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FRAMEWORK TO SUPPORT DECISIONS ON AUTHORIZING SCIENTIFIC SURVEYS WITH BOTTOM-CONTACTING GEARS IN PROTECTED AREAS WITH DEFINED BENTHIC CONSERVATION OBJECTIVES

Figure 1. The six administrative regions of the Department of Fisheries and Oceans (DFO) in Canada.

Context:

Protected coastal and marine areas in Canada can be created using a number of regulatory tools administered by different departments or agencies and for a range of conservation objectives. Canada's marine protected area (MPA) programs establish sites under three pieces of legislation: Marine Protected Areas under the Oceans Act, National Marine Conservation Areas under the Canada National Marine Conservation Areas Act, and marine National Wildlife Areas under the Canada Wildlife Act. The Fisheries Act authorizes the creation of areas for the protection of ecologically sensitive benthic species and habitats under Fisheries and Oceans Canada's (DFO) Policy on Managing the Impacts of Fishing on Sensitive Benthic Areas. The sensitive benthic area closures, such as coral and sponge conservation areas, are part of the other effective area based conservation measures being considered as counting toward Canada's commitment to the Aichi Biodiversity Target 11. DFO Oceans Management requested advice on the conditions under which scientific research survey and other research activities with bottom-contacting gears could be authorized and how they would be adapted to mitigate the damage of the science survey activities on defined sensitive benthic features.

The decision on whether or not bottom-contacting scientific surveys and research activities would be *authorized in a marine protected area or in a sensitive benthic closed area is the responsibility of DFO Oceans Management and DFO Fisheries and Aquaculture Management, respectively. To assist in this decision making process, DFO Science developed a national framework with an agreed set of assessment criteria that can be applied consistently across Canada to assess the impact of existing and proposed scientific activities on the benthic components of protected and sensitive benthic areas, as well as to assess the time series value of the scientific survey designs and protocols that include sampling in these protected areas. This Science Advisory Report is from the January 16-18, 2018 national science peer review meeting titled "A Framework to support decisions on authorizing scientific surveys with bottom-contacting gears in protected areas with defined benthic conservation objectives".*

SUMMARY

- A number of protected area and existing and proposed sensitive benthic area closure (herein protected area) boundaries overlap the geographic areas of scientific surveys using bottom-contacting sampling gears.
- In many DFO regions, scientific surveys using bottom-contacting gears have been conducted for several decades and are important for resource status assessment, recovery potential assessment, monitoring of species of conservation concern, and ecosystem status reporting.
- Immediate effects of most mobile bottom-contacting gear on benthic features include the loss of erect and sessile epifauna, habitat modification including scouring of glass sponge reefs, and removal of structure-forming taxa such as corals and sponges. Mortality mostly occurs through direct contact/removals and secondarily by predation. Sediment plumes from trawls can also cause smothering in filter-feeding organisms which can lead to mortality.
- The extent of physical impact of bottom-contacting gears on seabed habitat and fauna is related to the penetration of the gear in the sediment, collision impacts, removals by the gear, and sediment mobilization. The area impacted is a function of the area covered by a single sampling event (swept area) and the area affected by sediment resuspension from a sample, summed over the distribution of all samples.
- A proposed proxy of the level of harm to benthic habitat caused by scientific surveys with bottom-contacting gears is the relative magnitude of the recurrence time interval of the activity compared to the expected recovery time of the benthic components.
- The recurrence time interval (in years) for an activity, defined as the average time between successive benthic sampling impacts at a given site, is the inverse of the annual proportion of the protected area impacted by the activity when the distribution of sampling sites in the area is random.
- Recovery time in this report is defined as the length of time it takes for the benthic attribute to return to its state prior to scientific survey impact. The potential for recovery of benthic fauna following disturbance by bottom-contacting gear is determined by the characteristics of the benthic components. Longevity of individuals or the long periods over which some benthic habitat features develop must be taken into consideration.
- Taxa with lifespans or benthic features with ages that are less than one-tenth the estimated recurrence times of a benthic interacting science activity are likely to have time to recover to the levels that existed prior to the impact of the sampling activity. Taxa with lifespans or benthic features with ages that are greater than about a tenth of the recurrence times (an order of magnitude scale) may be susceptible to long-term degradation and lack of recovery.

- The choice of needing recurrence time to be ten times larger than lifespan to avoid long-term degradation (or lack of recovery) is important given uncertainties and knowledge gaps of benthic invertebrate life histories, indirect effects of gear impacts not quantified in the swept area estimates, and knowledge gaps of benthic community recovery rate and factors. It is meant to help prevent overestimation of recovery potential.
- In lieu of excluding scientific activities from protected areas, a switch to alternative monitoring methods or modifications to existing survey gear or procedures should be considered to mitigate impacts of the scientific activities on benthic features.
- The importance of scientific samples collected within a protected area with respect to the integrity of the survey's historical time series is case specific. A key consideration is the introduction of a time-varying bias in the time series of survey-based indices resulting from the exclusion of samples from protected areas. Such a bias will occur if the spatial distribution of a stock changes with respect to the protected areas.
- A national framework was developed that describes the information gathering process that will assist the management sectors in any region of Canada in their review for authorizing proposed scientific activities with bottom-contacting gears in protected areas. The framework is intended to facilitate dialogue between the science survey proponent(s) and the decision-making sector.
- Operationally, reviews of scientific activities must not be done in isolation. In some cases, protected areas may overlap more than one DFO administrative region. Coordination of requests, in some cases at the bioregional scale at which many surveys occur, will be required to ensure that the cumulative footprint of all proposed scientific activities on an annual basis is properly considered. Similarly, the potential consequences on scientific advice of excluding survey activities from all protected areas that overlap with a survey should be considered. The timelines for notification, review, and authorization decisions may therefore be much longer than indicated in policies or regulations.
- Some of the review associated with authorizations of scientific surveys in protected areas can be done periodically (effects of excluding stations from protected areas, recurrence intervals) whereas other components will require annual inputs (exact locations of sets within a protected area).

INTRODUCTION

The Government of Canada committed to, and accomplished, increasing the percentage pf protected coastal and marine areas of Canada to 5% by 2017 and is on its way to achieving 10% by 2020, as part of the agreed Convention on Biological Diversity Aichi Biodiversity Target 11. To achieve this goal, networks of marine protected areas and other effective area-based conservation measures are being established, herein referred to as protected areas. Protected areas with benthic conservation objectives are largely created to protect sensitive benthic species and their habitats, such as cold water corals and sponges; some of these species form biogenic habitats that serve as predation shelters, foraging centres, attachment substrate, and spawning and nursery grounds for marine biodiversity. A number of these protected area boundaries overlap with historical fishing areas and the areas for scientific surveys conducted by or in collaboration with Fisheries and Oceans Canada (DFO).

Existing bottom-contacting surveys contribute to the creation of a large diversity of scientific advice. At the time of this review, there were 57 re-occurring bottom-contacting research surveys that took place in the coastal, shelf and slope waters off Canada. The majority of these surveys are primarily intended to collect data and/or provide advice for single species or a small group of related species. Of the single species surveys, approximately two-thirds target demersal invertebrate species. There are 22 surveys that are considered multi-species surveys or surveys that are regularly used in the provision of scientific advice for a number of species. Twenty-six of all re-occurring surveys are conducted using bottom trawls, of which 15 are primarily annual multispecies surveys.

The multispecies trawl surveys are among the longest running annual ecosystem monitoring surveys in Canada, with a number of surveys in operation since the 1970s. These synoptic surveys also cover the largest surface areas among the various surveys in Canadian waters, with a combined survey domain of over 1.5 million km^2 after accounting for overlaps between surveys. Surveys provide indices of abundance for analytical assessments of stock status. They also provide information on a number of ecosystem aspects including species diversity and species distribution used in identifying conservation areas and developing ecosystem indicators, on abundance and distribution of secondary commercial species, and, on bycatch species. Since 2000, the surveys have become important for the status assessment, recovery potential assessment, and monitoring of species of conservation concern and for providing indices of population, community and ecosystem status.

There are presently no existing frameworks or approaches to assist in determining under what conditions scientific surveys employing bottom-contacting gear can be permitted in protected areas. Before bottom-contacting scientific research surveys can be authorized in protected areas, an assessment of the impact of the activities on the defined conservation objectives and of the importance of including or excluding the protected areas within the scientific survey protocols is required. The question is to what extent the current scientific research survey practices will have to be adapted to avoid or mitigate the harm caused by their bottom-contacting gears when sampling in protected areas with defined sensitive benthic features or conservation objectives for other properties of the benthos such as biodiversity. This decision will be informed by an assessment of risks posed by the sampling equipment and strategy, and benefits to be derived from the information obtained by the sampling activity. This information may support the monitoring for attainment of conservation objectives, both within protected areas (e.g., effectiveness of closures for other taxa) and in the broader ecosystem context (e.g., advice for sustainable fisheries, species recovery, and ecosystem status).

ASSESSMENT

The impacts of bottom-contacting gear on benthic species include both immediate and cumulative effects. DFO Science previously published a number of Science Advisory Reports of fishing gear impacts on benthic habitats, including corals and sponges. It was determined that mobile bottom-contacting gear (trawls, dredges, etc.) impacts corals and sponges the most, due to the sensitivity of many of these species, the extent of the seafloor affected, and the force exerted (DFO 2006; DFO 2010a). Whereas the impacts of mobile gear on coldwater corals and sponges have been extensively documented, the impacts of fixed gear (e.g. traps, pots, gillnets) are not as well studied.

Immediate effects of most mobile bottom-contacting gear are the loss of erect and sessile epifauna, smoothing of sedimentary bedforms with reduction of bottom roughness including scouring of glass sponge reefs, and removal of structure-forming taxa such as corals and sponges. Mortality mostly occurs through direct removals; however, dead, moribund and damaged individuals can be left on the sea floor where they may be vulnerable to predation. The depletion of large, emergent, attached fauna such as sponges, corals, and sea pens can be high in the first trawl tow over an area. Sediment plumes from trawls can also cause smothering in filter-feeding organisms which can lead to mortality.

Commercial fisheries can impact ecosystem function by selecting for species assemblages with relatively rapid turn-over rates and through serial depletion of habitat as may occur with long-lived species with low recruitment rates and restricted distributions or structure building taxa. Scientific surveys have a much smaller footprint than commercial fisheries, but will nonetheless result in some localized harm to benthic communities. The extent to which scientific surveys impact ecosystem functioning is not known, but will depend on the size of the survey footprint relative to the distributional areas of benthic taxa or features, and the frequency at which the surveys impact these taxa or features, relative to their ability to regenerate and recover following disturbance.

Traits of benthic components vulnerable to bottom-contacting gears

Existing trait-based frameworks for categorizing benthic component vulnerability effectively divide traits into two broad categories: exposure to the gear and sensitivity upon contact. Exposure is related to the form of the taxon, whether erect or emergent at the surface, and the living position in the sediment. Sensitivity to contact depends principally upon the fragility of the taxon, with taxa possessing exoskeletons or rigid structures often associated with higher incidence of damage or death. Sensitivity is also affected by body size, presumably in part as a result of relationships between the force of impact, body mass, fluid dynamics, and mobility.

The following factors are considered relevant for evaluating the degree of sensitivity and susceptibility of any benthic fauna species and/or community to fishing activities:

- range and spatial distribution;
- morphology and skeletal composition (rigid vs. flexible);
- means of attachment to the substrate;
- life history characteristics; and,
- habitat preferences.

Sensitivity categories for benthic fauna as it relates to particular life traits are summarized in Table 1.

Table 1. Sensitivity categories for benthic taxa to disturbance by mobile fishing gear (from Clark et al. 2016).

Sensitivity	Expected response to disturbance	Traits
High	Mortality of individuals in the swept area	Fragile, sessile, erect and emergent forms
Intermediate	Mortality of some individuals in the swept area	Fragile forms with no or limited mobility, surface dwellers
Low	Mortality of a few individuals in the swept area	More robust or small erect forms, dwellers in the top layer of the sediment with limited mobility
Tolerant	No response	Robust or mobile surface dwellers or subsurface dwellers with high burrowing capacity
Favoured	Individual may move into the area	Mobile scavengers and predators

When recovery is mentioned in this report, it refers to the return of the benthic attribute to the state prior to the scientific survey activity and not in reference to the return of the benthic attribute to a pristine state (DFO 2010b). The potential for recovery of benthic fauna following disturbance by bottom-contacting gear is determined by the characteristics of the benthic components. Poor recovery is due to key, linked biological parameters including: extreme longevity (from 100s to > 1,000 years) of individuals or the long periods over which some benthic habitat features develop; a high proportion of endemic species with risk of loss of biodiversity; distribution of some vulnerable seafloor communities as spatially discrete units often within a small area of the seabed so that small perturbations may have significant consequences; and fragmentation and risk of loss of source populations. Poor knowledge of ecosystem components and their relationships leads to uncertainty when assessing the potential for recovery of disturbed or damaged benthos.

If an impact completely removes the benthic features that were present prior to perturbation or if the distance between benthic features is great enough that recruitment from other sources cannot re-colonize the impacted area (fragmentation), the site may never recover (Boutillier et al. 2010). Such habitat fragmentation concerns are most important in areas of high fishing intensity with sessile structure forming organisms.

Criteria to assess impact of bottom-contacting scientific survey activities

The physical impact of bottom-contacting sampling gears on seabed habitat and fauna is related to the penetration of the gear in the sediment, collision impacts, removals by the gear, and sediment mobilization. The area impacted is a function of the area covered by a single haul (swept area) and the area affected by sediment resuspension from a haul, summed over the distribution of all hauls. The swept area for a haul is a function of the size of the opening of the gear and distance towed during bottom-trawling and dredging (Table 2). For fixed gear, the swept area would be the area of contact by the gear during fishing (including any area impacted by gear drift), and any area swept laterally during gear deployment and retrieval. The majority of direct impacts occur within the swept area. Impacts resulting from sediment resuspension will often affect a broader area depending on factors such as the sediment type and local currents and are therefore more case specific (e.g., Leys 2013).

Swept areas of individual sampling events (in km^2) for the Canadian surveys were estimated. For bottom trawls, the total swept area based on door spread was assumed as a worst case scenario, acknowledging that different trawl parts have different degrees of impact (e.g., most acute but narrowest in swept area for trawl doors; least acute and widest for trawl sweep lines). Additional sedimentation effects would have to be considered for specific cases. For fixed gears, an average lateral movement of the gear of 100 m was assumed, based on expert opinion in the absence of empirical data. For pots and traps, the total swept area was taken to be the area occupied by the gear including the potential lateral area swept during deployment and retrieval (Table 2). When empirical data become available, more refined estimates of footprint calculations should be used.

Table 2. Swept area (km^2) calculations for broad categories of bottom-contacting sampling gears.

Gear type	Swept area calculation
Bottom trawls	Target tow distance (km) x mean door spread (km)
Dredges and beam trawls	Target tow distance (km) x gear width (km)
Longlines and gillnets	Total gear length (km) x 0.1 km assumed lateral sweep
Pots and traps - single	Gear diameter (km) x 0.1 km assumed lateral sweep
Pots and traps - in a string	Total gear length (km) x 0.1 km assumed lateral sweep

The annual total swept area of a survey is estimated as the product of the best estimate (mean of the past five or ten years for example) of number of hauls and the haul-specific swept area divided by the interval periods between conducting the survey (in years; typically one year for most surveys). The estimated annual swept area of scientific surveys occurring in Canada varied from 0.1 to 0.2 km^2 for herring index net and sea scallop dredge surveys respectively, to over 500 km^2 for the large scale Newfoundland snow crab trap survey. Values for most other surveys were at scales of single to 10s of km^2.

The average proportion of the bottom within a protected area which would be impacted by the bottom-contacting survey gear is dependent upon the sampling design for the survey component overlapping the closed area (Fig. 2). Almost all re-occurring surveys in waters off Canada follow one of three designs: fixed station, random, or random-stratified. Survey set locations are selected randomly at the scale of the whole area (the sampling frame) in random station surveys and within strata for stratified-random designs (Fig. 2). Given the predetermined number of stations to be sampled and the random selection of the sampling locations, we refer to the average number of sets falling within a closed area annually, i.e., by chance alone there can be more or fewer stations selected in a closed area in any given year.

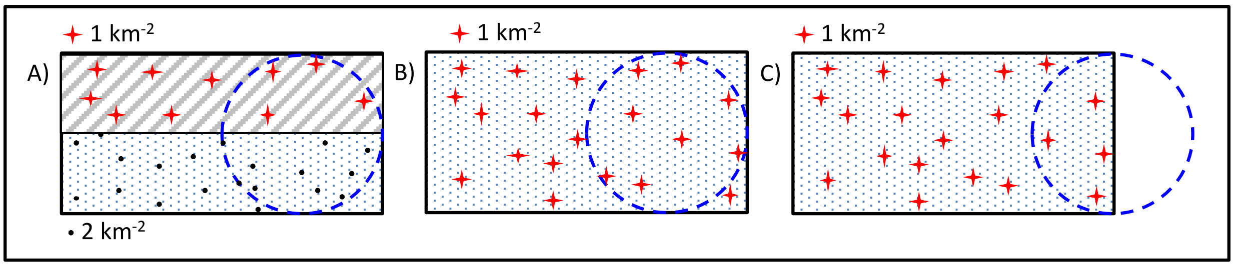

Figure 2. Example of the difference in the proportion of the protected area impacted by the scientific activity when A) two strata (shown by shading patterns) with different sampling intensities (symbols in each stratum and corresponding example of intensity as samples km^{-2}) completely overlap the protected area (dashed line circle); B) one stratum completely overlaps the protected area with a fixed sampling intensity; C) a protected area only partly overlaps with a survey domain, in this case one stratum overlapping one half of the protected area with the same sampling intensity as in panel B. For illustrative purposes, the proportion of the surface of the protected area impacted by the scientific activity is 50% larger in panel A compared to panel B and the proportion of the total protected area impacted in panel C is 50% that of panel B and 33% that of panel A.

The mean annual number of sample stations within a protected area is the product of the sampling intensity (samples per km²) of the corresponding survey domain (or stratum) and the surface area of the protected area overlapped by the domain/stratum, summed over all overlapping strata in the case of a stratified random design. The average proportion per year of the bottom of the protected area which would be impacted by the bottom-contacting scientific sample stations in random or stratified-random surveys over all strata (K; with K=1 for a random survey) for all surveys (S) is calculated as:

$$\text{Prop. Impact} = \frac{\sum_s^S \overline{swept\ area}_s * freq_s \sum_k^K sampling\ intensity_{s,k} * protected\ area\ size_{s,k}}{protected\ area\ size} \quad (1)$$

where $\overline{swept\ area}_s$ is the average swept area for a sample (km²; calculated as per Table 2) in survey *s*, $freq_s$ is the annual frequency (1 for annual surveys, 0.5 for biennial surveys, etc.) of survey *s*, $sampling\ intensity_{s,k}$ is the average number of sampling stations per km² within stratum *k* for survey s, protected area $size_{s,k}$ is the quantity (km²) of the protected area contained in stratum *k* of survey *s*, and the denominator is the total size (km²) of the protected area. The proportion impacted has units of $year^{-1}$.

The proportion of the bottom within a protected area that is impacted by a fixed station survey design will be constant in time and equal to the sum of the swept areas for all tows occurring in the area, divided by the surface area of the protected area.

The recurrence time interval (*R*; in years) for the entire protected area, defined as the average time between successive benthic sampling impacts at a given site, is the inverse of the annual proportion impacted (from equation 1):

$$R = \frac{1}{\text{Prop.Impact}} = \frac{\textit{protected area size}}{\sum_s^S \overline{swept\ area_s} * freq_s \sum_k^K\ sampling\ intensity_{s,k} * protected\ area\ size_{s,k}} \qquad (2)$$

In instances in which surveys overlap only partially with a protected area (panel C in Figure 2), it may be more appropriate to consider the recurrence time interval for the portion of the protected area which is overlapped such that:

$$R = \frac{\textit{protected area size * proportion protected area overlapped}}{\sum_s^S \overline{swept\ area_s} * freq_s \sum_k^K\ sampling\ intensity_{s,k} * protected\ area\ size_{s,k}} \qquad (3)$$

In cases in which sampling intensities within surveys vary among strata (panel A in Figure 2), or in which the overlap between sampling frames and the protected area varies among surveys, the recurrence time will be heterogeneous in space. Though the estimate from equation (3) will be correct for the average parcel of overlap, more refined calculations would be required if characterization of this heterogeneity is desired.

The value of R as defined above applies to random-based survey designs. For fixed-station designs, the calculation and interpretation is different. At fixed station locations within the protected area $R = freq_s$ while at all other locations *R* is infinite because as long as fixed stations do not change in time they will never recur at other locations.

Differences in sampling density across strata and the consequence on the calculation of recurrence time is illustrated in Figure 3 for the Scotian Shelf multispecies surveys on the east coast of Canada for which recurrence times vary among strata from around 1,000 years to 10,000 years. The shortest recurrence time estimates for ongoing scientific surveys in Canada were just over 600 years whereas most surveys were associated with average recurrence times on the order of thousands to tens of thousands of years.

An assessment of the impact of survey activities in a protected area must include all proposed scientific surveys that overlap with a protected area and therefore considers the cumulative effects of multiple surveys within a year.

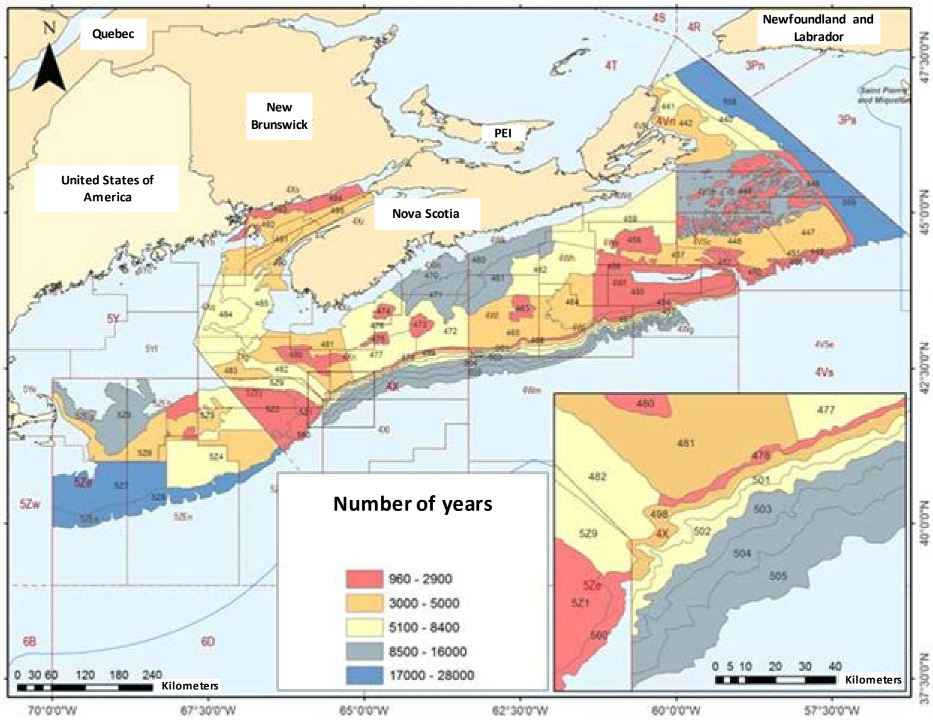

Figure 3. Estimated recurrence time interval (years) for individual survey strata in the multispecies bottom trawl surveys undertaken by the DFO Maritimes region. The recurrence time estimate by stratum is the number of years required to sample the entire seabed of the stratum based on current sampling effort of the survey. The tow door spread is assumed to be the width of the trawl footprint.

Metric of harm to benthic components associated with bottom-contacting gear impacts

In the absence of specific directed studies, a quantitative metric of the harm to species, communities, and benthic habitat forming structures (e.g. biogenic structures) resulting from scientific survey activities in a protected area is not possible at this time. A proposed proxy of the level of harm is the relative magnitude of the recurrence time interval of the activity and the expected recovery time of the benthic components.

Specific information on the time required for recovery of the benthic components following a benthic disturbance should be used when available. In the absence of such information, longevity, defined as the known or expected lifespan of the most sensitive benthic species or community features, or the age of biogenic structures or structuring components in a protected area, is proposed as a proxy for recovery time. This proxy may address a range of life history constraints likely present in benthic organisms such as episodic spawning and recruitment events, intermittent conditions for dispersion, and the development and construction of benthic features required for colonization (for example, glass sponge reefs).

Taxa or benthic features with longevity greater than around one tenth the recurrence times are susceptible to long-term degradation and lack of recovery. Many coral and sponge species have lifespans extending into 100s and 1000s of years. Glass sponge reefs, unique ecosystems in the Pacific Ocean, have ages that exceed several thousands of years; furthermore, the living portions of the reefs depend on the structural integrity of the underlying dead and buried structure which required a specific set of past geological conditions for its original formation and thus cannot recover when damaged (Conway 1999; DFO 2017a). The lifespans of such taxa or structures will be close to or may exceed the recurrence times of individual existing re-occurring surveys, let alone values for multiple overlapping surveys. Unless the impacts of these surveys are mitigated, these activities are likely to result in the long-term or permanent degradation of these populations or structures.

In contrast, recurrence intervals that are an order of magnitude (roughly 10 times) longer than longevity are believed to be sufficient in most instances to allow recovery to pre-impact population age / size structure. Some species of sea pens in the Gulf of St. Lawrence and the Newfoundland bioregions are considered relatively more resilient than other corals due to their shorter life spans and quicker growth rates, with expected recovery timescales of decades rather than centuries (DFO 2017b).

The choice of order of magnitude spread between recurrence time and recovery time is important given uncertainties and knowledge gaps of benthic invertebrate life histories, indirect effects of gear impacts not quantified in the swept area estimates, and knowledge gaps of benthic community recovery rate and factors.

Measures to mitigate harm caused by bottom-contacting scientific surveys

In cases for which the spatial distribution of the features with defined benthic conservation objectives in the protected area is discrete and known, it may be desirable to exclude these locations from the sampling domain for the scientific surveys.

In lieu of completely excluding surveys from protected areas, a switch to alternative monitoring methods or modifications to existing survey gear or procedures may be used to mitigate impacts of bottom-contacting gear on benthic components. There are two key factors to consider in evaluating possible mitigation measures. First, alternative methods should provide the type of data presently collected by ongoing surveys that are used in the provision of scientific advice. Second, it should be possible to calibrate the methods or correct the data post hoc to ensure the existing and modified methods provide a standardized measure of the properties being monitored.

The impact of bottom-contacting gear can be reduced by reducing the overall size of the sampling gear, reducing the physical pressure of bottom contact (i.e. reducing weight of gear components, such as the doors), shortening tow durations in the case of mobile gear, and reducing the number of contact points along the benthos (Valdemarsen et al. 2007). Trawl surveys typically employ pre-determined minimum acceptable and target tow durations; a mitigation option in closed areas may be the use of the minimum acceptable duration for survey sets. For scientific surveys that are part of the time series, any changes in survey gear would require calibration to ensure the temporal integrity of the time series indices.

Bottom-set gillnets and longlines, as well as pots and traps have a low to moderate impact on physical benthic habitat, however, the impacts on emergent taxa (e.g. corals and sponges) can be high during deployment and retrieval or as a result of losing the gear. Mitigation measures for these gears include use of biodegradable material, shortening soak times, and restricting deployment and retrieval to periods/areas with favourable weather, currents, and ice conditions.

Hook and line gears (i.e. handlines, rod and reel, trolls) have a generally low impact on physical benthic habitat, however, these gears can only sample a subset of aquatic organisms (primarily larger finfish) and may require considerable sampling effort to obtain indices that can discern changes in relative abundance of a wide range of monitored species.

Hydroacoustic methods are currently used by DFO during scientific surveys and can be undertaken over a range of spatial areas and over a broad range of habitats. However, hydroacoustic surveys do not reliably detect demersal species on or near the seafloor, or species that lack swim bladders. The ability to distinguish species and sizes of fish is limited and consequently further sampling to calibrate the acoustic signal is required.

Observational survey methods based on visual observations from divers, towed cameras, or remotely operated vehicles can sample benthic and demersal macrofauna with often little impact on the bottom. Those methods provide information on benthic epifauna characterisation and distribution, benthic habitat characterization, and identification of seabed type. However, available evidence and a lack of successful examples to date indicate that these methods are not effective for monitoring mobile and lower density organisms and are unlikely to be a suitable replacement for multispecies surveys currently undertaken using bottom trawls. The main challenges associated with observational survey methods include the accuracy of species identification, unclassified targets, movement, double counting of fish, restricted field of view resulting in limited spatial coverage at a sampling site and observations that are limited to conspicuous species and in waters with high visibility. The main advantages of these methods include their low or no impact on benthic species and habitats, little or no need to extract organisms, and the potential for high sampling density at fine spatial scales enabling research on small scale species-habitat associations and animal behaviour.

Consequences of changing scientific survey methods

All of the existing bottom-contacting surveys provide relative indices of abundance rather than absolute abundance estimates because the gears capture and retain only a proportion of the animals that are in the area swept by mobile survey gear (bottom trawls and dredges) or in the vicinity of fixed gear (gillnets, longlines, pots and traps). This proportion, often called catchability, typically varies among species and sizes of organism within a survey and can in some circumstances vary spatially within a survey area. The utility of a survey in providing a reliable index of abundance for a species or size group depends critically on the temporal stability of catchability. Modifications to survey gear, protocols or operations that cause a systematic change in catchability will result in a change in the abundance indices. Failure to account for these changes results in risks of confounding actual changes in abundance with changes due to survey operations in the abundance indices. It is for this reason that efforts are made to maintain consistency in survey design. When changes in survey operations are unavoidable or deemed necessary, such as a switch from day-only to 24-hr surveying, or a change in survey vessel or trawl, considerable efforts are undertaken to standardize or calibrate abundance indices. In the case of a gear change, this typically requires a period of simultaneous sampling/monitoring by both gears in order to develop a means of standardizing the indices to account for differences in catchability. This will also be required if changes are made within protected areas to mitigate harm.

Consequences of excluding scientific surveys in protected areas

Regular ongoing scientific surveys provide monitoring for temporal changes in the abundance and distribution of marine taxa. In the broader ecosystem, monitoring is required to evaluate the efficacy of management measures employed to meet objectives related to the sustainable use of renewable marine resources and the recovery of depleted species and species of conservation concern. Monitoring is also crucial for evaluating ecosystem-level effects of human activities and for understanding the consequence of large-scale environmental changes such as climate change and ocean acidification.

Protected areas generally represent sites with properties that distinguish them from alternative areas, such as high densities of taxa of conservation concern or high biodiversity. By the nature of containing special habitats, protected areas are likely to be favoured by some taxa, and marginal or neutral for others. Furthermore, environmental changes can affect the location of preferred habitats and use of these by marine organisms. These properties are likely to result in different ecological patterns and dynamics inside and outside protected areas.

Consequences to science and conservation within protected areas

Monitoring is required within protected areas to ensure the efficacy of the management measures with respect to their defined conservation objectives. For many protected areas, existing bottom-contacting scientific surveys are the only source of data on background conditions prior to and immediately following the closure, both within the protected area and neighbouring areas. While the surveys may not be suitable for monitoring many or all benthic components in a protected area, they may be used for assessing other ecological components that could benefit from the protection, such as demersal fish. Excluding surveys from protected areas can impair these benefits. The benefits of obtaining such information may render acceptable, in some circumstances, the associated harm caused by bottom-contacting scientific gear to the benthic components in the protected area.

Consequences to science and conservation in the broader ecosystem

Survey undercoverage with respect to a stock or species occurs when the survey area does not include places where the stock or species occurs. Undercoverage can cause bias in the properties estimated using survey data (e.g., mean abundance density). The exclusion of surveys from areas that were previously included in their sampling domain will generate new, or enhance existing, undercoverage for stocks and species that reside in the newly protected area. There is therefore a high potential for bias in time series indices of abundance developed from a survey domain that excludes the protected areas. Species or life-stages occurring exclusively in the protected area would no longer be monitored.

Strictly speaking, bias does not cause problems for resource monitoring if its magnitude and sign do not vary in time. Bias caused by undercoverage becomes problematic when the magnitude, and possibly the sign, of that bias vary non-randomly over time. There are two principal mechanisms that can generate time-varying bias in estimated relative abundance resulting from undercoverage: shifts in stock spatial distribution that are not proportional inside and outside the survey area and divergent (sub)stock demographic dynamics in the protected area relative to the broader area.

Changes in distribution are very common in mobile marine fauna, of which density dependent shifts are among the most pervasive. Existing theory predicts an expansion of population range into marginal habitats as abundance increases, such that percent changes in local density are expected to be greater in marginal than in optimal habitat. For stocks for which an unmonitored area constitutes part of or their entire preferred habitat, as abundance declines from a high level, densities estimated by the survey will decline more rapidly, resulting in what is termed hyper-depletion (trends and status for the stock appear more pessimistic than they truly are). Conversely, for stocks for which the unmonitored area constitutes potential but less favoured habitat, densities in the survey will remain disproportionately elevated as the stock is declining; this results in hyper-stability which creates an elevated risk of delaying management actions aimed at halting stock decline and promoting rebuilding. For stocks for which the protected areas are relatively small and include habitats that are not used or considered marginal, even at high density, the resulting biases in survey estimates are likely small enough to disregard, provided those habitats do not become more favoured with broad scale environmental change or as a result of the spatial protection. Conversely, for stocks for which the protected areas constitute a non-negligible portion of their range or for which the areas are disproportionately favored, the biases may be too large to disregard.

Different levels of stock productivity inside and outside protected areas can result in different patterns in abundance and stock dynamics, in turn leading to potential undercoverage bias if surveys are excluded from protect areas. The magnitude of the resulting time-varying bias is likely to increase with the degree of species site-specificity, restrictions on mobility of all life stages, the degree of benefit accrued from protection and the degree of undercoverage resulting from survey exclusion in the protected area.

Regardless of the cause, it is often difficult, if not impossible, to estimate bias caused by undercoverage in a survey. Consequently the potential for bias should be evaluated based on the preceding considerations, on a stock-specific basis. Furthermore, such an evaluation should include all of the individual protected areas that overlap with the survey.

There are two general approaches for accounting for the exclusion of surveys from protected areas when estimating indices of abundance. The first is to remove the unsampled area from the survey domain for estimation, thereby reducing the domain size. This approach is most susceptible to the biases described above. The second approach is to impute values for the unsampled area and to maintain the estimation domain. If the imputation is accurate, there will be no resulting bias in the survey series. However the more the imputed values differ from the true values for the unsampled area, the greater the bias will be and it may be impossible to forecast how biased the imputations will be in the future. In some instances, the anticipated magnitude of bias could be sufficiently high that the data from scientific surveys will either need to be disregarded entirely in the provision of scientific advice, or used with caution, given the risk of generating misleading advice. This can compromise the advice or reporting for species for which the surveys are the only or principal source of information on relative abundance and therefore represents a transfer of risk from the protected benthic components to these other ecosystem components.

Framework to support decisions on authorization of scientific surveys with bottom-contacting gears in protected areas

The framework describes an information gathering process that is applicable in any region of Canada and will assist the management sectors in their review of proposed scientific activities using bottom-contacting gear in protected areas. The framework can be used for ongoing and proposed scientific activities of different types and for different valued benthic components (e.g. corals and sponges, hydrothermal vents, cold seeps, benthic biodiversity in general). The framework does not prescribe decisions to be taken. Rather it is intended to facilitate dialogue between the science survey and research activity proponent(s), the management sectors that rely on scientific advice produced using information from scientific surveys and activities, and the management sector responsible for authorizing the research activities in the protected areas.

The framework consists of five elements.

1. A description of protected area(s) which is(are) within the survey domain(s) of the proposed scientific survey(s) and the benthic conservation objectives of the protected area(s), including:
    - A separate description of each protected area.

- A description of the type of closure(s) and related regulatory policy framework of the protected area(s) (including maps at the scale of the bioregion as well as at the scale of each protected area).
- A description of the benthic species, assemblages, biogenic habitats or physical habitats and features that link to the conservation objectives of the protected area(s). It is expected that this information would be available in the documentation supporting the protected area designations.
- Information on the expected recovery times of the benthic components. Specific information on time for recovery of the benthic components following a benthic disturbance should be used when available. In the absence of such information, the known or expected lifespan of the most sensitive benthic species / community features or the age of biogenic structures or structuring components in a protected area is proposed as a proxy for recovery time.

2. A description of the proposed scientific activity(ies) to be undertaken in the protected area including:

- The purpose of each survey (e.g. single species focus to support fisheries management; multi-species focus to support ecosystem considerations and fisheries management; monitoring specific to the protected area).
- The history (first year) and frequency of survey (such as long term annual survey versus periodic, one-time, or new survey).
- The type of proposed bottom-contacting gear to be used (mobile gear including trawl doors, footrope, and bottom contact construction; fixed gear including deployment plan).
- An estimate of the average direct footprint area of the activity at each sampling location; the footprint area would ideally include the indirect impact from other factors as for example sediment plumes, if available.
- The best available estimate of the sediment resuspension, transportation and fate if warranted by case specific circumstances, for example trawl gear deployments on soft substrates near glass sponge reefs.
- For each protected area, the calculated proportion of its area potentially impacted by each proposed survey and for all surveys combined, when known.
- For each survey stratum or the entire survey area, the proportion that is overlapped by the protected area(s).
- A calculated proportion of each survey's stratum or areas that have been removed in previous decisions to not survey in the protected area.
- A description of the frequency of failed tows resulting from interactions with the seabed within the protected area (if it has occurred or is known) and particular locations that are not sampled due to features that are not conducive to the gear used.
- A calculated recurrence time of the impact from sampling within each protected area encompassed by survey domain or strata and for the entire protected area, for all surveys.

3. An assessment of the susceptibility of the valued benthic components in the protected area(s) to the proposed scientific survey(s) activities.

- A summary of recurrence times of each activity (individual survey) within each of the protected areas overlapped by the survey.
- An assessment of impacts of multiple surveys in a specified protected area or areas.
- A summary of expected recovery time of the benthic components within each protected area overlapped by the survey.

4. Consideration of sampling options to mitigate impacts in protected areas. The review of options is intended to reduce potential impacts of scientific activities and could include:
   - The exclusion of scientific activities from the specific locations or entire protected areas with known benthic features that have a very long recovery period.
   - Preventing benthic impacts of activities from expanding within a protected area (i.e., limiting the sampling footprint).
   - Consideration of alternative sampling methods.
   - A combination of elements above.
5. An assessment of the consequences to integrity of time series or development of indicators that encompass areas extending outside the protected area and the potential benefits of benthic impacting scientific activities on conservation, protection and understanding of the protected area (if any) and to other management objectives outside the protected area:
   - A consequences analysis, i.e. potential bias in the monitoring indices (including age structure, size structure, etc.) within the survey domain that extends beyond the protected area(s) introduced by excluding the scientific activities from the protected area(s). Biases are expected for species whose relative distribution over time has changed into or away from protected area features.
   - The consequences of excluding the survey from multiple protected areas that overlap with the survey domain should be taken into consideration.
   - The identification of additional information that could be collected from the scientific survey to augment knowledge in protected areas.

Sources of Uncertainty

In the majority of cases, knowledge on benthic invertebrate life histories, recruitment dynamics, and colonization constraints and rates is limited, which in turn limits quantitative assessments of the recovery potential.

In the absence of specific information on recovery time of the benthic components, longevity (expected lifespan of the organism or the age of structuring biogenic features) is the proposed proxy of recovery time. However, further research to address the appropriateness of this metric should be considered.

Recovery time may also be affected by the time required for substrate to become suitable for colonization, larval dispersal, age-at-maturity, and population connectivity. The use of longevity as the default proxy for recovery potential is an estimate and it may under- or overestimate the recovery potential depending on the organism or habitat in question. Adding an order of magnitude buffer to the longevity when comparing to the recurrence time, as proposed herein, is meant to help prevent overestimation of recovery potential.

There is currently insufficient knowledge to make informed quantitative assessments of the impacts of bottom-contacting gear types on benthic species status (which could theoretically range from decline in fitness to mortality). In this paper, it is assumed that any direct contact of bottom-contacting gear with benthic components will result in complete mortality and destruction of benthic components within the bottom-contacting gear footprint.

There is also uncertainty around estimates of bottom-contacting gear impact footprints. Potential sources of this uncertainty include:

- Variability in exact gear set locations or specific haul trajectory.

- Insufficient knowledge on footprint of fixed gear, especially to what extent nets, lines, pots, and traps move across the benthos when being laid, pulled and during soaking. Examining how other assessment groups estimate gear-specific impacts would be informative (e.g. Marine Stewardship Council approaches).
- Difficulty in estimating the footprint of indirect impacts. At a minimum, the area of benthic habitat impacted by the bottom-contacting gear is estimated as a function of the length and width of direct contact. However, this approach does not take into account indirect impacts (e.g. sediment plumes known to adversely impact filter feeding organisms).

Assessment of potential impact in data poor areas (for example, frontiers and pristine offshore locations) is especially challenging because of insufficient knowledge on species composition, distribution and habitat suitability. Seabed characterization approaches such as multi-beam mapping and visual surveys could inform subsequent decisions on use of bottom-contacting gears in these areas. This consideration is particularly important in the Arctic.

Biases in survey indices resulting from the exclusion of survey activities in protected areas can only be quantified retrospectively or from simulation. There will be uncertainty associated with assumed or simulated bias over time in cases in which surveys have been excluded from protected areas. Uncertainty can become high in the face of environmental change given likely impacts on species distributions. Assessments of the consequences of exclusion to the integrity of survey indices should recognize this uncertainty. A review of methods for imputation and their robustness to species distributional change would improve our understanding of potential time-varying bias in survey indices.

Calculations of recurrence times are subject to uncertainties. Mitigation options associated with excluding specific locations in closed areas may be constrained by physical features of the habitat. There may not be sufficient distance to conduct a tow within survey protocols, especially for stations that are close to boundaries of protected areas, and depth variability may limit what is available for protocol compliant corridors/paths. In these situations, the sample location selection can be forced to a smaller survey area than the survey domain. Recurrence times over the realized survey area may therefore be less than calculated based on random selection over the entire protected area. However portions of the closed area which are not suitable for bottom-contacting gears are always excluded from the sample selection. These variants are difficult to quantify in terms of recurrence times; the use of an order of magnitude difference in longevity and recurrence time is intended to address this uncertainty.

To date, little research has been completed on detectability of various taxa in visual surveys, especially those done with remotely operated and autonomous vehicles. As new technology becomes available and new methods are developed, visual methods may become more effective for monitoring mobile, lower density organisms. In the future, data collected using visual survey methods should be compared with that collected using traditional survey methods, including side-by-side gear trials and calibrations.

CONCLUSIONS AND ADVICE

A number of newly defined protected areas and existing and proposed sensitive benthic area closure boundaries overlap with existing annual scientific surveys with bottom-contacting gears conducted by DFO and collaborators. These regular bottom-contacting surveys contribute to the maintenance of a large diversity of scientific advice that supports, among other things, sustainable fisheries management, the assessment of stock status, the monitoring and recovery of depleted species and species at risk, the identification of conservation areas and the development of ecosystem indicators for ecosystem-approaches to management as well as domestic and international reporting on the state of Canada's oceans.

Impacts of survey activities with bottom-contacting gear on benthic species include both immediate mortality or harm to benthic species and long-term habitat modifications. These effects can be cumulative over time. Sensitivity to contact depends principally upon the fragility of the taxon/communities, with emergent taxa possessing exoskeletons or rigid structures often associated with higher incidence of damage or death. Potential for recovery of benthic fauna following disturbance by bottom-contacting gear is determined by the characteristics of the benthic components that affect their productivity, including linked biological parameters such as longevity, age-at-maturity, growth, as well as structuring and accumulating benthic habitat features (glass sponge reefs). Poor recovery potentials for some species and habitats are due to biological parameters such as low productivity, extreme longevity of individuals (from 100s to > 1,000 years), and long periods over which some habitats develop.

Where specific information is available on the anticipated harm caused by scientific surveys with bottom-contacting gears and anticipated recovery potential, it should be used in the decision making process. In the absence of this case-specific information, the proxies proposed here are recommended.

- In the absence of more specific or direct measures, longevity is the proposed proxy of recovery time. Longevity could be defined as the known or expected lifespan of the most sensitive benthic species or the age of biogenic structures or features in a protected area. Where a particular physical habitat required for the re-establishment of key taxa in the community has been deleteriously altered or destroyed by the scientific activity, the anticipated time required for the habitat to return to the state that prevailed prior to that activity provides a measure of recovery potential analogous to longevity.
- Recurrence time (R) is the average expected time between temporally successive sampling events at a given site. Recurrence times are scale dependent and described as the footprint of research activities in a protected area relative to the size of the protected area exposed to these activities.
- The proposed measure of the extent of negative impacts of scientific sampling activities on the valued benthic components is the relative magnitude of the recurrence time interval of the activity compared to the recovery time of the benthic components.
- Recurrence time estimates of the scientific activities in the protected area and the recovery time would be interpreted as follows (guidance to managers):
    - Taxa with lifespans or benthic features with ages that are an less than one-tenth (order of magnitude or approximately 10-fold) of the estimated recurrence times of the benthic impacting science activity are likely to have time to recover to the levels that existed prior to the benthic impact of the sampling activity. For example, some species of sea pens in the Gulf of St. Lawrence and Newfoundland bioregions have shorter life spans and quicker growth rates than other corals, with expected recovery timescales of decades rather than centuries.
    - Taxa with lifespans or benthic features with ages that are greater than one-tenth the estimated recurrence times are susceptible to long-term degradation and lack of recovery. For example, for corals and sponge species and habitats with lifespans extending into 100s and 1000s of years, the recurrence interval of most scientific surveys in Canada may be too short to avoid, with a reasonable chance, long term degradation in a protected area.

The importance of scientific samples from a protected area with respect to the integrity of the historical time series from the scientific survey is case specific.

- For populations for which the protected areas are relatively small compared to the distribution of the populations, and include habitats that are not used or considered very marginal, even at high density, the resulting biases in survey estimates are likely small enough to disregard.
- For populations for which the protected areas constitute a non-negligible portion of their range or for which the areas are disproportionately favored, the biases may be too large to disregard.
- A key consideration is the introduction of a time-varying bias in the time series resulting from the sequential exclusion of surveys from protected areas. Such a bias will occur if the spatial distribution of a stock changes with respect to the protected areas. Spatially non-uniform productivity and distributional shifts resulting from environmental change or density dependence will affect the spatial distribution of a stock. Changes in management measures, including the introduction of protected areas, and ongoing large scale environmental changes are such that distributional shifts are likely for many populations.

A framework that describes the information gathering process for any region of Canada that will assist the review of proposed scientific activities with bottom-contacting gear, for diverse survey histories (e.g. ongoing recurring, new initiatives) and valued benthic components (e.g. corals and sponges, thermal vents, etc.) was developed. The framework does not prescribe decisions to be taken. Rather it is intended to facilitate dialogue between the science survey proponent(s) and the decision-making sector(s).

Operationally, reviews of scientific activities must not be done in isolation and considering only single proposed activities. In some cases, closed areas may overlap more than one administrative region. Coordination of requests at possibly the bioregion scale at which many surveys occur will be required to ensure that the cumulative footprint of all proposed scientific activities on an annual basis is properly considered. In these cases, the timelines for notification, review, and authorization decisions may be much longer than indicated in policies or regulations.

Some of the review associated with authorizations of scientific surveys in closed areas can be done periodically (effects of excluding stations from closed areas, recurrence intervals) whereas other components will require annual inputs (exact locations of sets within a protected area).In line with the objectives of the Government of Canada to protect 10% of coastal and marine areas by 2020 and possibly further targets into the future, the consequences of excluding scientific surveys using bottom-contacting gears to the time series integrity of population, community and ecosystem status indices will need to be periodically revisited.

Marine Protected Areas (MPAs) have their own permitting requirements for proposed scientific activities in these areas. Most of the information gathered for decision-making in protected areas would also be useful in the application for sampling in MPAs.

OTHER CONSIDERATIONS

There are locations within the survey domains of all Canadian multispecies scientific mobile gear surveys that are not sampled because of rough bottom or steep topography. These unfavourable bottom trawling areas may provide longstanding refuge to vulnerable benthic taxa by virtue of their relative inaccessibility to scientific mobile gears currently used (Clark et al. 2016; Link and Demarest 2003).

Survey vessels may have impacts on conservation objectives other than those detailed here. Such impact descriptions, including vessel noise, acoustic data collections, etc., are required for Oceans Management activity permits in MPAs but they are not considered here. Elements of this framework may however be relevant for consideration of authorizations related to impacts other than those originating from bottom-contacting gears.

SOURCES OF INFORMATION

This Science Advisory Report is from the January 16 to 18, 2018 national peer review on the framework to support decisions on authorizing scientific surveys with bottom contact gears in protected areas with defined benthic conservation objectives. 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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APPENDIX

Appendix1. List of invited participants to the national science peer review meeting of January 16 to 18, 2018, on the framework to support decisions on authorizing scientific surveys with bottom-contacting gears in protected areas with defined benthic conservation objectives. The symbol in the column corresponding to the date indicates the presence (« X ») or absence (« A ») or part of the day ("PM") of the participant for that date.

Name	Affiliation	16 Jan.	17 Jan.	18 Jan.
Jacinthe Amyot	DFO Oceans, Pacific	X	X	X
Sean Anderson	DFO Science, Pacific	X	X	X
Hugues Benoît	DFO Science, Quebec	X	X	X
Gérald Chaput	DFO Science, Gulf (co-chair)	X	X	X
Don Clark	DFO Science, Maritimes	X	X	X
Anya Dunham	DFO Science, Pacific	X	X	X
Nicholas Duprey	DFO Science, Ottawa	X	X	X
Evan Edinger	Memorial University	PM	X	X
Geneviève Faille	DFO Science, Quebec	X	X	X
Susanna Fuller	Ecology Action Centre	X	X	X
Beth Hiltz	DFO Fisheries Management, Central and Arctic	X	X	X
Venitia Joseph	DFO Science, Gulf	X	X	X
Ellen Kenchington	DFO Science, Maritimes	X	X	X
Mariano Koen-Alonso	DFO Science, Newfoundland and Labrador	X	X	X
Caroline Longtin	DFO Science, Ottawa	X	X	X
Paul Macnab	DFO Oceans, Maritimes	X	X	X
Andrew Majewski	DFO Science, Central and Arctic	X	X	X
Amy Mar	DFO Fisheries Management, Pacific	X	X	X
Emilie-Pier Maldemay	DFO Oceans, Ottawa	X	X	X
Denise Méthé	DFO Science, Gulf	X	X	X
Andrea Morden	DFO Fisheries Management, Quebec	X	X	X
Liisa Peramaki	DFO Science, Ottawa	X	X	X
Monik Richard	DFO Oceans, Gulf	X	X	X
Rick Rideout	DFO Science, Newfoundland and Labrador	X	X	X
Lisa Setterington	DFO Science, Ottawa (co-chair)	X	X	X
Jason Simms	DFO Fisheries Management, Newfoundland and Labrador	X	X	X
Stephen Snow	DFO Oceans, Newfoundland and Labrador	X	X	X
Doug Swain	DFO Science, Gulf	X	X	X
Diana González Troncoso	Institutot Español de Oceanografia (IEO)	X	X	X
Kris Vascotto	Groundfish Enterprise Allocation Council	X	X	X
Wojciech Walkusz	DFO Science, Central and Arctic	X	X	X
Vonda Wareham	DFO Science, Newfoundland and Labrador	X	X	X

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National Capital Region
Fisheries and Oceans Canada
200 Kent Street Ottawa, ON K1A 0E6

Telephone: 613-990-0293
E-Mail: csas-sccs@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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