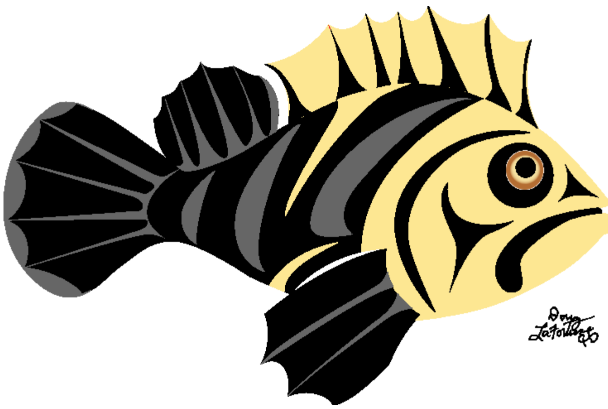
Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2026/020

ECOLOGICAL MONITORING ADVICE FOR ROCKFISH CONSERVATION AREAS



Rockfish by Doug LaFortune of the Tsawout Nation.

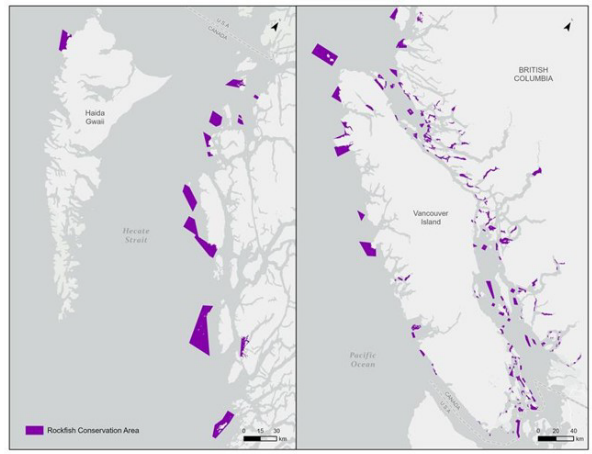


Figure 1. Map of Rockfish Conservation Areas on the Pacific Coast

CONTEXT

As part of the 2002 Rockfish Conservation Strategy, spatial management measures termed Rockfish Conservation Areas (RCAs) were proposed to reduce the fishing mortality for Inshore Rockfish, in concert with other management measures (Yamanaka and Logan 2010). In 2007, a network of 164 RCAs was implemented coastwide where several fisheries that catch Inshore Rockfishes were closed. No monitoring program currently exists to assess the success of RCAs in meeting their ecological conservation objectives, which are to increase the abundance and size of Inshore Rockfish and Lingcod within RCAs, and to protect their habitat. In light of Fisheries and Oceans Canada's (DFO) commitment to manage fisheries (under Sustainable Fisheries Framework and Precautionary Approach) and benthic areas (Sensitive Benthic Areas), DFO Fisheries Management requested advice on how to monitor and assess the effectiveness of RCAs at meeting their ecological conservation objectives.

This Science Advisory Report is from the June 2-4, 2025, regional peer review on Ecological Monitoring Advice for Rockfish Conservation Areas. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Rockfish Conservation Areas (RCAs) are a network of 162 area-based management measures that were fully established in British Columbia (BC) by 2007.
- A review of data previously collected in RCAs showed that while most RCAs have been sampled using various tools since their implementation, there is no coastwide

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pre-implementation dataset that can be used to assess changes over time across the RCA network.

- Monitoring advice is presented for assessing the effectiveness of RCAs at meeting their ecological conservation objectives at a coastwide scale (full details in Jeffery et al. In prep.[1])
  - The ecological conservation objectives of RCAs are to increase inshore Rockfish and Lingcod population densities, to increase the abundance of Inshore Rockfish in older age and larger size classes, and to protect Inshore Rockfish and Lingcod habitat.
- Indicators, metrics and research question are identified for each of the ecological conversation objectives.
- A conceptual diagram model of the RCA system is presented and, along with directed acyclic graphs (DAGs) is used to guide the survey design and methods, and to identify the required monitoring variables.
- An analytical approach is presented to guide future analyses aimed at assessing RCA effectiveness and mechanisms of RCA effectiveness.
- A method of selecting reference areas and sampling sites is identified to carry out a control impact (CI) or early-later-control-impact (ELCI) study design.
- A 5-phased implementation is presented to guide data and collection and analysis. Complementary research topics for inshore Rockfish or their habitat in RCAs that indirectly support coastwide RCA monitoring and address knowledge gaps are outlined. The recommendations for coastwide monitoring of RCA effectiveness are:
  - Implement a new coastwide monitoring program following the advice in the paper using transect-based benthic imagery tools that can collect data on all of the indicators, for example, ROVs, SCUBA, etc.;
  - Focus sampling on the identified indicators and metrics (with a focus on rockfish size, in particular), using an early-later-control-impact design with the proposed phased approach, and with a sample size that is informed by the power analysis;
  - Identify reference areas that are similar to adjacent RCAs but without protections. Select sampling sites (transects) within RCAs and reference areas that are randomized, spatially-balanced, and control for confounding variables (depth, structural complexity, and pre-RCA fishing effort). Prioritize the representative, focal RCAs presented in the paper in future RCA monitoring surveys;
  - Collect environmental data concurrently with visual data using appropriate tools and through collaborations with other groups;
  - Collaborate with coastal First Nations and other governmental or non-governmental organizations in Pacific Canada to conduct monitoring and other research related to RCAs following the advice provided in this paper;
- This monitoring advice can be implemented to determine RCA effectiveness at meeting their conservation objectives now and over time. Future RCA monitoring (past phase 5 in the implementation plan) will be important to evaluate ongoing changes in RCA effectiveness over time and may help to inform Inshore Rockfish stock assessments.

[1] Jeffery, S., Gale, K.S.P., Nephin, J., Gemmell, O., Burke, L., Paleczny, M., Francis, F., Chaves, L., Siegle, M., Frid, A., Dudas, S., Bluteau, C., and Haggarty, D. In prep. Ecological Monitoring Advice for Rockfish Conservation Areas. DFO Can. Sci. Advis. Sec. Res. Doc.

- Key uncertainties in the interpretation of this advice include uncertainties in the modeled data; gaps in knowledge of fishing activity occurring in RCAs; the time lag between RCA implementation and the onset of monitoring; the extent to which historical and ongoing management measures and spillover effects influence fish density inside and outside RCAs; the impacts that permitted and non-permitted activities within RCAs may have on Rockfish or Lingcod and their habitat; and how Rockfish, Lingcod and their habitat will respond to climate change and other global stressors.
- RCAs were implemented with little to no consultation or engagement with Indigenous groups, leaving their knowledge largely absent from the past decision-making processes. Going forward, as the coastwide monitoring plan is implemented in collaboration with interested First Nations, the inclusion of Indigenous perspectives, values, and priorities should be increased, both to support the rights of First Nations, and to reflect the evolving role of First Nations in RCA monitoring.
- Information about compliance within RCAs will be important for exploring potential factors that contribute to RCA effectiveness.
- Future work comparing and calibrating catchability and/or detectability among survey tools will be important when examining trends observed with different survey tools.
- Advice stemming from this document can be used for other initiatives related to monitoring Inshore Rockfishes; the data collected as a part of this monitoring plan may have other applications related to Inshore Rockfish conservation (e.g., helping to inform boundary reviews).
- Guidance is provided for assessing RCAs based on their ecological conservation objectives. There are other ways RCAs may contribute to Inshore Rockfish conservation, for example, by buffering against population declines (e.g., Wilson et al. 2025).

INTRODUCTION

As part of Canada's federal commitment to marine conservation, Fisheries and Oceans Canada (DFO) is responsible for managing protected areas within its mandate; evaluating effectiveness through monitoring is one component of management. Although most Rockfish Conservation Areas (RCAs) have been in place for 20 years, no coastwide program has been developed to assess their ecological effectiveness, or their impact on Inshore Rockfish and their habitat.

RCAs were developed to protect Inshore Rockfish species, along with Lingcod, which share habitat associations and some life history traits. DFO classifies eight rockfish species (*Sebastes* spp.) as Inshore Rockfish: Quillback, Copper, China, Brown, Black, Tiger, Yelloweye and Deacon (formerly thought to be Blue Rockfish in Pacific Canada). These eight species are grouped together because they co-occur in nature and in the fishery. The two most prevalent Inshore Rockfish species in rockfish fisheries are Quillback and Yelloweye.

Rockfish life history and vulnerability to exploitation

Inshore Rockfish and Lingcod prefer complex habitats, including rocky reefs and biogenic habitats such as kelp, eelgrass, corals, and sponges. Inshore Rockfishes tend to recruit into shallow areas as juveniles and move deeper as adults; juveniles are therefore more prevalent on shallow rocky reefs, and in eelgrass or kelp beds, while adults are generally associated with deeper rocky reefs, sponges, and corals (Richards 1986). Rockfishes are vulnerable to exploitation for several reasons: they are long-lived, late-maturing, and slow-growing and can therefore take many years to recover if depleted (Parker et al. 2000); many rockfish species have high site fidelity and small home ranges, which limits immigration of adult fish from surrounding areas if an area is depleted (Parker et al. 2000); and popular conservation methods for other fishes (e.g., catch and release strategies) are largely ineffective for rockfishes (Parker et al. 2000, 2006; Yamanaka and Logan 2010; Haggarty 2019).

All RCAs overlap with the traditional and treaty-designated territories and harvesting grounds of Indigenous peoples. Rockfishes, which can be caught year-round near many coastal villages, have been contributing to the food security, sovereignty, and culture of coastal Indigenous peoples since Time Immemorial. Coastal First Nations have long recognized the vulnerability of rockfish species and developed conservation strategies to prevent overfishing (Lepofsky and Caldwell 2013; Rodrigues et al. 2018).

Implementation of RCAs

The history of DFO management controls on rockfish fisheries is detailed in Yamanaka and Logan (2010) and in the research document[1]. Driven by conservation concerns, calls came in 2001 for stricter groundfish stock conservation, specifically for Inshore Rockfishes (Parker et al. 2000). A customary harvest plan was not possible because of the lack of sufficient stock data to determine precautionary harvest levels, so DFO developed an Inshore Rockfish Conservation Strategy to address the conservation concerns (Yamanaka and Logan 2010). This strategy included four measures, one of which was to establish areas closed to fishing[2]. In response, DFO designated a network of RCAs as harvest refuges to buffer against scientific uncertainty and decrease fishing mortality of exploited Inshore Rockfish species. By February 2007, a network of 164[3] RCAs was implemented using the *Fisheries Act*. RCAs were created with little consultation and no engagement with Indigenous groups, leaving their knowledge largely absent from the decision-making process.

Commercial and recreational fisheries with direct and incidental catch of Inshore Rockfish species were restricted from fishing inside RCAs, except for fisheries such as prawn trapping, which has less impacts on rockfish than targeted fisheries (Antonelis et al. 2018) (Table 1). Food, Social and Ceremonial (FSC) fishing is permitted inside RCAs because it is a constitutionally protected right that has immense cultural importance to Indigenous people’s wellbeing. Fishing for traditional foods is essential to continue cultural practices and transfer Indigenous knowledge across generations.

[2] Details of how all measures were addressed are outlined in Yamanaka and Logan (2010).

[3] There are currently 162 RCAs: in 2018, Lyell Island RCA and South Moresby RCA became “strict protection zones” within the Gwaii Haanas National Marine Conservation Area Reserve and Haida Heritage Site (Council of the Haida Nation (CHN) and Government of Canada 2018) and ceased to be considered RCAs (DFO 2019).

Table 1. Fisheries that are prohibited and permitted within RCAs by fishing sector.

Sector	Prohibited fisheries	Permitted fisheries
Commercial	Groundfish bottom trawl	Groundfish by mid-water trawl
	Groundfish hook-and-line for halibut, inside rockfish, outside rockfish, lingcod, dogfish	Invertebrates by hand-picking or dive
	Sablefish by trap	Crab by trap
	Salmon trolling	Prawn by trap
		Scallop by trawl
		Salmon by seine or gillnet
		Herring by gillnet, seine and spawn-on-kelp
		Sardine by gillnet, seine, and trap
		Smelt by gillnet
		Euphausiid (krill) by mid-water trawl
		Opal squid by seine
Recreational	Groundfish by hook-and-line	Invertebrates by hand-picking or dive
	Salmon trolling, jigging or mooching	Crab by trap
	Spearfishing	Shrimp/prawn by trap
		Smelt by gillnet

Monitoring for RCA effectiveness

Monitoring of conservation areas is critical for tracking and assessing the outcomes of management intervention and policies to determine if goals and objectives are being met (Dunham et al. 2020). RCAs were developed to address conservation at a coastwide scale, as such, DFO aims to monitor RCAs on a coastwide scale to evaluate their overall effectiveness at meeting their ecological conservation objectives. The focus of this monitoring advice is on ecological performance monitoring as defined by Dunham et al. (2020).

ASSESSMENT

Conservation Objectives

The monitoring methods presented are designed to assess the ecological conservation Goal 1 and objectives for RCAs in Table 2. Although not directly linked to an ecological conservation goal, quantifying prohibited fishing activities (i.e., compliance) is important for understanding progress towards Goal 1 and is discussed further in the Analytical Approach and Tools and Data Sources sections.

Table 2. RCA conservation Goal 1 and its associated objectives. Note: Operational conservation goals and objectives were defined and published on [DFO's website](#) in 2025. Although this was the first time these objectives were published, they represent the goals and objectives for RCAs at the time they were created.

Goal		Objective	
1	Inside RCAs, Inshore Rockfish and Lingcod populations and their habitat are protected for the long term.	1.1	Increase Inshore Rockfish and Lingcod population densities inside RCAs.
		1.2	Increase the abundance of Inshore Rockfish in older age classes inside RCAs.
		1.3	Protect the quality and quantity of Inshore Rockfish and Lingcod habitat inside RCAs, including rocky reefs and biogenic structures.

Indicators and Metrics

To measure progress towards these objectives, the following indicators were identified that are clearly linked to each objective:

- Objective 1.1 and 1.2: Inshore Rockfish and Lingcod, specifically: Yelloweye, Quillback, Copper, China, Tiger, Black, Brown, and Deacon Rockfish, and Lingcod.
- Objective 1.3: Rocky reef habitat (specifically the physical rock structure) and biogenic habitat (including kelp, eelgrass, reef-building glass sponge, other sponges, coral, and other emergent biocover).

Recommended metrics for these indicators were identified by cross-referencing the RCA indicators with those in similar monitoring documents. The resulting list of metrics are divided into *priority* metrics on which to focus data collection, and *secondary* metrics that would be appropriate if time, resources, and tools allow (Table 3).

Table 3. Recommended metrics for RCA monitoring indicators. Higher priority indicators are marked with + and highlighted in green; secondary/optional indicators are marked with x and highlighted in yellow. See text for details on each indicator/metric combination.

Indicator	Inshore Rockfish and Lingcod	Emergent coral and sponge	Reef-building glass sponge	Kelp and eelgrass	Rocky reefs
Abundance	+	+	+	+	+
Biomass	+	-	-	+	-
Distribution	-	+	+	+	+
Diversity	-	+	-	-	-
Size/age structure	+	x	-	-	-

Indicator	Inshore Rockfish and Lingcod	Emergent coral and sponge	Reef-building glass sponge	Kelp and eelgrass	Rocky reefs
Condition	-	x	+	x	-
Patch dynamics	-	x	x	x	x
Indicator taxa	-	-	x	-	-
Recovery potential	-	-	+	-	-
Complexity	-	-	-	-	+

Research Questions

The goal for RCA monitoring is to determine whether RCA closures have had a measurable effect on the indicators. Specific research questions were developed from the objectives and indicators (see research document[1]) to help guide data collection and sampling design (e.g., “Is the abundance and/or biomass of Inshore Rockfish and Lingcod in RCAs currently higher than it was in the past, and is the amount of change more than in similar unprotected areas?”). These primary research questions are focused on whether or not RCAs are meeting the ecological conservation objectives. Secondary questions looking at the mechanisms or reasons why RCAs may or may not be effective are also important and are discussed in the context of the analytical approach.

Analytical Approach

A conceptual model to identify important variables

A structural causal modelling approach (Pearl 2009) was used to identify variables needed in statistical analyses to assess the total effect of RCAs on the indicators (details in research document[1]). To properly interpret the effect of RCAs, statistical models (like generalized linear mixed-effects models) must control for confounding variables to ensure that differences between RCA and reference sites are due to protection, not underlying differences in habitat or fishing history. A conceptual model (also called a conceptual diagram), which visually represents cause-and-effect, was developed to map the variables and relationships within the RCA system (Figure 2). The conceptual model identifies the primary outcome variables (i.e., indicators, such as fish density and habitat condition), treatment variable (RCA vs. reference area), and potential confounding factors (e.g., depth, substrate, environmental conditions, human activity inside and outside RCAs).

Directed acyclic graphs (DAGs) were subsequently used to identify potential statistical biases, and to identify and define the roles of the covariates that will be important for assessing and understanding the effect of RCAs on the outcome variables. DAGs were developed for two generalized outcome variables: Inshore Rockfish density/size (Objectives 1.1 and 1.2) and biogenic habitat abundance/condition (Objective 1.3). DAGs reveal which variables should be controlled for (i.e., included in the statistical model), and which should not, in order to answer a particular research question while minimizing biases (Arif and MacNeil 2022). The variables that need to be controlled for are considered the ‘minimum adjustment set’. Additional variables that are not part of any causal or biasing pathways can also be added to the statistical model as covariates, while still allowing for cause-and-effect interpretation between the treatment and the outcome. Variables that are part of causal pathways are known as mediators and can obscure the cause and effect relationship. For Inshore Rockfish density/size, the minimum adjustment set was *substrate complexity*, *depth*, and *pre-RCA fishing activity* and the mediators were *extractive rockfish activities within RCAs*, *biogenic habitat*, and *prey density.* For biogenic habitat abundance/condition the minimum adjustment set was *depth* and *pre-RCA fishing activity,* and the mediations were *rockfish extractive activities within RCAs*.

For the primary research questions that focus on the total effect of RCAs on the indicators (e.g., “Is the abundance of Inshore Rockfish and Lingcod in RCAs higher than in similar unprotected areas?”), mediator variables should not be included as covariates in statistical models. For the secondary research questions that focus on understanding *why* RCAs are, or are not, effective (e.g., “To what extent do rockfish extractive activities within RCAs affect the relationship between the abundance of Inshore Rockfish and Lingcod and RCA treatment?”) mediator variables such as *rockfish extractive activities within RCAs* are essential to include as covariates in the statistical models.

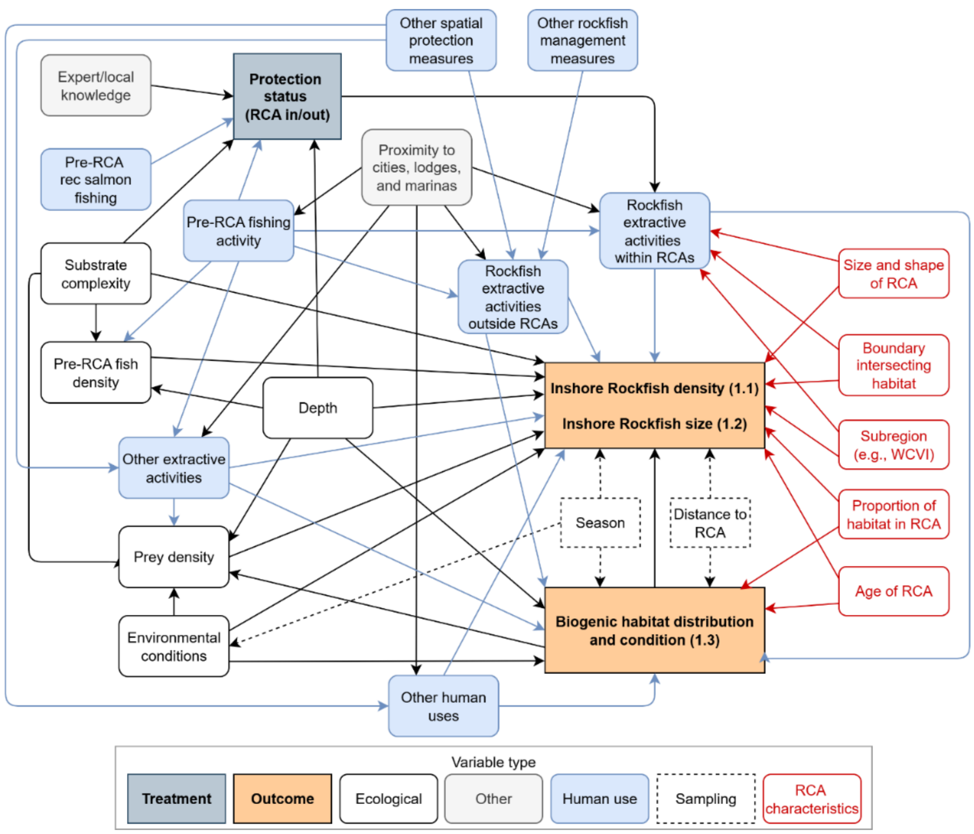

Figure 2. Conceptual model (diagram) showing links between RCA treatment, the outcome variables, and other variables. The outcomes are the metrics that will be used to measure changes in the monitoring indicators between the RCAs and reference sites. The conservation objectives that relate to each outcome are shown in brackets on the outcome boxes. See Appendix C of the associated research document[1]. for definitions of each variable and justifications of the relationships.

Recommendations for statistical models

Recommendations are made for the use of an empirical approach to assess RCA effectiveness that relies on statistical models and field data to evaluate the direct effect on the indicators. For type of statistical model, a flexible, hierarchical model such as a generalized linear mixed-effects model (GLMM) or generalized additive mixed-effects model (GAMM) is recommended. These models allow for the use of data collected from different sampling tools and account for the hierarchical nature of data collected from repeated measurements within a subregion and site (e.g., RCA). For variable selection (also sometimes referred to as model section), it is recommended that a causal structural modelling approach be used to develop initial model structure by considering the roles of the potential covariates that were derived from the DAGs (e.g., a confounder variable) and the research question you are attempting to answer (e.g., is an RCA effective?, or why is an RCA effective?) and then refined using data-driven selection methods such as goodness-of-fit measures in conjunction with ecological knowledge (e.g., "Which environmental variables are known to be strong drivers of rockfish growth or survival?").

Interpretations of statistical models

Eight simplified scenarios that depict possible changes over time in the indicator variables within RCAs and reference areas are presented in the research document[1], and interpretations are provided in the context of the primary research questions. These interpretations will guide how the results of RCA effectiveness are interpretated once the RCA monitoring plan is implemented.

Tools and Data Sources

A literature review of existing ecological data for RCAs was completed to:

1. compile records of data collected prior to RCA implementation ("before" data), or after RCA implementation ("early" data) that could be compared with future monitoring data to assess change over time, and
2. to understand the history of research within different RCAs.

This literature review revealed that much of the existing ecological data in RCAs appear to have limited application for characterizing baseline or early RCA conditions at a coastwide scale. However, some previously collected data may be useful for answering other research questions (see Complementary Research section).

Available sampling tools for measuring the indicators and metrics were reviewed to provide recommendations for tools that are appropriate for monitoring and assessing the effectiveness of RCAs. To collect data on the outcome variables and all of the ecological variables (Figure 2), it is recommended that transect-based benthic imagery tools (e.g., remotely operated vehicles [ROVs], manned submersibles, towed cameras, SCUBA diving, etc.) be used. Benthic imagery tools are widely used in ecological monitoring to collect data on fish and their habitat and have been shown to be effective tools for assessing rockfish recovery in the California MPA network (Perkins 2024). They can also be used to collect data on environmental conditions (e.g., temperature, salinity) concurrently with imagery. It is also possible to collect size information for fish using these tools, with stereo-cameras being the preferred option. Imagery-based tools offer advantages over extractive methods (e.g., fishing surveys) in that they do not impact fish populations, can be used over high-relief and fragile habitats (e.g., sponge reefs, Rooper et al. 2010), and provide fish size estimates without involving the catching or handling of fish.

Variables that are recommended to be measured using transect-based benthic imagery tools include:

- Fish density and size

- Biogenic habitat and distribution condition
- Substrate complexity
- Depth
- Prey density
- Environment conditions (using seniors, such as those on CTDs, attached to imagery equipment)

Data sources that are available for variables that don't require surveying, or that are not possible to monitor with ROVs are outlined in the research document[1]. Considerations for using different types of tools for monitoring RCAs are summarized in the research document[1]. Although any type of transect-based benthic imagery tool could be appropriate for monitoring RCAs, specific guidance is provided on data collection focusing on using ROVs as the main survey tool due to tool availability, depth range, established capacity at DFO, and earlier surveys that used ROVs to survey RCAs.

To understand the mechanisms contributing to RCA effectiveness, data on Rockfish extractive activities within RCAs will be required (see Recommendations for statistical models).To facilitate this, the research document[1] also contains a review of tools used for monitoring fishing activity within RCAs, including vessel tracking tools (e.g., AIS, aerial surveys, etc.), creel surveys, commercial fishing logbooks, and First Nations fisheries monitoring program data.

Study Design and Methods

Recommendations are provided for practical aspects of data collection, including broad- and fine-scale site selection, recommendations on the type of study design (i.e., whether sampling over time is required), and the required amount of sampling effort. While ROVs are the focus of our methods, the methods apply broadly to any transect-based benthic imagery survey.

Broad-scale site selection

Methods for how to identify reference areas for each RCA are outlined in the research document[1]. Areas identified with these methods are similar to their paired protected area in all (or most) aspects other than the presence of fishing, with particular focus on matching confounding variables. They are also separated by one kilometer from their paired RCA to minimize the potential for spillover effects. These methods result in reference areas that are adjacent to their paired RCA, sized relative to their paired RCA, matched to the depth range of their paired RCA, and not influenced by any other protection measures.

A manageable subset of RCAs on which to focus monitoring is also presented; although the main goal of the proposed RCA monitoring program is to assess the RCA network at a coastwide scale, it is not realistic to sample all 162 RCAs (Figure 4A), and so a smaller number will be monitored. These representative RCAs were identified using a cluster analysis to group RCAs based on their similarities in geographic, ecological, and human use characteristics, and then subsetting the RCAs from each of the clusters by considering the following factors: amount of suitable habitat; the presence of unique features; the distribution across the four clusters of RCAs and six geographic subregions to ensure an even coastwide distribution; and a balanced amount of protected area. The resulting list of focal RCAs is a subset that captures the full range of variability that exists across all the RCAs (e.g., big, small, deep, shallow, etc.), while being a manageable number to effectively survey. Details of the selection process are outlined in the research document[1]. The resulting 55 focal RCAs selected for coastwide monitoring are shown in Figure 3B and listed in Table 4.

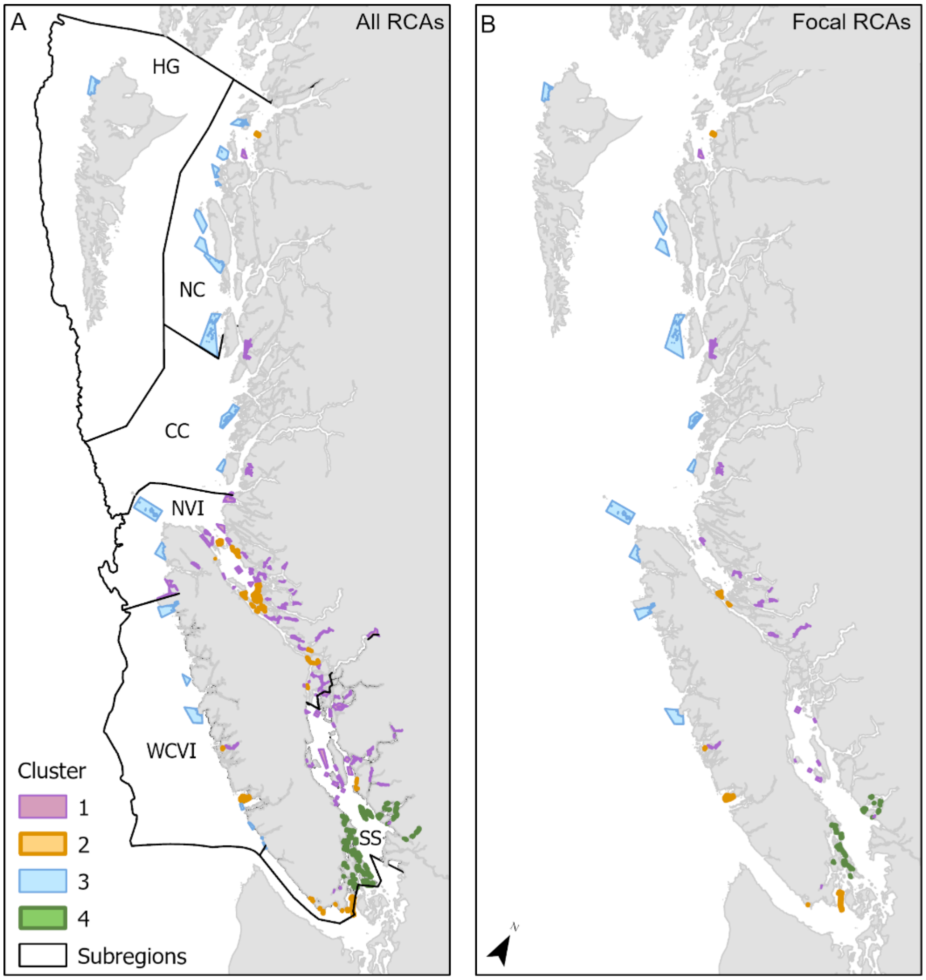

Figure 3. A) All 162 RCAs assigned to clusters based on shared characteristics, with subregions delineated (CC = Central Coast; HG = Haida Gwaii; NC = North Coast; NVI = North Vancouver Island; SS = Salish Sea; WCVI = West Coast Vancouver Island). Boundaries of HG, NC, CC, and NVI align with the Great Bear Sea MPA network process (MPA Network BC Northern Shelf Initiative 2023), except using an internal "analysis-only" boundary in place of the original overlapping boundaries between CC and NC. The boundary between SS and WCVI aligns with the boundary between the Inside and Outside management areas. B) 55 RCAs on which to focus monitoring.

Table 4. List of focal RCAs identified as priorities for coastwide monitoring. This list may be refined during the survey planning phase of implementations (as outlined in Section 7.2.3 in the research document[1]. Subregions= CC: Central Coast; HG: Haida Gwaii; NC: North Coast; NVI: North Vancouver Island; SS: Salish Sea; WCVI: West Coast Vancouver Island.

Subregion	Cluster	Name	Subregion	Cluster	Name
CC	1	Fish Egg Inlet	SS	1	Davie Bay
CC	1	Kitasu Bay	SS	1	Dinner Rock
CC	3	Goose Island	SS	1	Lasqueti Island South
CC	3	West Calvert	SS	1	Mid Finlayson Arm
HG	3	Frederick Island	SS	1	Mitlenatch Island
NC	1	Gull Rocks North	SS	1	Savoie Rocks - Maude Reef
NC	1	Gull Rocks South	SS	1	Sisters Islets
NC	2	Hodgson Reefs	SS	1	West Vancouver
NC	3	North Danger Rocks	SS	2	Becher Bay East
NC	3	West Aristazabal Island	SS	2	D'Arcy Island to Beaumont Shoal
NC	3	West Banks Island	SS	4	Bedwell Harbour
NVI	1	Belleisle Sound	SS	4	Bowyer Island
NVI	1	Bond Sound	SS	4	Burgoyne Bay
NVI	1	Greenway Sound	SS	4	De Courcy Island North
NVI	1	Loughborough Inlet	SS	4	Navy Channel
NVI	1	Shelter Bay	SS	4	Pam Rock
NVI	1	Thompson Sound	SS	4	Pasley Island
NVI	1	Viscount Island	SS	4	Passage Island
NVI	1	Wellborne	SS	4	Prevost Island North
NVI	2	Cracroft Point South - Sophia Islands	SS	4	Reynolds Point - Link Island
NVI	2	Weynton Passage	SS	4	Ruxton - Pylades Island
NVI	3	Scott Islands	SS	4	Saltspring Island North
NVI	3	Topknot	SS	4	Trincomali Channel
WCVI	1	Bedwell Sound	SS	4	Upper Centre Bay
WCVI	1	Saranac Island	SS	4	Valdes Island East
WCVI	2	Broken Islands Group	SS	4	Woolridge Island
WCVI	2	Vargus Island to Dunlap Island			
WCVI	3	Checleset Bay			
WCVI	3	Estevan Point			

Fine-scale site selection

Methods, and a sample application of the methods for selecting sampling sites (i.e., transects) within RCAs and their paired reference areas, are presented in the research document[1]. To maximize statistical power to detect an RCA effect without introducing bias in the analysis, *sampling sites are randomly selected;* spatially balanced across the treatment (i.e., RCAs) and reference areas; and similar in their physical and biological characteristics – specifically relating to the three confounding variables identified by the DAG (depth, substrate complexity and pre-RCA fishing effort). A case study is provided illustrating how Indigenous Knowledge could be used to inform the initial process of site selection by adjusting the methods to incorporate information from Indigenous Knowledge Systems (IKS).

A simulation-based power analysis was conducted to:

1. Determine which type of survey design is best able to detect an increase in Inshore Rockfish density within RCAs.
2. Inform the level of sampling effort required to ensure adequate statistical power.

The two main options for an RCA monitoring study design are: control-impact (CI) where conditions inside RCAs are compared to those outside of RCAs, and before-after-control-impact (BACI) or early-late-control-impact (ELCI) where changes are assessed within RCAs over time relative to areas outside RCAs. Given the lack of available baseline data for RCAs we tested the CI and ELCI designs specifically.

It was found that a CI study design consistently generated lower power scores compared to the ELCI design; the CI design reached adequate power after a 30% increase in Inshore Rockfish inside RCAs with 300 transects, while the ELCI design reached adequate power with half the number of transects (~150 transects) at the same effect size. Detailed methods and results are presented *in the* research document[1].

The advice outlined in this document was developed to maximize the statistical power available to detect differences between RCAs and reference areas over time. However, even with the approaches outlined here, detecting an effect of RCA will be challenging (see bullets in the Sources of uncertainty section). To further improve statistical power, analyses could focus on sensitive indicators (e.g., Yelloweye, Quillback Rockfish, and Lingcod) and metrics that consider size, which are more responsive to fishing pressure than abundance. If an RCA effect is not found, statistical power could be improved further by evaluating effectiveness for only a subset of the focal RCAs that have the biggest changes in fishing activity and where stronger effects are more likely. However, this would limit conclusions that could be drawn to only the subset of RCAs, rather than all RCAs.

To buffer against the possibility that our new coastwide monitoring is occurring too late after implementation to detect an RCA effect, we can re-survey DFO's 2009–2011 ROV sites that were sampled soon after the establishment of RCAs on a portion of our coast.

Complementary Research

This monitoring advice focuses primarily on analytical methods for assessing RCA effectiveness at a coastwide scale. Any monitoring of Inshore Rockfish or RCAs that falls outside the coastwide monitoring approach outlined in the research document[1] is considered "complementary research". Complementary research can provide valuable contextual information for interpreting the coastwide effectiveness analysis, can help improve individual RCAs or the RCA network, or can address targeted research or management questions. It strengthens RCA monitoring by providing nuanced insights that support effective decision-making, improve conservation outcomes, and uphold Indigenous stewardship practices.

Examples of complementary research outlined in the research document[1] include:

1. Non-compatible survey methods: Monitoring or research on RCAs using survey methods that do not fit into the modelling approach presented in the research document[1].
2. Monitoring rockfish abundance and size in areas outside of RCAs: using the indicators and sampling design presented here for assessing Inshore Rockfish in areas that are not RCAs.
3. Changes over time within an RCA: Assessing changes over time within specific RCAs, without comparisons to reference areas.

4. Lethal sampling of Inshore rockfish and lingcod: Lethal sampling of fish can yield insights that are unattainable from visual surveys such as fish age, trophic position, sex, maturity etc.
5. Assessing spillover effects from RCAs: Assessing the amount of dispersal of adults or larvae from within the protected area into adjacent habitat where fishing is permitted (e.g., Wilson et al. 2025).
6. Assessing juvenile abundance or recruitment: targeted monitoring of juvenile abundance.

A meta-analysis approach, such as that used by Lee et al. (2018) to reconstruct historical trends in kelp forest species using multiple lines of evidence, could be used to answer questions about coastwide effectiveness using a more diverse set of research methods than what is proposed in this advice. If such a framework was developed for RCA monitoring, some of the approaches that we consider "complementary" in this section could be incorporated into coastwide analysis in the future.

While coastwide monitoring programs provide standardized data for large-scale assessments, complementary research offers valuable contextual information that can address knowledge gaps, improve local management strategies, and inform broader conservation efforts. For example, research that investigates juvenile abundance, local habitat conditions, or spillover effects can provide insights that coastwide monitoring methods may overlook. By incorporating diverse data sources—such as Indigenous-led food fishing surveys, localized monitoring initiatives, or studies using alternative sampling methods—researchers can better understand trends, and population dynamics at smaller scales.

Moreover, some complementary research methods could contribute data that may eventually be integrated into coastwide analyses if analytical frameworks evolve to accommodate diverse sampling approaches. Ultimately, complementary research strengthens RCA monitoring by providing nuanced insights that support effective decision-making, improve conservation outcomes, and uphold Indigenous stewardship practices.

Implementation

Guidance is provided on how monitoring, analysis, and reporting could be implemented over a multi-year period. Results from the power analysis suggests that a large number of transects (more than 200) will be required to detect an RCA effect when effect sizes are small (e.g., 20% increase in fish abundance). Surveying this number of transects is likely not feasible in a single year, and so data collection and analysis will require a phased approach.

Implementation of monitoring has been divided into five phases (Figure 4). Monitoring will be initiated by implementing Phases 1 through 5 sequentially, with the first coastwide analysis of RCA effectiveness occurring in Phase 5. Subsequent monitoring will repeat Phases 4 and 5 alternatingly to assess ongoing effectiveness.

Reporting on results will be critical to monitoring success and should follow each data collection and analysis phase. Details on the purpose, type of report and audience are outlined in the research document[1], along with recommendations for best data management practices.

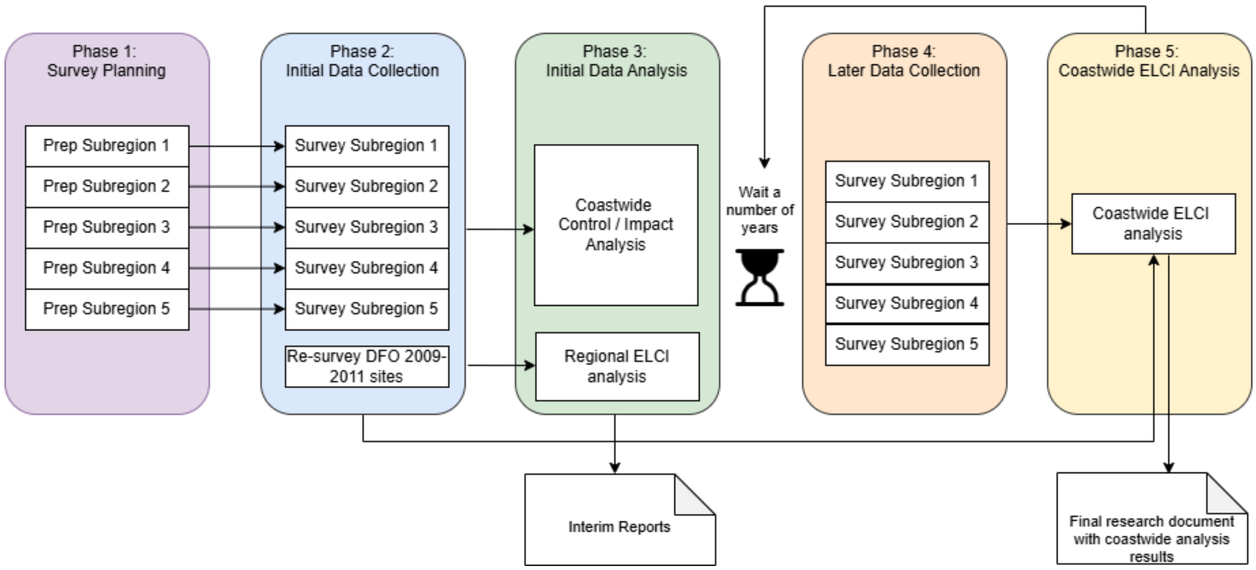

Figure 4. A flow chart of the 5 phases of RCA monitoring implementation. The number of surveys and years required to complete Phase 2 and 4 will depend on resources available for monitoring.

Phase 1: Survey Planning

The overall goal for the survey planning phase is to refine where to sample in a given survey year. Ahead of each survey, a subregion will be chosen for monitoring, and focal RCAs, reference areas, and transect locations will be reviewed for suitability. Operational considerations will influence which RCAs can be surveyed, as well as priorities shared with DFO by First Nations in the region. Figure 5 outlines the iterative steps involved to ensure that focal RCAs and their reference areas are suitable and well-matched to each other, and that sampling sites are in appropriate locations. Co-development with First Nations should guide this process wherever possible. A case study is presented in the research document[1] in which Indigenous priorities are used in broad-scale survey planning.

Adjustments may need to be made in the field because of unpredictable factors such as weather that prevent safe ROV deployment; however, wherever possible it is desirable to follow the survey plan to reduce the potential for introducing bias in the choice of sampling sites.

Phase 2: Initial Data Collection

Phase 2 is the initial data collection phase and has two components:

1. Collecting data following the proposed site selection methods and survey planning steps in Phase 1, and
2. Re-surveying sites DFO sampled in 2009-2011 following the methods and protocols detailed in (Haggarty et al. 2017).

Phase 3: Initial Data Analysis

Phase 3 is the initial data analysis phase and has two components:

1. A control-impact analysis using the initial coastwide data collected in Phase 2
2. A regional early-later-control-impact analysis using the early DFO 2009-2011 survey data and the re-surveyed DFO 2009-2011 site data from Phase 2.

Before data analysis can be undertaken, data from each survey will need to be processed and collected video will need to be annotated, which can be a very time consuming process and needs to be accounted for in the planning stage.

Phase 4: Later Data Collection

Phase 4 is a second data collection phase where later data for a coastwide early-later-control-impact analysis will be collected. Consistent with Phase 2, this phase will occur over several years, with sampling limited to one part of the coast annually. The same focal RCAs and sampling sites should be re-surveyed in Phase 4 to increase statistical power, and every effort should be made to survey RCAs at the same time of year as they were surveyed in Phase 2.

Phase 5: Coastwide ELCI analysis

Phase 5 is the final analysis phase, in which a coastwide early-later-control-impact analysis is completed using the initial data from Phase 2 and the later data from Phase 4. Analyses should follow the guidelines and recommendations for statistical models described in the Analytical Approach.

Data collection considerations

Collaborations with coastal First Nations and other governmental or non-governmental organizations is an important part of RCA monitoring. All data intended for coastwide analysis, whether collected by DFO or partners, should follow standardized methods for site selection, data collection, and processing to reduce bias and ensure scientific rigor. If data are collected with compatible methods and shared with DFO for the purpose of contributing to RCA effectiveness monitoring they will be combined with data collected by DFO and used in data analysis. Data that does not meet these requirements is discussed in the Complementary Research section. Prior to analysis, data collected by different groups should be assessed for balance among RCA characteristics, confounding variables, and broad- and fine-scale spatial distribution (i.e., subregional bias, clustering of transects, or oversampling in one area). Subsetting or filtering of the data may be necessary to reduce statistical bias.

Reporting

Results will be reported at each key phase:

- Survey summaries as DFO Technical Reports
- Preliminary findings as technical reports or peer-reviewed papers
- Final coastwide conclusions as Science Advisory Reports for management and stakeholders

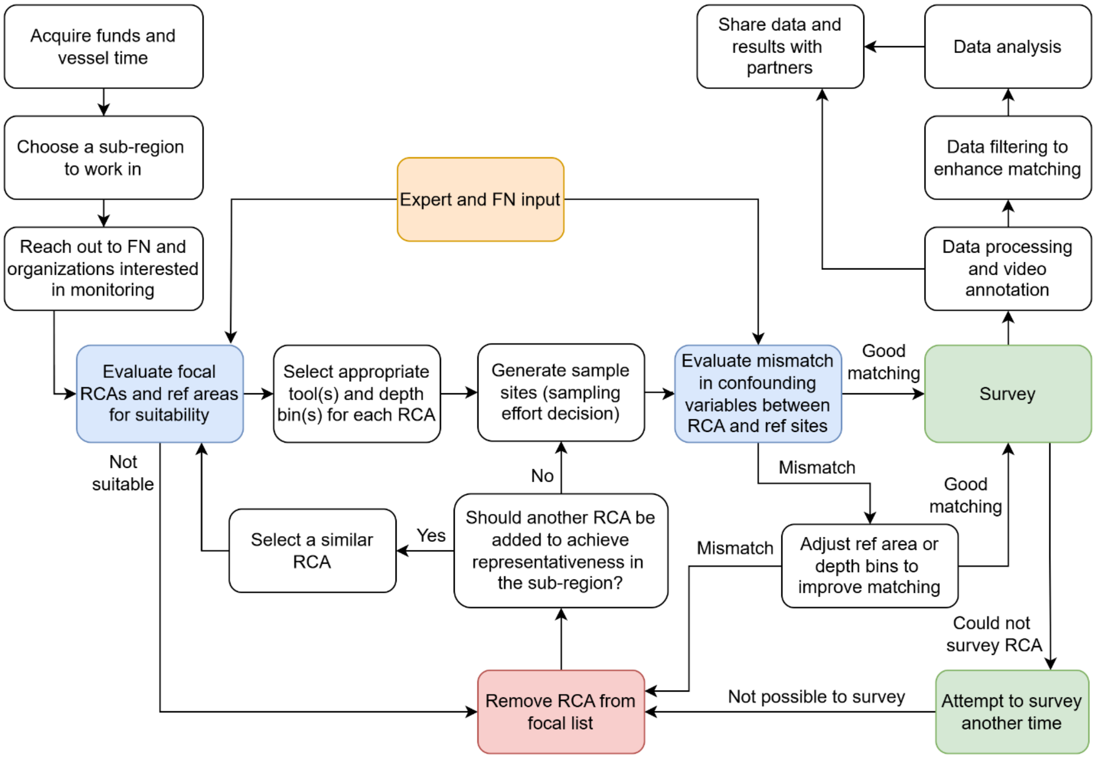

Figure 5. Flow diagram showing the steps from survey planning to data analysis for the coastwide monitoring of RCAs. FN=First Nations; ref = reference.

SOURCES OF UNCERTAINTY

- Limitations in available data introduce uncertainties in the provided advice, including:
  - Uncertainties in the modeled data used in the cluster analysis, choice of reference areas, and sample site locations; and
  - Gaps in our knowledge of fishing activity targeting Rockfish occurring in RCAs may limit our ability to understand RCA effectiveness.
- Uncertainties in the power analysis used to estimate the sampling effort required to detect an effect of RCAs include:
  - Estimates of sampling effort required are based on Brown Rockfish in California. Because rockfish growth and recruitment vary by species and geographically, the timelines for detecting reserve effects may be different for Inshore Rockfish in BC, and for species other than Brown Rockfish. If the RCA effect is higher or lower in BC for Inshore Rockfish species or Lingcod, the level of sampling effort and time to detect an effect will differ from what is presented here.
  - The simulation design assumed that the same effect size will apply to all Inshore Rockfish species and all RCAs. In reality, effect sizes are likely to vary across RCAs and species. If the degree of variability is large, the level of sampling and the distribution of sampling may differ from what is presented here.
- The ability to detect an RCA effect may be limited for several reasons:
  - This monitoring advice was developed 18 years after RCA implementation, so changes that occurred early on will have been missed.

- Management changes resulting from the Rockfish Conservation Strategy occurred simultaneously with the implementation of RCAs. Both historical and ongoing management measures (e.g., decreasing commercial quotas and recreational catch limits) can influence fish density inside and outside RCAs.
- Potential spillover effects have been accounted for in the current approach by spatially separating the RCA and reference areas (1 km gap), and by recommending the inclusion of distance to RCA as a covariate in statistical models. However, if spillover is occurring from RCAs into adjacent areas including reference areas, RCA effects would be underestimated.
- The proposed survey design does not prioritize RCAs that have had a large change in rockfish extractive activities (e.g., RCAs with initially high fishing effort and low current fishing effort). Since reducing fishing effort is the main driver of potential RCA effects, RCAs with little change in fishing pressure are less likely to show changes in the outcomes of interest (i.e., more fish, bigger fish).

- RCAs vary in their habitat quality and characteristics. Although the recommended study design takes into account this variability, uncertainties exist in the data used to represent the range of RCA characteristics. Because of this, uncertainties remain regarding the representativeness of our choice of RCAs to monitor.
- There are uncertainties about how rockfish will respond to climate change and whether changing ocean conditions will impact the effectiveness of the RCA network.
- The lack of pre-RCA data limits the available statistical approaches for assessing RCA effectiveness.
- Benthic imagery tools are limited in their ability to detect rockfish in complex habitats. Research will be needed to determine how to accurately estimate rockfish densities in complex habitats.
- There are uncertainties about the impacts that permitted activities, such as crab and prawn by trap fisheries, log storage, and coastal infrastructure, within RCAs may have on Rockfish or Lingcod and their habitat (as outlined in Thornborough et al. 2020).
- The analytical approach recommended to assess coastwide effectiveness relies on statistical models and data on the outcome variables and covariates. There are other ways RCA effectiveness could be assessed, including other statistical methods and approaches that pair Western Science with local and Indigenous knowledge. For example, data collected using different tools, survey designs, or knowledge systems could be woven together using meta-analytical, Bayesian, or other methods to reconstruct pre-RCA conditions (e.g., techniques in Eckert et al. 2017; Lee et al. 2018; Watkins 2024).
- Historical approaches to RCAs, and the path DFO took for involving First Nations in developing this monitoring advice, have led to the limited inclusion of Indigenous knowledge in this monitoring advice. More specifically:
    - A lack of established protocols and support for Indigenous involvement in federal government processes, coupled with restrictive timelines in science advisory processes has hindered true co-production of this advice. For this, and likely many other reasons, the document contains limited inclusion of IKS and Indigenous perspectives, leading to a document that does not reflect a knowledge co-production process. Such a process would have paired IKS and Western science equitably to generate shared goals, objectives, methods, and outcomes (Reid et al. 2022). Effective knowledge co-production requires time and financial resources to bring together diverse

participants, preferably in person, to foster meaningful relationships, build trust, and develop an appreciation for the different knowledges that contribute to a pluralistic collaboration (Cooke et al. 2021; Almack et al. 2023).

- The Western science approach used to develop the study design and statistical methods has many limitations and uncertainties (outlined above). Some of these may be mitigated by a more equal pairing of Western science and IKS.
- Limitations stem from the original process used to develop the RCAs where the locations of RCAs, their conservation objectives, and the details of the fisheries closures, were decided upon with limited First Nations input.

Early and meaningful co-development with First Nations will be needed during the implementation of this RCA monitoring advice to help overcome these limitations.

CONCLUSIONS AND ADVICE

Guidance is provided for the development of a coastwide monitoring program for assessing the effectiveness of RCAs at achieving their ecological objectives; these are to increase Inshore Rockfish and Lingcod population densities, to increase the abundance of Inshore Rockfish in older age and larger size classes, and to protect Inshore Rockfish and Lingcod habitat.

The following actions are recommended for RCA effectiveness ecological monitoring:

- Implement a new coastwide monitoring program following the advice in the paper using transect-based benthic imagery tools that can collect data on all the recommended indicators, for example, ROVs, SCUBA, etc.
- Focus sampling on the identified indicators and metrics (particularly rockfish size), using an early-later-control-impact design with the proposed phased approach, and with a sample size that is informed by the power analysis.
- Identify unprotected reference areas that are ecologically similar to RCAs. Select sampling sites (transects) within RCAs and reference areas that are randomized and spatially-balanced, and control for confounding variables (depth, structural complexity, and pre-RCA fishing effort). Prioritize the representative, focal RCAs presented in the paper in future RCA monitoring surveys.
- Collect environmental data concurrently with visual data using appropriate tools and through collaborations with other groups.
- Collaborate with coastal First Nations and other governmental or non-governmental organizations to conduct monitoring and other research related to RCAs following the advice provided in this paper.
- Prioritize the development of trust-based relationships with First Nations to co-develop survey design and planning using Indigenous Knowledge Systems wherever it is possible to do so, and when the knowledge is shared with DFO for that purpose.
- Include data collected by First Nations and other organizations in the coastwide analysis on RCA effectiveness if they are collected with the recommended tools, following the site selection methods outlined in this document, and if the data are shared with DFO for this purpose.
- Implement RCA effectiveness monitoring using the 5-phased implementation plan to guide data collection and analysis.

Advice stemming from this document can be used for other initiatives related to monitoring Inshore Rockfishes; the data collected as a part of this monitoring plan may have other applications related to Rockfish conservation (e.g., helping to inform boundary reviews).

The ability to detect an effect of RCAs using this monitoring advice may be reduced by the fact that baseline data for RCAs does not exist and monitoring advice is being developed only now, two decades after the implementation of RCAs. Starting monitoring before, or soon after, implementation is important to be able to detect changes attributable to spatial closures, and should be prioritized for new spatial closures.

ADDITIONAL CONSIDERATIONS

This advice document was created with input and contributions from many First Nations. As we move forward, it will be important that the advice is implemented in collaboration with interested First Nations, with the inclusion of Indigenous knowledge, perspectives, values, and priorities, both to support the rights of First Nations, and to reflect the evolving role of First Nations in RCA monitoring.

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