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Considerations for the Authorization of Bottom-Contacting Scientific Surveys Within Protected Areas in the Newfoundland and Labrador Region

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Canada is working toward protecting 25% of the country's oceans by 2025, and 30% by 2030 through the creation of a network of protected areas. These areas have been created to guard sensitive benthic taxa and critical fish habitat from anthropogenic activities such as the potential damaging effects of commercial fishing with bottom trawls and other bottom-contacting gears. Fisheries and Oceans Canada (DFO) and its research partners conduct research surveys using (often similar) bottom contacting gears. The footprint of these surveys is magnitudes lower than that of commercial bottom trawl fishing; nevertheless, managers must evaluate the impacts vs. benefits of scientific surveys in relation to these closures in order to determine if the operation of these surveys within the protected areas pose an unacceptable risk relative to the conservation objectives of those areas. Here we summarize research on the potential impacts of bottom-contact fishing in relation to sensitive benthic taxa. Analyses for the various protected areas suggest that the impacts of ongoing research activities that use bottom-contacting gears within the protected areas are minimal and should not hinder the conservation objectives of those closures. While bottom-contacting surveys are valuable for monitoring benthic taxa within protected areas, other less-destructive methodologies are available that could likely collect equal or better-quality data on these species. However, the loss of these survey data within the protected areas would create time-varying bias in general ecosystem indicators and some of the species-specific survey indices used to assess marine resources of commercial and biological interest in the broader ecosystem. The exclusion of oceanographic data collected within protected areas results in small decreases in estimated temperatures that differ among the closures and exclusion scenarios investigated. Mitigation measures that could be applied to lessen the impacts of surveys on protected areas are discussed, though some would be difficult (at best) to apply without compromising existing survey standardized time series and could take several years to evaluate the feasibility of their implementation. This information is presented in support of a DFO Canadian Science Advisory process that took place on October 5–9, 2020. This report and the advisory process do not provide decisions on authorizing survey activities in the protected areas within the Newfoundland and Labrador (NL) Region, rather they provide the background information necessary to support those decisions.

1. INTRODUCTION

In response to international conservation targets, Canada previously set and surpassed a goal of protecting 10% of the country's marine and coastal areas and is currently working toward protecting 25% of the country's oceans by 2025, and 30% by 2030. In the NL Region, a number of closures have been established to protect ecologically sensitive benthic taxa and features, some of which may be easily damaged by and slow to recover from bottom-contacting fishing activities such as bottom trawling. Other closures in the Region aim to protect critical fish habitat.

While these closures were generally implemented with the intent to mitigate potentially harmful commercial and industrial activities, it must be acknowledged that many regularly occurring scientific surveys employed by Fisheries and Oceans Canada (DFO) and its research partners also use bottom-contacting gears, with the potential to have adverse impacts on sensitive benthic areas and therefore could influence the achievement of conservation objectives. On the other hand, these science surveys played an important role in identifying the sensitive benthic areas being protected and may be valuable for monitoring closure success going forward. Furthermore, they also collect data that are absolutely critical in determining population status and trends for commercial and non-commercial species in the broader ecosystem and underpin Canada's sustainable management of its fisheries (Benoît et al. 2020b). Managers tasked with making decisions as to whether or not to permit scientific activities within protected areas will therefore need to evaluate not only the potential impacts of the survey bottom-contacting gear, but also the potential consequences that not allowing surveys to operate within these areas could have on the provision of science advice for aquatic resources in the broader ecosystem context.

DFO has implemented spatial closures in the NL Region under two pieces of Canadian legislation. Closures under the *Oceans Act* are referred to as Marine Protected Areas (MPAs) and are the responsibility of DFO's Marine Planning and Conservation Branch. Closures under the *Fisheries Act* are referred to as Marine Refuges (MRs) and are the responsibility of DFO's Resource Management and Indigenous Fisheries Branch. In 2019, the Government of Canada adopted new national protection standards for MPAs and MRs. In MPAs, these standards prohibit four industrial activities: oil and gas, mining, dumping, and mobile bottom trawling. In MRs, DFO will use a risk-based approach for prohibiting or limiting activities, which will be assessed on a case-by-case basis. In both types of areas, some activities may be allowed if they are consistent with the conservation objectives of the area. For example, proposed scientific activities will be assessed by regional managers based on the risk posed to the conservation objectives and will require approval of an Activity Plan, which outlines the sampling methods, impacts to the area, and mitigation strategies.

DFO has produced a National Framework to guide the evaluation of ongoing recurrent scientific activities (surveys) within protected areas (DFO 2018; Benoît et al. 2020b) and this framework is now being used to help develop science advice to support decisions regarding the operation of scientific surveys within specific regions/closures (DFO 2020a; Benoît et al. 2020a). Here we apply aspects of the framework to examine closures in the NL Region in an effort to provide managers with the advice they need to make fully informed decisions about ongoing research activities in relation to closures in this Region.

In addition to the MPAs and MRs within Canadian waters, numerous closures to protect Vulnerable Marine Ecosystems (VMEs) have been established outside Canada's Exclusive Economic Zone (EEZ) on the nose and tail of the Grand Bank (Figure 1). These closures fall under the jurisdiction of the Northwest Atlantic Fisheries Organization (NAFO), of which Canada is a contracting party. Many of the marine resources (e.g., fish stocks) that Canada is responsible for managing extend into these closed areas, and vice versa, with some NAFO-managed stocks having distributions that overlap with closures inside the Canadian EEZ. It is also important to note that three of the surveys examined here (i.e., the Canadian-NL spring and fall Research Vessel [RV] multispecies bottom trawl surveys, the collaborative post-season snow crab trap survey) extend outside the Canadian EEZ and, in the case of the bottom trawl surveys, their survey footprints overlap with both Canadian and NAFO closures. Any examination of potential survey impacts and consequences for excluding surveys from protected areas in the NL Region should therefore include both Canadian and NAFO closures. Here we consider that regulatory differences between the closures established to protect sensitive benthic taxa inside and outside the Canadian EEZ are secondary to the objective of the closure. We therefore include Canadian MPAs and MRs, as well as NAFO VME closures, in our analyses and refer to them collectively as 'protected areas.'

1.1. PROTECTED AREAS IN THE NL REGION

Only protected areas in the NL Region that overlap with one of the regularly occurring bottom-contacting scientific surveys (see below) are discussed in this report. This includes 1 MPA and 4 MRs established by DFO, as well as 4 NAFO closures (Figure 1; Table 1). Other protected areas exist in the Region that are more coastal in nature, but these do not overlap with the surveys analysed here.

The Laurentian Channel MPA (Figure 1) is located off the southwest coast of the island of Newfoundland and is approximately 11,580 km^2. It was officially designated as a MPA in April 2019. The MPA protects significant concentrations of sea pens and also has conservation objectives related to Black Dogfish, Smooth Skate, Porbeagle sharks, Northern Wolffish, and Leatherback Sea Turtles. The Laurentian Channel MPA regulations prohibit activities that disturb, damage, destroy or remove living marine organisms or any part of their habitat, unless approved by the Minister upon review of an Activity Plan. The MPA includes the seabed, the subsoil to a depth of five metres, and the water column above the seabed.

In 2017, four MRs were established off the coast of NL (Figure 1). The Hopedale Saddle Closure (15,411 km^2) in NAFO Div. 2H and the Northeast Newfoundland Slope Closure (55,353 km^2) in NAFO Divs. 3KL were created to protect large and small gorgonian corals, sponges, and other benthic taxa, fish and shellfish (Table 1). All bottom-contacting commercial fishing activities are prohibited in these areas. The Hawke Channel Closure (8,837 km^2) in Div. 2J and the Funk Island Deep Closure (7,274 km^2) in Div. 3K were established to protect benthic habitat and Atlantic cod. The use of bottom trawls, gillnets, and longlines are prohibited in these areas.

Many of the protected areas in the NL Region have been established (in part) to protect coral and sponge aggregations that were identified by DFO Science in support of the Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas. Significant Benthic Areas (SiBAs) (different from Sensitive Benthic Areas, which are areas defined based on their exposure to proposed or ongoing fishing activities) have been identified and delineated throughout the NL Region at the functional group level (small and large gorgonians, sea pens, and sponges) and represent areas where dense aggregations of these groups occur (Kenchington et al. 2016a; Figure 2).

In 2009, the Food and Agriculture Organization (FAO) defined the term VMEs and developed criteria to be used to identify these areas (FAO 2009). Examples were provided of species groups that may contribute to forming VMEs and these included various types of cold water corals and sponges. This work eventually led to the eventual delineation of 30 VME habitats in the Northwest Atlantic (Figure 2), which are equivalent to Canada's SiBAs. 21 of these areas were subsequently closed to bottom-contact fishing gear in the NAFO Regulatory Area (NRA; Figure 1). The NAFO VME closures include areas to protect seamounts, as well as areas with coral (including sea pens) and sponge concentrations. Seamounts are not included in our analyses since the science surveys discussed here do not cover those areas. Likewise, NAFO VME closures on the Flemish Cap (NAFO Div. 3M) that protect corals and sponges are not included here since they are not overlapped by any ongoing recurrent Canadian survey.

In total, four NAFO VME closures were included in our analyses. The 3O Coral Closure (13,999 km²) was established January 1, 2008. This transboundary closure is located partially in the NRA and partially within the Canadian EEZ. In 2017 the portion of the closure within the Canadian EEZ (10,422 km^2) was also designated as a MR by Canada. The other three NAFO closures, the Tail of the Bank Closure (144 km²), the Flemish Pass/Eastern Canyon Closure (5,417 km²) and the Sackville Spur Closure (988 km²) came into effect January 1, 2010 and are entirely within the NRA (Figure 1).

1.2. BOTTOM-CONTACTING SCIENTIFIC SURVEYS IN THE NL REGION

There are five recurring surveys employing bottom-contacting gears that occur in one or more of the protected areas in the NL Region (Table 2). While other recurring scientific surveys take place in the region, they are not included here because they either do not use bottom-contacting gear or do not overlap with any of the protected areas being considered.

1.2.1. Fall Multispecies Bottom Trawl Survey

The Fall RV survey started in 1977 with coverage of Div. 2J and expanded to include Div. 3K in 1978 and Div. 3L in 1981. The southern Grand Bank (Divs. 3NO) was added to the survey in 1990. Div. 2H was covered sporadically in the early 2000s and became part of the annual survey in 2011. The current design includes coverage of Divs. 2HJ3KLNO, an area greater than 500,000 km^2. The survey has been subject to many intentional (e.g., Divs. 2G and 3M, which were sporadically covered, are no longer included in the current survey design) and unintentional (i.e., mechanical, weather-related issues) changes in spatial coverage over the years (Rideout and Ings 2020).

The survey uses a stratified random design, with the current design calling for 674 fishing sets allocated across 211 strata (Figure 3) and the survey usually occurs between September and December. This is typically a two-vessel survey and in recent years those vessels have been the CCGS *Teleost* and the CCGS *Alfred Needler*. Multiple gear changes have also taken place over the survey time series, with the most recent change taking place in 1995. The current trawl deployed in these surveys is the 1800 Campelen shrimp trawl with Rockhopper footgear and a 12.7 mm codend mesh liner. This is a four-panel trawl with a stretched mesh circumference of 72 m at the fishing circle with large side panels extending from ahead of the footgear back to the end of the 2nd belly. The upper and lower bridles are 40 m long (McCallum and Walsh 1996). This trawl is towed at a speed of 3.0 knots for 15 minutes during all Spring and Fall RV surveys.

Gear conversion factors (to convert biomass data collected prior to 1995 using Engel gear to Campelen equivalents) do not exist for all species, and therefore only the Campelen time series was analyzed here. The multispecies survey provides information on species distribution, biomass, and abundance for various groundfish, shellfish and other invertebrate species, as well as other biological (e.g., growth rates, maturation schedules, diet, etc.) and physical (e.g., bottom temperature and salinity) information.

1.2.2. Spring Multispecies Bottom Trawl Survey

The Spring RV survey started in 1971 in Divs. 3LNO and expanded to include Subdiv. 3Ps in 1973. The current survey design covers Divs. 3LNOPs (Figure 3), an area greater than 320,000 km^2. The survey employs a stratified random design with the same stratification scheme as the fall survey. The spring survey covers 129 strata with a planned 478 fishing sets. This survey typically takes place between April and June and is generally a single vessel survey, unless unexpected mechanical or vessel issues force the need for a second vessel (Rideout and Ings 2020). The switch to the Campelen trawl occurred in 1996 for the spring survey.

1.2.3. Unit 2 Redfish Survey

The Unit 2 Redfish survey is an industry-lead survey conducted since the late 1990s and is coordinated by the Atlantic Groundfish Council under section 10 of the *Fisheries Act* through a Collaborative Agreement with DFO. This is the only survey that covers the entirety of the Unit 2 redfish management area (Figure 4) and is generally conducted in late August and early September. While the vessels used for the survey have changed over time, surveys conducted after 2011 have relied on <65' mobile gear vessels. The survey is conducted once every two years and employs 10–15 minute hauls using a modified Campelen 1800 shrimp net with a wingspread of 15–17 m, Thyborun rectangular doors and single rockhopper disks. While the target level of effort is 140 sets across 36 strata, more recent surveys have focused on 120 survey sets to ensure timely completion. Sets are randomly distributed within each stratum, with effort proportionately weighted to the area of each strata (with a minimum effort of 2 sets per stratum). In the 2020 survey, a hydroacoustic component was added to begin investigating less-invasive sampling techniques that could potentially be used in protected areas closed to bottom-contacting gears.

1.2.4. Collaborative Post-Season (CPS) Trap Survey

The CPS Snow crab trap surveys (Figure 5) were initiated in 2003 and have occurred each year following the fishery, typically beginning in early September, and ending in November. They are conducted by Snow Crab harvesters accompanied by at-sea observers and focus on commercial (i.e., deep) fishing grounds within individual Crab Management Areas (CMAs). Survey stations are fixed and generally follow a grid pattern, with a maximum station spacing of 10'x10' (nautical miles). At each station, six (inshore) or ten (offshore) commercial (133–140 mm mesh) baited traps are set together, evenly spaced along a rope. This is referred to as a fleet. Since 2016 there has been an expansion of small mesh traps used in the survey and as of 2020 84% of the stations included one small mesh trap. If a small mesh trap is in use at a station, the fleet would then consist of seven traps (inshore) or 11 traps (offshore). Biological sampling of male crab is conducted by observers at-sea from a single large-mesh trap at each station. Sampling includes determination of carapace width, shell condition (soft, new, old), leg loss, and presence of Bitter Crab Disease (BCD). The CPS survey has been transitioning to a partly random stratified design since 2016. In 2019, approximately 50% of survey stations were random while 50% remained fixed (systematically chosen from existing core stations). The changes were invoked to increase both vertical and horizontal coverage in areas beyond prime commercial fishing grounds toward encompassing a more representative depiction of all population components into the assessment. The definition of core stations was established in 2018 to account for changing distribution in occupied sets over time. The definition of core stations was selected as those sampled in seven of the last 10 years, as of 2019. The stratification scheme used for biomass estimation for this survey closely conforms to the footprint of the fishery and by extension the assumed distribution of dense aggregations of exploitable crab within CMA boundaries (Figure 5). Until a longer time series for the random stations is established, only data from stations within the core strata are used for biomass estimation.

1.2.5. Longline Halibut Survey

The Longline Halibut Survey is run collaboratively by industry and DFO-Maritimes Region and was started as a fixed station survey in 1998 on the Scotian Shelf and the Southern Grand Banks (NAFO Divs. 3NOPs4VWX5Zc). In 2017, a new stratified random halibut survey was initiated that included survey areas in depths not well sampled under the fixed survey design. A subset of the fixed stations (100) continued to be sampled after 2017 to allow for calibration with the new survey design and to provide advice for the Atlantic Halibut stock assessments, however, those stations will be phased out in the next year or two (DFO 2020b). Since the fixed station survey will not be carried into the future, four years of data (2017–20) from the stratified random survey were included in the analysis for proportion of impact and recurrence time intervals as the survey strata overlap with the Laurentian Channel MPA, the 3O Coral closure as well as the two MPAs from the Maritimes Region, St. Anns Bank and the Gully. A standard set for the survey is a 5.5 km longline with 1,000 hooks.

2. POTENTIAL SIGNIFICANT ADVERSE IMPACTS OF SCIENTIFIC SURVEYS ON CONSERVATION OBJECTIVES OF PROTECTED AREAS

2.1. REVIEW OF SIGNIFICANT ADVERSE IMPACTS DUE TO BOTTOM CONTACT GEAR ON BENTHIC HABITAT

2.1.1. Vulnerability and Role of Benthic Taxa

Concerns regarding the potential impacts of bottom contact gear on benthic communities were first raised by The International Council for the Exploration of the Sea (ICES) in 1970 (Jones 1992) and since then, there has been extensive scientific evidence on the severity and longevity of bottom contact gear impacts globally (see Jones 1992; Gilkinson et al. 2006; Ragnarsson et al. 2016; Clark et al. 2016; 2019). Bottom contact gear can damage benthic communities in several ways, through the removal of key species, damaging or tipping of others, and can lead to indirect effects such as smothering of organisms (Trannum et al. 2010; Larsson and Purser 2011) and smoothing of the seascape (Puig et al. 2012; Paradis et al. 2017). Impacts can vary depending on bottom type and the species composition of the area being impacted. Areas such as VMEs, which contain species with a high degree of structural complexity (e.g., large branching corals, *Geodia* sponge complexes) are particularly vulnerable to bottom contact gear, primarily on the initial pass (Freiwald et al. 2004; Watling and Norse 1998; Neves et al. 2015b).

When physically impacted by bottom contact gear, organisms that live attached to hard substrate (e.g., large gorgonians, soft corals) will likely be tipped or overturned, and not able to re-position themselves, likely decreasing in health or perishing on the seafloor. Some sea pen species can upright themselves once dislodged, since they live anchored in soft sediment through a muscular peduncle (Williams 1995). This capacity to uproot themselves has only been documented in a few species including *Funiculina quandrangularis* and *Pennatula phosphorea* (Eno et al. 2001) and *Halipteris willemoesi* (Malecha and Stone 2009). In the Gulf Region, the sea pen *Pennatula aculeata* has been considered “much less catchable and possibly less susceptible to injury” to Campelen trawling than other sea pen species in the region due to their ability to withdraw into the substrate and/or a potential to uproot themselves (Benoît et al. 2020a). However, bycatch rates of *P. aculeata* in the NL Region are still some of the highest among sea pens. In at least six instances between 2015–18 (in Divs. 3O and 3P), the abundance of *P. aculeata* colonies caught in RV surveys was >100 colonies (as reported in the catch data), with two instances of catches of 700–800 colonies per set (V. Wareham-Hayes, unpublished data). This does not include large catches where only biomass was reported. In one instance, a bycatch of 10.6 kg of this species was recorded, but no abundance data were associated to the record. The catch of 880 colonies had a weight of 1.8 kg. Therefore, despite catchability issues, these sea pens are still vulnerable to Campelen gear and large amounts can be removed from their populations through trawling. Furthermore, for sea pens, the possibility to uproot themselves after physical disturbance does not come without constraints. Dislodged *F. quandrangularis* colonies took six days to return to an erect position (Eno et al. 2001), while only 50% of dislodged *H. willemoesi* were able to recover. Colonies of the latter with fractured skeletons (i.e., internal axis) did not survive, and dislodged colonies experienced higher levels of predation (Malecha and Stone 2009). Additionally, once damaged or injured, corals can become more susceptible to parasitic species (e.g., *Paramuricea* sp.; Bavestrello et al. 1997), and impacts can affect their distribution and health (e.g., Baker et al. 2019).

Cold-water coral and sponge recovery times from disturbance are not well understood yet. However, there is evidence of high longevity and slow growth rates for certain species, which can indicate recovery times that exceed decades. Sea pen longevities can range between 10–80 years (Wilson et al. 2002; Neves et al. 2015b; Neves et al. 2018; Murillo et al. 2018), while some large gorgonians can be 100 years in age or more (Mortensen and Buhl-Mortensen 2005; Sherwood and Edinger 2009). Calculations of sea pen VME recovery time based on biomass data and commercial fishing effort for the NRA indicated an average recovery time of 10.1 years to sustain 50% of sea pen biomass (NAFO 2016). These numbers are comparable to estimates of longevity for some sea pens (i.e., decades, Neves et al. 2015b; Murillo et al. 2018).

Information on sponge longevity and growth rates are even less common than for corals, as they do not lay down growth rings/bands like corals (e.g., Sherwood et al. 2005; Neves et al. 2015b; Neves et al. 2018). Kahn et al. (2016) found that glass sponges with small-scale mechanical damage can recover within one year, but that larger-scale impacts (1.5x2 m^2; crushed sponges) showed no signs of recovery after three years. Grant et al. (2018) documented sponge ‘coughing’ arrests (restricting the flow of water through their body) that were correlated with increased suspended sediment concentrations (SSCs) from tidal flow, which are below known SSCs generated by bottom contact gear such as trawls. During ‘arrest’ periods sponges were no longer feeding. Grant et al. (2018) examined the impacts of SSCs on glass sponge reefs in Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs MPA. The tolerance thresholds that triggered arrests varied between the three sponge species, from minor response to arrests lasting several hours. Furthermore, modeling of sediment transport indicates that sponges found as far as 2.6 km from the source plume can be affected, highlighting the potential impacts of non-mechanical damage associated with trawling. In some cases, there is no evidence of recovery several years after the fact. For example, video observations of a 1998 trawl path in SE Baffin Bay showed no visible signs of recovery of a bamboo coral population (*Keratoisis flexibilus*, published as *Keratoisis* sp.), with coral fragments still spread on the seafloor and no evidence of new growth in those areas (Neves et al. 2015a). These observations corroborate slow growth rates for bamboo corals in the region (e.g., Sherwood and Edinger 2009). Piston core samples taken at the site indicate that this bamboo coral community has been continuously occupying the area for at least 2,000 years (Edinger et al. 2017).

Corals and sponges can have a diverse array of associations with other organisms; hence removal of these key species by bottom contact gear means further habitat loss for fish (Baillon et al. 2012; Kenchington et al. 2013; Moore et al. 2008), invertebrates (Klitgaard 1995; Henry

2001; Buhl-Mortensen and Mortensen 2004; De Clippele et al. 2015; Maldonado et al. 2017; Neves et al. 2020; Wareham-Hayes et al. 2017), and even microbial communities (Kennedy et al. 2014; Kellogg et al. 2016; Verhoeven et al. 2016; Verhoeven and Dufour 2018). One of the key ecosystem functions of deep-sea sponges is also the provision of habitat for other species (Ribeiro et al. 2003; Fuller et al. 2008) and increasing surrounding biodiversity (Hawkes et al. 2019). In fact, Desmosponges have been shown to host such a diverse array of invertebrates (Buhl-Mortensen et al. 2010; Maldonado et al. 2017) that they have been referred to as 'veritable living hotels' (Klitgaard 1995). Sponges can provide an added level of habitat complexity, through the small inner pores and channels within each sponge. These small spaces can provide protective cover for eggs and juveniles from other invertebrate and fish species. For example, observations of eggs of the squid *Rossia* sp. at various stages of development have been frequently documented inside sponge cavities (Mercer 1968) or within the fibrous framework of sponges (Aldrich and Lu 1968; Wareham-Hayes et al. 2017). *Rossia* spp. squids play an important role as a prey species in Arctic food webs (Golikov et al. 2019).

2.1.2. Significant Adverse Impacts

Significant adverse impacts (SAI) are those that "compromise the ecosystem integrity (structure and function), i.e., impairs the ability of populations to replace themselves, degrades the long-term natural productivity of the habitat, or causes significant loss of species richness, habitat or community type on more than a temporary basis" (FAO 2009; 2016). A full assessment of SAI takes six factors into consideration:

1. intensity or severity of the impact,
2. spatial extent of the impact,
3. sensitivity/vulnerability of the ecosystem,
4. ability of an ecosystem to recover,
5. extent to which ecosystem functions may be altered and
6. timing and duration of the impact (FAO 2009).

NAFO's Working Group on Ecosystem Science Assessment (WGESA) has developed an approach for the assessment of SAI from bottom-contact commercial fisheries on VMEs in the NAFO Regulatory Area (NRA), using a combination of scientific survey and fishing VMS (Vessel Monitoring System) data. From the analysis of the first factor (i.e., intensity or severity of the impact), sea pens were considered vulnerable, while sponges and gorgonians were considered extremely vulnerable. However, when the analysis considered other factors (i.e., spatial extent of the impact - including an index of VME sensitivity) sponge grounds and gorgonian VMEs were rated as low overall risk, while sea pens were rated as at high risk (Durán-Muñoz et al. 2020). The combination of population level effects and low survival for sea pens results in a relatively high risk of SAI (Kenchington et al. 2011). It is important to emphasize that sea pens (and small gorgonians such as *Acanella arbuscul*a) live primarily associated with soft substrate, which has a higher likelihood of being trawled than rocky/mixed bottoms, where large gorgonians and sponges are mostly found (Wareham and Edinger 2007; Edinger et al. 2011; V. Wareham-Hayes, unpublished data). SAI assessments at the functional group level (i.e., large gorgonians, sea pens) might also hide the potential for inter-specific variation. For instance, Benoît et al. (2020a) considered that the sea pen *P. aculeata* is likely to be more resilient to trawling than other sea pens found in the Gulf Region (i.e., *Anthoptilum grandiflorum*, *Halipteris finmarchica*, and *Pennatula grandis*).

SAI from scientific surveys (i.e., RV surveys) on corals and sponges have not been assessed in the NL Region, and these cannot be easily disentangled from the impacts of commercial fishing, which were a significant source of bottom impact before these areas were closed (Kulka and Pitcher 2002; Edinger et al. 2007). High fractions of the SiBAs in the NL Region have been exposed to varied fishing activities, where 20 and 25% of the footprint of offshore fisheries overlaps with large gorgonian and sea pen SiBAs, respectively (Koen-Alonso et al. 2018). Nevertheless, we examined the overlap between DFO-NL RV survey sets and SiBAs (large gorgonians, small gorgonians, sponges, and sea pens) inside of closed areas between 1995–2019, to identify how often RV sets fall inside these special areas within closed areas.

The data examined include RV sets (start positions) completed between 1995–2019 encompassing NAFO zones 2HJ3KLNOP, for a total of 28,445 sets (Table 3). For this period, a total of 2,035 sets fell within NL protected areas (Table 3). Of the number of sets falling within a given protected area, the proportion of those sets that also fell within a SiBA ranged between 0.3 and 74% (Table 3). In the 3O Coral and Sponge Conservation closure, 51% and 29% of the sets fell within a Small gorgonian or Sponge SiBA, respectively. In the Funk Island closure only one set intersected a sponge SiBA adjacent to the protected area (mostly outside), and in the Hawke Channel closure, no SiBAs have been identified (Table 3). In the Hopedale Saddle closure, 49% and 40% of the RV sets fell inside a Sponge or Large gorgonian SiBA, respectively, with only a small proportion of sets falling inside a Sea pen or Small gorgonian SiBA (0.3% each, Table 3). In the Laurentian Channel MPA, 61% of sets fell inside a Sea pen SiBA and no other SiBAs have been identified in this MPA (Table 3). In the Northeast Newfoundland Slope closure, 74% of sets fell inside a Sea pen SiBA, and 29% in a Sponge SiBA (Table 3).

The high overlap between RV survey sets and SiBAs in some areas is not surprising, as these surveys formed the basis for the modelling work resulting in the identification and delimitation of these special areas (e.g., Kenchington et al. 2016a; 2016b). Nevertheless, the numbers help to reinforce that RV surveys often occur in areas of significant concentrations of corals and/or sponges (Table 3). In some cases, RV strata fall completely within a protected area, which means that sets for these strata cannot be relocated to an alternate position outside of the closed area.

Examination of catch weights and abundance can also provide a picture of the amount of coral and/or sponge being removed during RV surveys. Although coral and sponge biomass is recorded at sea for every successful set, coral and sponge abundances are not always recorded, especially for large catches, where a subsample is taken, and total abundance is extrapolated based on wet weight. Yet, at several instances the RV dataset contains records of high numbers of sea pens in a set. Sea pens are usually found less damaged than gorgonians, which are more brittle, so determining their abundance tends to be more straightforward. Between 2006–19, 47 sets contained records of >100 sea pens per set. Of these, five sets contained >500 sea pens per set (3O, 3P). These numbers are not negligible and, as indicated by Kenchington et al. (2011), removal of this amount of sea pens can indeed cause population-level impacts. Abundance data can be even more challenging to determine for sponges because specimens are rarely intact (often fragmented) (e.g., Jørgensen et al. 2016), thus documented catch weights are conservative estimates of the actual impact.

2.2. COMPARING THE FOOTPRINT OF BOTTOM-TRAWL SURVEYS TO COMMERCIAL FISHING

It is difficult to get an accurate comparison of swept area for the NL Regions bottom-contacting scientific surveys versus the swept area of bottom-contacting commercial fishing gear, however, an initial analysis of just one commercial fishing gear type using satellite data offers a glimpse at the magnitude of difference in scale between the two. VMS data was used to estimate fishing activity for one mobile groundfish trawl gear type (bottom otter trawl [stern]) in the NL commercial fishery. Tracks were created using the once hourly ‘pings’ a given fishing vessel transmits (unpublished data) and ‘fishing’ vs ‘steaming’ time was separated based on predictable fishing speeds (Koen-Alonso et al. 2018). The fishing pings were converted to linear tracks using a cubic Hermite spline (cHs) method (Hintzen et al. 2010). This method offers a more realistic way to map fishing trajectories based on the speed and heading parameters associated with each ping. These fishing tracks for the years 2005–14 were compared to the RV survey tracks created by using the start and end coordinates for each set and a mean door spread of 50 m. Similarly, tracks were created for the Unit 2 Redfish survey using available start and end coordinates and mean door spread of 48 m. Depending on the target species for the commercial fishery and the size of the vessel, mean door spread can range from 10’s to 100’s of meters wide (Amoroso et al. 2018). Door spread was used for the width of the swept area as the doors and bridle come into contact with the bottom. The primary function of the doors and bridle are to provide spread for the trawl gear (hydrodynamic and ground shear force) and to help herd fish into the mouth of the net (Løkkeborg 2005; He 2007; 2015). RV survey tracks were limited to 2005–14 to make the data comparable and all tracks were clipped to the boundary of each protected area and total area (km^2) for each was calculated (Table 4).

These data show a clear difference in the scale of bottom-contact impact between the RV survey and commercial fishing, even just for a single mobile fishing gear type. The largest swept area in a single protected area for the RV survey and Unit 2 Redfish survey were 17.71 km^2 and 8.452 km^2 respectively in the Laurentian Channel MPA, whereas for the commercial bottom trawl it was approximately 712 km^2 in the Northeast Newfoundland Slope closure. Several factors need to be taken into consideration when comparing these data. First, these VMS tracks for a single gear type only represent a fraction of the overall commercial fishing footprint. VMS data is not necessarily available for all vessels and must be linked to actual logbook records in order to be used for this purpose; therefore, these tracks do not represent all the actual fishing for that gear during the years specified. Furthermore, based on vessel-days, only 1.3% of all the commercial fishing effort in the NL Region is attributed to the groundfish mobile fishery and 98.5% of that is georeferenced (Koen-Alonso et al. 2018). Secondly, since VMS pings are only recorded every hour, any fishing activity with a duration of less than an hour would be missed using this method. Another consideration is that this particular gear type appears to be aggregated to certain areas where the targeted groundfish species are found (e.g., along the edge of the continental shelf) whereas other gear types may introduce more effort on the mid-shelf or nearshore areas. This is evident when looking at the areas contacted in the Funk Island Deep and Hawke Channel closures (0 km^2 and 4.27 km^2 respectively), however, these two fisheries closures were established from 2002–05 and so commercial fishing was restricted during the time period investigated here.

2.3. CALCULATION OF PROPORTION OF AREAS IMPACTED AND RECURRENCE TIME INTERVAL FOR SCIENTIFIC SURVEYS

2.3.1. Proportion of Impact and Recurrence Time Interval

In order to determine the scale of potential significant adverse impacts of bottom-contacting scientific surveys on the seabed, the proportion of impact for each protected area must be assessed. Each survey covers different areas of the Region therefore, some protected areas may only be impacted by one of the surveys described here but others may be impacted by multiple surveys. Using guidance from the national framework document (DFO 2018), the proportion of impact and recurrence intervals, as described below, were calculated for each protected area, by survey, as well as the cumulative values for multiple surveys, where applicable.

Proportion of impact is defined as the average proportion, per year, of the bottom of the protected area which would be impacted by the bottom-contacting scientific gear in random or stratified-random surveys over all strata (K: with K=1 for a random survey) for all surveys (S) and is calculated as:

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

where

- $\overline{swept\ area}_s$ is the average swept area (km^2) for a sample in survey *s*,
- $freq_s$ is the annual frequency (1 for annual, 0.5 for biennial, etc.) of survey *s*,
- $sampling\ intensity_{s,k}$, is the average number of sampling stations per km^2 within stratum *k* for survey *s*,
- $protected\ area\ size_{s,k}$, is the amount of the protected area contained in stratum *k* (km^2) for survey *s*,
- and the denominator is the total size of the protected area (km^2) (DFO 2018).

In the case of a fixed station survey, ideally, impacts would be constant in time and equal to the sum of the swept areas for all tows in the area, divided by the total area of the closure.

The recurrence time interval (R) is defined as the average time (years) between successive benthic sampling impacts at a given site, and where the entire protected area is covered by a survey, the inverse of the proportion of impact is used.

$$R = \frac{1}{Prop.Impact} \quad (2)$$

When a survey only partially covers a protected area, the national framework (DFO 2018) recommends that the recurrence time interval be calculated for just that proportion of overlap as follows:

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

where the *proportion protected area overlapped* is the area of the survey strata that fall into the protected area divided by the total size of the protected area. When calculating the overall recurrence time intervals for multiple surveys the proportion of protected area overlapped is calculated from a merged polygon of strata for all surveys together.

2.3.1.1. Multispecies RV Survey

Some protected areas are sampled in both the spring and fall multispecies RV surveys while others are only sampled in one survey and not the other. For protected areas that are sampled by both surveys, the analyses were combined to get an overall proportion of impact and recurrence interval for the two RV surveys (i.e., spring and fall combined).

Only sets from the Campelen time series (1995–2019) were used for these analyses, and since that gear type was first introduced in the fall of 1995, the spring Campelen series starts in 1996, giving 25 and 24 years of data, respectively. All sets were included (successful and unsuccessful) and any historical sets in NAFO Div. 3M were removed since the RV survey no longer operates there. The gear used is a Campelen 1800 shrimp trawl with a standard tow distance of 1.48 km and mean door spread of 50 m (McCallum and Walsh 1996). Based on that, the mean swept area for each haul is 0.074 km^2.

2.3.1.2. Unit 2 Redfish Survey

The industry-led Unit 2 Redfish survey is designed as a random-stratified survey using a modified Campelen trawl, like that used in the DFO multispecies RV surveys. It covers multiple DFO Regions including Newfoundland and Labrador, Maritimes, Gulf, and Quebec, however, at the time that these analyses were performed there was no accessible complete version of the survey strata spatial polygons. Instead, a combination of strata from the NL multispecies survey, one stratum (496) from the Maritimes Region Ecosystem Assessment Strata, and strata 415–417 from the Northern Gulf of St. Lawrence were used (Figure 4). These strata intersected with the protected areas of interest for the Redfish survey and were merged from each of the regions to allow for the calculation of the proportion of each protected area impacted by the survey ($year^{-1}$). The same calculations that were used for the DFO multispecies survey were applied to the Redfish survey as they are both random stratified survey designs. A mean swept area of 0.0667 km^2 was calculated based on a recommendation from Benoît et al. (2020b) that trawl door spread can be estimated using a ratio of 3 of the wingspread (15–17 m), and a standard tow distance of 0.75 nm (1.389 km). Two additional MPAs from the Maritimes Region (St. Anns Bank and the Gully) were included in these analyses since there were a few sets that fell within their boundaries.

2.3.1.3. Collaborative Post-season (CPS) Trap Survey

The gear set-up for the Snow Crab survey varies by area and changes based on the mesh size of the crab trap. Fleets of 6 traps are used in inshore areas, with a fleet of 7 traps if a small mesh trap is added. Fleets of 10 traps are used in offshore areas, with a fleet of 11 traps if a small mesh trap is added. This survey is transitioning to include a small mesh trap on every station as was mentioned above. The harvester instructions dictate that traps are to be spaced at 25 fathom intervals along the string and that a standard 20 lbs weight be affixed to both down-ropes of each fleet with the weights located 15 fathoms from the end trap.

In order to get an estimate of swept area for the sets in the protected areas of interest, the mean number of traps per station was calculated using only stations within the boundaries of the protected areas. An average of 10 traps in a fleet at intervals of 25 fathoms with a weighted head and tail rope of 15 fathoms length was used. As the survey is moving towards including small-mesh traps, the offshore stations will eventually all have 11 traps but for now this is the best estimate of potential bottom area impacted. Following a recommendation from the national framework (Benoît et al. 2020b), a more precise estimation of the swept area for pot and trap gear based on Doherty et al. (2018) was used to calculate the footprint of the snow crab survey. The conical traps used for the survey have a diameter of 1.3 m giving a total static footprint of 1.33 m^2. The swept area for the entire fleet is then assumed to be 36 times the static footprint of a single trap multiplied by 10 for the mean number of traps in a fleet. The estimated mean swept area for a single station is 0.0004788 km^2.

Due to limitations in the survey dataset, it was difficult to determine which stations were part of the fixed or random survey design, so for the purposes of these calculations, only stations that fell within the boundaries of the protected areas were included. Based on the formula for proportion of impact above (Equation 1), the sampling intensity was calculated as the mean number of stations (sets) per survey (*s*). The formula was adjusted as follows:

$$Prop.Impact = \frac{\sum_{s}^{S} \overline{swept\ area}_s * \ freq_s \sum_{k}^{K} mean\ number\ of\ sets_{s,k}}{protected\ area\ size} \quad (4)$$

where the *mean number of sets*$_{s,k}$ replaces the *sampling intensity*$_{s,k}$ and the *protected area size*$_{s,k}$. For random stratified surveys, such as the spring and fall multispecies RV surveys, sampling intensity is calculated per strata, divided by area of strata to get the number of sets per km^2, and then multiplied by the area of that strata that falls within the protected area boundary. For the crab survey, rather than assuming all stations in a strata are random, which we know they are not, we are only taking the actual density of the stations that fall into the proportion of the strata within the protected area to avoid some of the variability in spatial distribution seen in larger strata or those that appear to contain several fixed sampling stations.

2.3.1.4. Longline Halibut Survey

The calculations for the Longline Halibut Survey were approached the same as for the RV surveys and the Redfish survey. The swept area for this survey is unknown and so an estimated value was calculated using a recommendation from the national framework, gear length multiplied by 0.1 km assumed lateral sweep (DFO 2018). Based on the data collected in the four years of the survey thus far, a mean gear length of 5.1 km was used giving a mean swept area of 0.51 km^2. In comparison to the swept areas for other gears considered here this seems relatively high (refer to Table 2), however, without further investigation into the actual area contacted by the longlines from deployment to retrieval time, this is the best available information.

2.3.2. Summary of Analyses

2.3.2.1. Multispecies RV Surveys

The two multispecies RV surveys have a combined average of 1,161 sets per year with more sets occurring during the fall survey (~691 sets/year) than in the spring survey (~479 sets/year; Table 2). With a mean swept area of 0.074 km^2 per set, the mean total area of bottom contacted by the survey gear is 35.44 km^2 per year for the spring survey and 51.13 km^2 for the fall. The proportion of area in each protected area impacted by the bottom-contacting gear was calculated for each of the two surveys (Table 5) and combined to get an overall value for the fall and spring RV surveys (year^{-1}). The spring survey only impacted the Laurentian Channel MPA, the 3O Coral Closure and a portion of the Northeast Newfoundland Slope Closure (NAFO Div. 3L). The values for proportion of impact should be interpreted as the average annual proportion of each protected area that is contacted by the survey gear. The recurrence time interval is then interpreted as the number of years it would take for a given location, within the proportion of protected area surveyed (e.g., overlapping strata containing sets), to be sampled again. Of all the protected areas, the Laurentian Channel MPA had the highest proportion of area impacted by the overall RV survey (0.000173 year^{-1}) and the lowest recurrence time interval (5,717 years; Table 5). The Hopedale Saddle closure had the second lowest recurrence interval at 6,705 years. The Sackville Spur NAFO closure had the smallest proportion of impact (0.000003 year^{-1}), however, the highest recurrence interval was in the Funk Island Deep Closure (13,461 years).

2.3.2.2. Unit 2 Redfish Survey

The Unit 2 Redfish survey has a smaller total survey area compared to the RV surveys and only had sets in three protected areas: the Laurentian Channel MPA in the NL Region, and St. Anns Bank MPA and the Gully MPA from the Maritimes Region. Even though the two MPAs from the Maritimes Region only had very few sets in them (St. Anns Bank, n=25; the Gully, n=1) over the full survey time series, they were included in the analysis for consistency. The proportion of area impacted for St. Anns Bank and The Gully were 0.000018 and 0.000002 $year^{-1}$, respectively, whereas the proportion was 0.000066 $year^{-1}$ for the Laurentian Channel (Table 5). The mean number of sets per survey (approximately every 2 years) for the Unit 2 Redfish was 110 sets, and given a mean swept area of 0.0667 km^2, the mean total area of bottom contacted by the survey gear was 7.337 km^2 per year (Table 2). Recurrence time intervals for the Redfish survey were relatively high in comparison to the RV surveys, due in part to its biennial design.

2.3.2.3. Collaborative Post-season (CPS) Trap Survey

The crab trap survey had relatively low proportions of impact for all of the protected areas it overlapped with. The Funk Island Deep closure (0.000002 $year^{-1}$) and the Hawke Channel closure (0.000001 $year^{-1}$; Table 5) were the highest values for proportion of impact. The mean number of stations per survey (year) for the full survey was 1,085 fleets (8,986 traps) and had the smallest total mean swept area (0.519 km^2) of all the surveys (Table 2). The Northeast Newfoundland Slope closure and the Laurentian Channel MPA had negligible impact from the crab trap survey (1.72E-8 and 2.63E-7 $year^{-1}$ respectively) as only a few stations were identified in each protected area (refer to Figure 5 for crab strata overlap). Recurrence times were relatively high compared to all other surveys, for example, the Laurentian Channel MPA and the Northeast Newfoundland Slope closure were 1,604,532 and 1,179,123 years respectively (Table 5).

2.3.2.4. Longline Halibut Survey

The Longline Halibut Survey strata overlapped with four protected areas of interest in these analyses, the Laurentian Channel MPA, the 3O Coral closure and the two MPAs from the DFO Maritimes Region, St. Anns Bank and the Gully. It should be noted that of the four years of data in the random-stratified survey time series thus far, only 12 sets were completed in the Laurentian Channel, 9 in St. Anns Bank, 3 in the Gully, and none in the 3O Coral closure. Even though there were no sets in the 3O coral closure, there was still some sampling intensity present in the strata that overlapped the northern edge of the closure and so it was assumed that there may be some assigned sets there in the future based on the random-stratified survey design. Proportion of impact values were relatively high in the three MPAs with St. Ann's Bank being the highest at 0.000189 $year^{-1}$, and recurrence times were found to be quite low (4,759–6,994 years; Table 5), however, these values are likely much different than the other surveys due to the relatively high swept area for the gear (Table 2).

2.3.2.5. Cumulative Impacts

The cumulative proportion of impact and recurrence intervals for all five surveys are outlined in Table 6. The cumulative values for proportion of impact are simply the sum of the values in Table 5 for each survey, however, the recurrence intervals are calculated based on the total proportion of the protected area that had sets allocated to it (i.e., area of the overlapping strata containing sets). Since these areas overlap across surveys, the cumulative survey area overlap (km^2) was calculated by merging all four sets of strata and getting the total proportion of survey area overlapping each protected area (Table 6). The inverse of the cumulative proportion of impact for all surveys was multiplied by the proportion of the protected area with overlapping surveys to get the cumulative recurrence interval as stated in Equation 3 above. The protected area with the highest cumulative proportion of area impacted was the Laurentian Channel MPA (0.000383 $year^{-1}$). It also had the lowest cumulative recurrence time interval at 2,612 years. The St. Ann's Bank MPA had the next highest cumulative proportion of impact along with the Gully MPA (0.000208 and 0.000104 $year^{-1}$ respectively, both heavily influenced by the Longline Halibut Survey (Table 6). They also have low recurrence time intervals, both at 4,810 years (Table 6).

Overall, the proportion of impact area and recurrence time intervals for these surveys are not substantial in relation to the entire footprint of the protected areas or when compared to the commercial fishing footprint (refer to Section 2.2). Some protected areas are more affected by the bottom-contacting surveys than others, however, the impacts seem to be minimal across the board. It should be highlighted that corals, sponges, and other benthic organisms typically have patchy distributions, even within the protected areas, and that the outcome of these types of analyses might differ if performed at a small spatial scale.

3. POTENTIAL IMPLICATIONS OF RESTRICTING / PROHIBITING BOTTOM-CONTACTING SCIENTIFIC SURVEYS IN PROTECTED AREAS

3.1. GENERAL APPROACH/METHODS

A fully informed decision regarding whether to allow research survey activities within protected areas cannot be made without also considering the potential consequences of not surveying within those areas. The potential impacts of excluding scientific surveys from protected areas were simulated by resampling existing survey data to remove any data collected within protected areas and recalculating the relevant stock/ecosystem indicators from the subsampled survey time series.

The potential impacts of excluding data collected in protected areas were evaluated by comparing the two time series, with and without exclusion. In some of these analyses we also explored potential time-varying biases created by the exclusion of data within the protected areas by examining trends in the annual log of the ratio between the two time series (i.e., a value of 0 would mean that the base and scenario runs have identical index values for a given year, log(1)=0, negative values would indicate that the scenario run renders lower index values than the base run, and positive values indicate that the scenario run renders higher index values than the base run). We were particularly interested in the potential for time-varying biases as these may compromise the scientific advice produced from the surveys (see Benoît et al. 2020b). To that end, we fit a generalized additive model (GAM) to the time series of log-ratio values. Significant results for the smoother for the covariate 'year' indicated the potential for a time varying bias. Here we examine the potential impacts of these excluded data for physical oceanographic data, indicators of general ecosystem trends, as well as indices used for specific demersal fish and shellfish assessments.

As per Benoît et al. (2020a) we did not examine closures on an individual basis but rather grouped protected areas according to their primary conservation objective. Specifically, the Hopedale Saddle Closure, the Northeast Newfoundland Shelf Closure, the 3O Coral Closure, The Tail of the Bank Closure, The Flemish Pass/Eastern Canyon Closure, and the Sackville Spur Closure were all considered here as "Sponge/Gorgonian Coral Closures" (although we note that some of these had additional conservation objectives not related to corals and sponges). The Laurentian Channel was categorized as a "Sea Pen Closure." We distinguish between Sea Pen and Gorgonian closures (although both are corals) due to distinct sensitivities of gorgonian corals relative to sea pens when it comes to benthic disturbances. And finally, The

Hawke Channel Closure and the Funk Island Deep Closure were grouped as "Fish Habitat" closures. These fish habitat closures were included upon request, even though there was considered to be little to no justification for excluding scientific surveys from operating within them.

The potential impact of losing data from protected areas was evaluated for each of these closure categories, as well as all categories combined, as indicated below:

- **Scenario A**: Exclusion of sets from Sponge / Gorgonian Coral Closures
- **Scenario B**: Exclusion of sets from Sea pen Closures
- **Scenario C**: Exclusion of sets from Fish Habitat Closures (note that this scenario was examined for the ecosystem assessments and species-specific demersal fish and shellfish assessments but not the analyses of physical oceanographic data)
- **Scenario ABC**: Exclusion of sets from all closure types (note that in some instances this has been referred to as AB or AC if one of the closure types is not relevant for the survey/area being examined.

3.2. PHYSICAL OCEANOGRAPHY

Analyses of environmental oceanographic conditions are inherent aspects of the science advice provided during DFO ecosystem assessments. While most of the oceanographic data used for this advice are acquired without seafloor contact, the collection of some types of data (e.g., temperature) also rely on two gear-types that make contact with the bottom: oceanic moorings and trawl-mounted CTDs.

3.2.1. Moorings

Moorings consist of an underwater vertical array of instruments temporarily anchored in a certain location. The instruments are generally left on site for long periods (months to years). This technology is thus non-mobile once deployed. In the open ocean, the moorings are generally recovered by detaching the instruments using an acoustic release and leaving the anchoring weight on site. The advantage of moorings is that they can provide continuous information of various types (physical and biogeochemical environmental conditions, presence of fish or marine mammals, etc.) and over long periods of time. Deploying moorings inside closures is sometimes used as a strategy to avoid the loss or damage of the instruments due to potential contact with fishing gear. Currently there are no suitable alternatives to oceanographic moorings and no specific analyses related to moorings are presented in this document. While it is acknowledged that the deployment of moorings within protected areas may have some impact on benthic taxa, it is expected that the footprint of these impacts would be very small (the footprint of the weight left behind may vary but is usually on the order of ~1 m^2 per deployment). In rare occasions, for example when the acoustic release is not working, attempts to recover the mooring with dragging techniques (e.g., grapple) may also be used, increasing the potential adverse impact to the seafloor.

3.2.2. Bottom Temperature

Bottom temperature maps are produced annually using all available bottom or near-bottom observations collected during Spring (April-June) and Fall (September-December) seasons (see Figure 6). These observations are used to determine the average bottom conditions and thermal habitats in different areas of the NL shelf (NAFO divisions, SFAs, etc.). These bottom temperature estimates are limited to depths shallower than 1,000 m, as the large majority of the observations used for this task are obtained during the DFO RV Multispecies Survey using CTD installed on the fishing gear (e.g., Cyr et al. 2020).

The scenarios tested here are slightly different than those previously described for the other analyses: Scenario A (exclusion of sets in Sponge/Gorgonian Coral closures), Scenario B (exclusion of sets in Sea pen closures), Scenario AB (exclusion of sets in the 2 previous closures together) and Scenario ABC (exclusion of sets in all closure types, including the fish habitat closures). Note that Scenario C was not evaluated on its own with respect to the loss of temperature data. The strategy developed here to assess the impact of removing the data acquired using bottom contact gear inside protected areas (see Figure 6) consists of removing them from all historical analysis since 1980 according to the scenarios presented above, then recalculate the annual average per NAFO division, and compare them to those obtained without any removal (the reference scenario). This method is applied for sampling using spring (NAFO Divs. 3LNOPs) and fall (2HJ3KLNO) data between 1990 and 2019.

The result of this analysis is presented in the form of scorecards in Figure 8 for spring and Figure 9 for fall data. For each NAFO division, the five first rows represent the average seasonal bottom temperature in this division for the reference scenario (no exclusion) and the four exclusion scenarios. Each cell is color-coded according to its departure from the 1980–2010 climatological average in terms of normalized anomaly (see Figure 7). The relative change (%) of each scenario compared to the reference is also quantified for each NAFO division (four last rows of each panel, in bold). The 1990–2019 average change (using absolute values) is also presented at the end of each line. Note that some scenarios do not necessarily apply to all NAFO divisions. These have been grayed-out in Figure 8 and Figure 9. It is also worth noting that data from some closures within certain NAFO divisions might affect the bottom temperature in another nearby divison. This is because the 3D interpolation method used can propagate the information from one area to another (e.g., a deep cast in the Laurentian channel may help constraining the bottom temperature on a shallower nearby slope when limited other information is available). This is the case for spring bottom observations in 3Ps and 3O which are respectively impacted by scenario A (outside 3Ps) and B (outside 3O). These scenarios have thus been left in the scorecards.

The largest difference between the reference and any scenario is observed in division 2H, the northernmost region of the stratified survey, and where the physical observations are scarcer. The removal of sets from fish habitat closures (scenario A), led to differences with the reference scenario ranging between -7.1% and +5.0%, for an average of 2.9% (in absolute value). For this division, scenario A also led to changes in the provision of advice for some years (e.g., 2001, 2012, 2015, 2016), in that the bottom conditions characterized as “normal” further appeared “warmer” or “colder” than normal, or vice-versa (see first two rows of Figure 9).

With Division 2H set aside, the impact of removing observations within closures was less than 2% on average for all scenarios, divisions, and seasons, and virtually never changed the advice (or sign of the anomalies). The largest difference between the reference and any scenario is observed in 3Ps and is related to the exclusion of data from the Laurentian Channel MPA (scenario B in Figure 8). On average, for the 1990–2019 period, the difference ranged between -8.7% and +0.6%, for an average of 1.6% (in absolute value). The largest difference (8.7% colder than the reference) was observed in 2008.

The second largest impact is observed in NAFO division 2J (fall) and is related to the Hawke Channel closure (appears in scenario ABC in Figure 9). On average for the 1990–2019 period, this scenario led to changes ranging between -5.2% and +1.3%, with an average of 1% change compared to the reference. The third largest impact is observed in NAFO division 3K (fall) and is related to the Funk Island closure (appears in scenario ABC in Figure 9). On average for the

1990–2019 period, this scenario led to changes ranging between -2.8% and +3.7%, with an average of 0.8% change compared to the reference.

It is not surprising that Scenario B (Sea pen closures) and Scenario C (Fish Habitat closures) lead to larger differences compared to the reference because, unlike other closures in deep waters (e.g., from Scenario A), these areas are located well inside the 1,000 m bathymetric contour (used here to delimit the shelf edge) where the bottom temperatures are calculated. The only exception is in NAFO division 2H where the closure encompasses a significant portion of the shelf (see Figure 6). Combined with the general scarcity of the data in this area (other oceanographic surveys are limited in this remote region), this explains why the removal of sets from this division lead to large year to year differences compared to the reference scenario. After 2H, closures of Scenario A mostly impacted NAFO division 3LNO during the fall (scenario A in Figure 9), with an average difference of 0.7% compared to the reference. This is because these closures occupy a large part of the slope around the Grand Bank.

Finally, it is worth noting that, except for 2H, most changes observed here for any scenario mostly lead to colder temperatures than the reference scenario (indicated by negative percent changes). This is because most of the closures are located in troughs, channels, or along the slopes, in a depth range below the cold intermediate layer, and thus in waters warmer than those on the top of the shelf (see for example Figure 6).

3.3. ECOSYSTEM ASSESSMENTS

Along with environmental oceanography, trends in fish communities play an important role in the science advice provided within NL DFO ecosystem assessments. The data used to look at these trends in fish communities comes from the Spring and Fall RV Multispecies Surveys.

The NL Region can be described in terms of four Ecosystem Production Units (EPUs): the Labrador Shelf (2GH), the Newfoundland Shelf (2J3K), the Grand Bank (3LNO), and southern Newfoundland (3Ps) (NAFO 2014; 2015; Pepin et al. 2014). Trends in fish communities are described in terms of these four units, with the exception of the Labrador Shelf (2GH) where the RV Multispecies Survey only conducts limited sampling in the 2H portion of the region. Not all areas are surveyed in both the fall and spring survey. The more northern EPUs (2H and 2J3K) are only surveyed in the fall, 3LNO is surveyed in both the spring and fall, and 3Ps is only surveyed in the spring. This gives 5 EPU-season combinations, with fish trends summarized separately.

Trends are summarized by fish functional groups. These groups are defined by general fish size and feeding habits: small, medium, and large benthivores, piscivores, plank-piscivores, planktivores, and shellfish (commercial species only) (Wells et al. 2017; Wells et al. 2019).

Three indices derived from the RV surveys are typically used to describe the fish community:

1. RV Biomass,
2. RV Abundance, and
3. the RV Biomass/RV Abundance ratio (BA ratio).

RV Biomass and RV Abundance are estimated based on the standard random-stratified design of the survey and using a subset of core strata selected for their consistent coverage over time. These core strata typically do not include inshore and deep-water areas because these are surveyed less frequently, often due to operational issues (vessel breakdowns, weather, etc.). The BA ratio is a derived index from the biomass and abundance and is used to characterize average fish size.

For the purpose of this study, ecosystem survey indices were calculated as usual, including all valid sets (base run), and compared with similar series where sets were excluded as required by each scenario (scenario runs). The analyses here start in 1995–96 and use the Campelen time series only. To overcome reductions in sample area caused by the requirement of a minimum of 2 sets per strata, some strata were merged. Some strata that overlapped with closures were merged in all scenarios looking at closures to maximize the survey area retained throughout the time series. These merges were systematically done as an attempt to keep similar depth profiles and not extend to a wider geographic area. The merged strata were also used to calculate stratified estimates for demersal fish from the Multispecies RV surveys (see Section 3.4). Merged strata were used only in the scenarios runs (with excluded sets), not the base run. For each EPU-season combination, only scenarios that occurred within the EPU were considered: 2H (A), 2J3K (A, C, ABC), 3LNO (A), 3Ps (B). To compare changes in fish trends, two basic aspects were considered using log-ratio and the change of this log-ratio over time by fitting them using a GAM with year as a covariate. The mean log-ratio, Standard Deviation (SD) of the log-ratio, and percent deviance explained by the year from the GAMs were used to identify key patterns and summarize results by EPU.

3.3.1. Labrador Shelf (2H)

The only scenario applicable to 2H is A, with removal of sets from Hopedale Saddle MR. This EPU has the more limited time series among EPUs, with the least sampling coverage both spatially and temporally. There was significant time varying bias in RV Biomass of medium benthivores and plankpiscivores, in BA ratio of medium benthivores, plankpiscivores, and planktivores, but no bias across time in RV Abundance (Appendix B). Of particular note is the bias in the medium benthivores where the trend in RV Biomass differs between the base and scenario A (Figure 10). The trend within the base run shows stable biomass with recent declines, whereas in scenario A there appears to be building of biomass before the more recent declines. Additionally, plankpiscivores show visible differences in the trends for both RV Biomass and BA ratio (Figure 10), and the index increases with the removal of data from the protected area. The large and positive log-ratio is caused by extrapolating biomass into an area with traditionally lower estimates.

3.3.2. Newfoundland Shelf (2J3K)

In 2J3K there are multiple protected areas resulting in three closure exclusion scenarios to be tested: scenario A with removal of sets from Northeast Newfoundland Slope MR, scenario C with removal of sets from Hawke Channel and Funk Island Deep MRs, and finally a combination of the two (ABC).

A significant time-varying bias was observed for RV Biomass of both planktivores and shellfish when sets from scenario A (Northeast Newfoundland Slope closure) are removed (Figure 11). This bias in both functional groups has low SD and low mean log-ratio but the pattern is consistent through time. However, when sets from scenario C (Hawke Channel and Funk Island Deep closure) are also removed, this creates a much greater variability in the log-ratio, which results in masking the significant bias across time from scenario A when these two scenarios are considered together (i.e., scenario ABC). Similar patterns (i.e., variability of one scenario masks significant bias across time of another) occur with abundance in small and large benthivores, and shellfish with significant bias in scenario A but not C or ABC, and planktivores with bias in scenario C but not A or ABC (Appendix B).

There are also cases where significant bias in one scenario drives the pattern in the combined scenario. This is the case with RV Biomass of piscivores, where the exclusion of sets in scenario C (Hawke Channel and Funk Island Deep closures drives a strong time-varying bias which is also observed in the combination scenario (ABC). A similar pattern is observed with RV Biomass of medium and large benthivores but in these cases, it is the strong bias across time associated with the removal of sets from scenario A (Northeast Newfoundland Slope closure) that drives the bias across time observed in the ABC scenario (Figure 11). This type of pattern (i.e., where bias across time from one scenario drives the bias across time of the combined scenario) is also observed in abundance of piscivores (Appendix B).

The combination of scenarios can also have cumulative impacts leading to significant patterns over time not detected in the individual scenarios. This can be seen in the BA ratio of planktivores where there is no significant bias across time in either scenario A or C, but the combined ABC scenario shows a significant bias across time (Appendix B).

Finally, bias across time can be significant in all three scenarios, as is the case of the BA ratio of medium benthivores (Appendix B).

3.3.3. Grand Bank (3LNO)

The only scenario applicable to 3LNO is A. The closures here have very minimal overlap with the core strata used in the estimation of indices for fish functional groups (Table 7). There were very few sets removed from this EPU that are used in describing the structure and trends of the fish community, resulting in few functional groups showing significant bias across time in their indices, and no measurable differences in the index values across scenarios (Appendix B). The few functional groups that had significant bias were those found along the shelf edge such as benthivores. Abundance of piscivores in the spring survey had significant bias across time but the mean log-ratio and variation was small, and likely driven by one or two years.

3.3.4. Southern Newfoundland (3Ps)

The only scenario applicable to 3Ps is B with removal of sets from the Laurentian Channel MPA. Bias across time in this EPU is broad and affects multiple functional groups. Systematic bias was observed in RV Biomass for 4 out of 7 functional groups, and 5 of 7 and 2 of 7 functional groups for RV Abundance and BA ratio, respectively (Appendix B). The bias can be large and visible in the trends, for example abundance of piscivores where the index both increases and decreases depending on the years, and shows a general increase in bias to large estimates in more recent years (Figure 12).

3.3.5. General Patterns

While impacts on ecosystem-level survey indices by the different scenarios considered vary by fish functional group and EPU, management decisions affecting survey operations within protected areas cannot target specific functional groups or specific indices. A practical evaluation of the impact of foregoing survey efforts within protected areas requires a more integrated perspective of the type of changes that can be expected from such actions. In order to generate this general evaluation, results from the different scenarios and indices have been summarized based on key metrics: absolute mean value of the log-ratio between indices to gauge the overall (i.e., positive or negative) departures from the base run, SD to the log-ratio to gauge variability of these departures, and the deviance explained by the year effect in the GAMs to gauge how important the bias across time is in defining the changes observed in the log-ratio time series. Basic accounting of the results also provides an overview of how often some specific impacts were observed.

The largest absolute mean log-ratio, SDs, and deviance explained by year in the GAMs were seen in 2H and 3Ps (Figure 13). This indicates greater difference between the base run and scenario datasets. The high SD demonstrates that in these regions there is greater variation, and that the difference between scenario and base runs is not consistent. The high deviance explained by the year in GAMs indicates that an important component of the observed variability corresponds to a temporal pattern; it is not simply noise. This means that in these regions the potential of impact on science advice is larger.

In both seasons, 3LNO has very low absolute mean log-ratio and SD. The percent deviance explained by the year component of the GAM displayed a similar pattern to mean log-ratio and SD, with comparatively low variability being explained by bias across time.

The magnitude of potential impact differs for each EPU based on the area that overlaps with each protected area. The area of overlap between the core strata and the protected areas is largest in 2H and 3Ps (Table 7). These two EPU also have a large percentage of strata that overlap and a large mean number of sets that are removed. The low absolute mean log-ratio and SD in 3LNO is the result of very few strata and few sets falling within the protected areas in that EPU.

With the exception of shellfish and small benthivores, all functional groups have variable mean log-ratio and SD with some cases of high log-ratio and SD (Figure 13). The generally low mean log-ratio and SD of shellfish and small benthivores indicates that these functional groups are less sensitive to removal of sets from protected areas than the other functional groups.

Of the 147 trends of fish functional groups indices examined, 40 were significant. These patterns occurred more in some areas and in some functional groups than others. The 3Ps EPU, which has only the Laurentian Channel MPA under scenario B, shows bias across time in 52% of the fish functional groups across all three indices (Figure 14), making this EPU the one most affected by removal of sets, and potentially the more sensitive to changes in ecosystem-based science advice.

Under scenario A (removal of sets from sponge and gorgonian coral closures), 2J3K has 38% of fish functional groups across all indices with significant bias across time, the highest of the 4 EPU-seasons that this scenario applies to.

Among fish functional groups, medium benthivores shows bias across time in 48% of comparisons across all indices, scenarios, and functional groups. This is the highest of all functional groups. Alternatively, shellfish has only 10%, making it the lowest.

Overall, most functional groups tend to show relatively small absolute discrepancies in their indices between the scenario and base runs, but many of these small discrepancies still show bias across time, indicating that excluding sets from protected areas has the potential for impacting ecosystem advice, especially because fish functional groups are impacted disproportionately, meaning the perception of the structure of the fish community can be distorted. While many of these distortions would be statistically significant, they are likely to be less of an issue from a practical perspective in 2J3K and 3LNO EPUs given the small absolute magnitude of the observed discrepancies, but they can pose major issues in 2H and 3Ps EPUs. In any case, the fact that bias across time is a rather pervasive observation across fish functional groups and EPUs suggests that changes over time in the use of habitats associated with protected areas is a fairly common ecological process; if these patterns continue into the future, even those distortions considered minor today may become more important in the years to come.

3.4. DEMERSAL FISH ASSESSMENTS

3.4.1. Multispecies RV Surveys

Methods and scenarios used to examine the potential consequences of restricting the collection of trawl data from within protected areas follow those described previously. Stratified estimates were recalculated (Table 8) for 47 demersal fish time series (14 species, 31 stocks). Some of these fish stocks are assessed annually, some are assessed on a 2–3 year cycle, some have been assessed periodically, and a couple have never been formally assessed (Table 8). This list includes stocks that are managed by Canada, some that are jointly managed by Canada and France, and some that are managed by NAFO. Some are species of commercial interest, while others are species at risk. Given the number of stocks and survey time series analysed here we present only a single survey index for each one. For those stocks that have an age-structured assessment model, we present analyses based on mean number per tow (MNPT) while for those based on surplus production models or raw survey indices, we present our analyses based on estimates of total biomass.

For strata that overlapped partially with a protected area, it was assumed that data collected within the portion of those strata outside the protected area were representative of the portion inside the area. All efforts were made to mimic the stratified estimates produced in the respective assessments, i.e., if the assessment used index strata then those same index strata were used here; any years that were omitted from the assessment due to survey coverage issues were also excluded here. Survey sets that occurred all or partially within the protected areas were excluded. Removal of these data commonly resulted in only a single successful set remaining in some strata. Since the calculation of stratified estimates requires a minimum of two successful sets per stratum, these strata were merged with neighbouring strata to produce new ‘megastrata’ to ensure no unnecessary loss of data from the analyses. In years where one or more of the strata typically included in the formation of the megastrata were completely missed in the survey, they were not included in the merger.

The results for all stock specific analyses on the potential impacts of removing RV bottom-trawl data collected from within protected areas in the NL Region are presented in Appendix C. Here we highlight specific examples to demonstrate different impacts on stock specific time series.

For stocks on the Grand Bank (Divs. 3LNO), the exclusion of RV bottom-trawl data that was collected from coral and sponge protection areas generally did not have a large impact on the survey indices. In some instances, such as the fall survey time series for 3LNO American Plaice (Figure 15), the removal of data collected from coral and sponge protection areas did result in a significant time-varying bias but the differences between the time series were very small. For some stocks located on the Northeast Newfoundland Shelf, the exclusion of data from coral and sponge protection areas is more problematic. For example, for Witch Flounder in Divs. 2J3KL, the exclusion of these data led to more substantial differences in the data time series and also a significant time-varying bias (Figure 16).

The exclusion of RV data from sea pen protected areas (i.e., the Laurentian Channel MPA) resulted in a significant time-varying bias in the survey time series for several stocks, including redfish in Subdivision 3Ps (Figure 17). For that stock, the loss of data from within the sea pen closure resulted in a positive bias in the middle of the time series and a negative bias at the end of the time series. The largest negative bias in the most recent year of the series is interesting given the recent rapid increase of Unit 1 and 2 redfish (which includes 3Ps) that is expected to continue. The exclusion of the RV survey from the sea pen closure could be an issue with respect to the provision of science advice if this recent negative bias is associated with the stock increase.

For stocks that overlap spatially with more than one type of protected area (e.g., coral and sponge closures, fish habitat closures) the scenario of excluding RV data from all protected areas typically reflected biases created by excluding protected areas of a single type. For example, for Witch Flounder in Divs. 2J3KL the fact that excluding data from all closures results in a significant bias in the time series is not surprising, given that the same is true for excluding each of the closure types individually (Figure 16). In other cases, the individual closure types may not create a significant bias when excluded on their own but can create a significant bias when excluded together (Figure 18).

It is important to note here that, while time-varying biases introduced by excluding data collected from within protected areas, is of major concern for the provision of science advice, impacts that do not result in bias must also be accounted for. For example, while the loss of these data did not create a significant time varying bias in the RV time series for Greenland halibut in Subdiv. 3Ps (Figure 19), there was a relatively large influence on the survey indices that would still have to be accounted for in the assessment of this stock, the calculation of reference points, etc.

For the demersal fish stock-specific analyses performed here there were a total of 22 time series – scenario combinations that demonstrated a significant time-varying bias (Figure 20). Of the 38 survey time series that overlapped with coral and sponge protection areas, the exclusion of data from these areas (i.e., Scenario A) resulted in a significant time-varying bias for 6 of the time series (16%). The stock that demonstrated the largest impact of excluding data from coral and sponge protection areas was Divs. 2J3K witch flounder (Figure 20).

For analyses pertaining to the exclusion of RV surveys from sea pen protected areas (i.e., Scenario B), removing data from the protected area resulted in a significant time-varying bias (Figure 20) for 5 of the 12 time series (i.e., 42%). The mean differences for these comparisons were larger than for the coral and sponge protection areas, with 5 of the time series having a difference of 5–20% from the base run and two that differed by more than 20% from the base run. Nine of the series had a maximum difference of greater than 20% from the base run in at least one year.

For the analyses that excluded data from fish habitat protected areas (i.e., Scenario C), 4 of the 10 (40%) comparisons resulted in a significant time-varying bias for the survey time series. The mean differences between scenario C estimates and base run estimates were generally small but was 13% for Greenland halibut in Divs. 2J3K. It is also of concern that the bias caused by removing data from fish habitat closures for Witch Flounder in Divs. 2J3KL continues to get larger as the stock continues to grow.

For stocks/time series where the RV surveys overlapped more than one closure, exclusion from all closures (Scenario ABC) resulted in significant time-varying bias in 7 out of the 14 time series. In almost all of these instances there was also significant bias introduced by exclusion of data from one of, and sometimes each of, the individual closure types, so the bias observed by excluding all closure types is not surprising. In one case however (American Plaice in Divs. 2J3K), exclusion of data from coral and sponge protection areas (Scenario A) alone did not result in significant bias and neither did exclusion from fish habitat protection areas (Scenario C), but the cumulative effects of removing data from both protected area types (Scenario ABC) did introduce a significant time-varying bias. Such results suggest that the impacts of excluding scientific surveys from protected areas should not only be looked at with respect to specific closure types but also with respect to the cumulative effects of exclusions from the various closure types.

3.4.2. Unit 2 Redfish Survey (Preliminary Analysis)

The Unit 2 redfish stock covers multiple DFO Regions, and the assessment of this stock is conducted collaboratively between DFO Quebec and DFO NL. It was decided that both Regions should be involved in any analyses regarding potential changes to the Unit 2 redfish survey as it is such an important data source for the stock assessment. Such a collaboration could not take place in time for this meeting and is instead proposed for the next Unit 2 redfish assessment. So rather than the data resampling exercises undertaken here for other surveys, the approach for the Unit 2 redfish survey was to simply get a preliminary look at the distribution of biomass captured in each survey year, within the protected areas. This will provide some insight into whether there will be any obvious potential for bias in the stock assessment process from losing sets within the protected area boundaries. The intention is to use the results as a first step only with a recommendation that the potential loss of survey sets be more comprehensively assessed during the next regular stock assessment meetings for Unit 2 redfish.

The redfish survey occurs in portions of NAFO Divisions 3Pn, 3Ps, 4Vn, and 4Vs and is adjacent to, or overlaps, with not only the Laurentian Channel MPA, but also two protected areas within the DFO Maritimes Region: the Gully MPA and St. Anns Bank MPA. There are only a few sets in the redfish survey that fall into these two MPAs, however, they are included in the analysis for consistency.

The Unit 2 redfish survey dataset contained set details from surveys conducted on average, every two years, from 2000 to 2018, with a total of 1,103 sets over 10 years of surveys. The data were visually examined, and 17 outliers (incorrect geographic coordinates) were identified and removed from the dataset based on their spatial location. The remaining 1,086 sets were used to make annual datasets for interpolation.

An inverse distance weighted (IDW) interpolation was used to create continuous rasters of redfish biomass (kg/tow) from the point data. Optimal parameters for IDW were calculated in R (version 3.6.3). The search radius was chosen based on the mean number of neighbours per set (ideally 5–10). The power function and number of neighbor parameter inputs were chosen based on a root mean square error (RMSE) function using a search radius of 40 km. Although these parameter values were calculated for each individual year, a single value for each parameter that produced relatively low RMSEs for each dataset was applied across all years for simplicity. IDW rasters were made for each year using a variable search radius (where number of points = 8 and maximum distance = 40 km) and power of 1. The output cell size was set to 5 km. The annual rasters (Figure 24), were clipped to the redfish survey area polygon. We did not have an up to date polygon for the complete survey area and therefore some areas with survey sets were clipped out of the analysis at this point (Figure 25). The areas left out were typically low biomass areas and were not overlapping any protected area (Figure 26). While this approach was considered acceptable for these preliminary analyses, a more thorough analysis should be conducted for the next assessment meeting of this stock.

To calculate the proportion of biomass within the three protected areas (The Gully MPA, Laurentian Channel MPA, St. Anns Bank MPA), the sum of biomass within four zones, the full survey area as a whole and each of the three MPAs, was calculated for each annual raster. The rule of thumb for assigning a cell to a zone or not was dependent on whether more than 50% of the cell was within a zone's polygon. For example, if only a corner of a cell (i.e., <50%) was within an MPAs polygon, the biomass value of that cell was not counted in the MPAs summed biomass. The annual proportion of biomass within the protected area was calculated by dividing the sum of biomass within a protected area by the sum of biomass for the entire survey area and was reported as a percentage of the total annual survey area biomass (Figure 27). The mean percentage of biomass across all years, in each protected area, was also shown to illustrate annual deviations from the mean.

The annual rasters in Figure 24 are displayed on the same color scale across all years to indicate years in which the biomass caught during the survey was higher or lower than others. For example, 2018 shows a much larger area covered with the higher biomass classes (e.g., orange and red). This trend was predicted in the 2015 Unit 1 and 2 stock assessment (DFO 2016) due to large cohorts from 2011–13. Much of this high biomass is found in the more northern portion of the Unit 2 study area, overlapping with both the Laurentian Channel and St. Anns Banks MPAs. St. Anns Bank is also a hotspot in 2016 whereas, earlier years in the time series show hotspots along the southern portion of the study area, along the edge of the shelf (Figure 24). The Laurentian Channel MPA does appear to contain moderate amounts of redfish biomass throughout the time series as well (i.e., 2000, 2007, 2009, 2014).

The mean annual percentage of biomass found in the Laurentian Channel MPA was 15.9% over the full time series (Figure 24). St. Anns Bank had a mean annual percentage of 4.8%, however, this value seems to be mainly driven by the high biomass caught there in 2016 and 2018. If this high biomass for the Unit 2 redfish stock continues to increase or change rapidly, the influence of removing sets in the St. Anns Bank MPA may create some bias in the overall biomass estimates. It should be noted that there are only a limited number of sets that actually fell into that MPA as well (n=25; 2000–18). Further investigation would be needed to evaluate the actual impact of excluding those sets using the proper stock assessment methods. The Gully MPA only contained 1 set over the full time series and had an overall mean annual percentage of biomass of 0.1%. Any removal of sets from this protected area are not likely to have any impact on the results of the Unit 2 redfish assessments.

3.5. SHELLFISH ASSESSMENTS

Both Northern Shrimp (*Pandalus borealis*) and Snow Crab (*Chionoecetes opilio*) are assessed annually for most management areas in the NL Region. Northern Shrimp is assessed on a Shrimp Fishing Area (SFA) scale with science advice provided at the same scale (DFO 2019a). Snow Crab is assessed on an Assessment Division (AD) scale with science advice provided at that scale (DFO 2019b).

Northern Shrimp and Snow Crab biomass indices from DFO multispecies trawl survey data are generated using ogive mapping methods (Ogmap) (Evans et al. 2000). This method utilizes a domain (vertex points with known latitude, longitude, and depth) covering an assessment area in order to integrate survey catch rates over that area. Ogmap relies on the swept area of a trawl when generating biomass indices from survey data. For the purpose of this study, the domains utilized in assessments (Mullowney et al. 2019) remained the same, while survey points inside of protected areas were excluded for each applicable scenario. The trawl survey data from 2006 in NAFO Div. 3Ps was excluded from the analyses as it was incomplete. Additionally, the trawl survey data from 2000, 2002, 2003, 2005, 2007 and 2009 in SFA 5 were excluded as the survey did not cover the 2H portion of that SFA.

Snow crab biomass indices for trap survey data are generated using a modified version of OgMap (‘OgTrap’) and incorporates data from the CPS Trap survey, DFO Inshore Trap surveys (White Bay, Notre Dame Bay, Bonavista Bay, Trinity Bay, Conception Bay, St. Mary’s Bay, and Fortune Bay), and the Torngat Joint Fisheries Secretariat Trap survey in NAFO Div. 2H. Survey catch rates are integrated within specified polygons in OgTrap and the swept area is altered to conform to the effective fishing area of a crab trap. The following survey data was excluded from the CPS trap survey analysis due to incomplete surveys: AD 2HJ (2005, 2017, 2018 and 2019), and AD 3Ps (2015 and 2016). 2019 was also excluded from the analysis of trap survey data for

AD 3Ps as stations were purposely removed from within the Laurentian Channel MPA in that year.

For Northern shrimp, biomass estimation was limited to fishable biomass (>17 mm carapace length) and for Snow crab, biomass estimation was limited to exploitable biomass (≥95 mm carapace width male Snow crab). Trap survey data were limited to exploitable sized Snow Crab from large-mesh traps.

3.5.1. Snow Crab Assessments

3.5.1.1. Multispecies RV Survey

Only ADs 2HJ, 3K, 3LNO and 3Ps were examined, as the multispecies trawl survey does not cover ADs 3L Inshore and 4R3Pn. As with other species, baseline and scenario biomass estimates were compared and log-ratio subjected to a GAM to determine whether there were significant time-varying biases.

In AD 2HJ, excluding sets from the Fish Habitat closures (i.e., Hawke Channel closure) causes a time-varying bias for the exploitable biomass index, with the bias becoming more negative throughout the time-series (Figure 21). Excluding sets from Scenario A on its own does not result in a significant time-varying bias, however, in combination with the Hawke Channel closure, a very similar negative time-varying bias occurs. Since the late-2000s, the survey catches of exploitable Snow crab in AD 2HJ has been contracting from along the shelf into the basins, particularly the Hawke and Cartwright Channels, therefore excluding survey sets from within these areas affects the exploitable biomass estimates for that AD. In AD 3K, excluding sets from Scenario ABC (particularly the Funk Island Deep closure and the Northeast Newfoundland Slope closure) causes a time-varying bias for the exploitable biomass index, with slightly positive biases at the beginning and end of the time-series and negative bias throughout most of the time-series, peaking in 2003 and 2004 (Figure 21). The exclusion of sets from coral and sponge closures (the Northeast Newfoundland Slope closure) tends to result in a higher exploitable biomass estimate, whereas the exclusion of sets from Fish Habitat closures (the Funk Island Deep closure) tends to result in a lower exploitable biomass estimate. This is because the sets within the Northeast Newfoundland Slope closure do not contain exploitable Snow crab and those missing zeros inflate the exploitable biomass estimate, whereas the sets within the Funk Island Deep closure contain exploitable Snow crab and the missing weights lower the exploitable biomass estimate. The establishment of the Hawke Channel and Funk Island Deep closures were harvester-driven as these are prime fishery grounds for Snow crab (Figure 21). In AD 3LNO, excluding sets in the Sponge/Gorgonian Coral closures causes a time-varying bias for the exploitable biomass index, with a positive bias highest at the beginning of the time-series. There were no time-varying biases for the exploitable biomass index in AD 3Ps. The sets within the Laurentian Channel MPA do not contain exploitable Snow crab and those missing zeros do not significantly affect the exploitable biomass estimate. Even though the removal of these sets does not result in a significant time-varying bias, the removal consistently results in an increased exploitable biomass estimate across the time-series.

3.5.1.2. CPS Trap Survey

Only ADs 2HJ, 3K, 3LNO and 3Ps were examined, as there are no closures within ADs 3L Inshore and 4R3Pn. As with other species, baseline and scenario biomass estimates were compared and log-ratio subjected to a GAM to determine whether there were significant time-varying biases. The following AD and closure combinations were investigated:

- AD 2HJ – Scenario C
- AD 3K – Scenario C

- AD 3LNO – Scenario A
- AD 3Ps – Scenario B

As the biomass estimates from the CPS Trap survey are generated using specific polygons/strata in OgTrap rather than the entire extent of the survey, not all closures present in an AD were evaluated because they did not overlap with or were adjacent to the OgTrap polygons.

In AD 2HJ, excluding sets from the Hawke Channel closure (Scenario C) did not result in a significant time-varying bias (Figure 22). However, the removal of these sets tends to result in both higher and lower exploitable biomass estimates throughout most of the time-series, ranging from the exploitable biomass estimate being 46% lower than the baseline estimate to 23% higher than the baseline estimate. The completion of the CPS trap survey is particularly poor in AD 2HJ and in many years the coverage of the survey is not adequate for analysis, as is the case for the last three years. This is also compounded by the fact that the survey in AD 2HJ has been operating on a severely depleted biomass for most of the time-series. In AD 3K, excluding sets from Fish Habitat Closures (i.e., Funk Island Deep closure) causes a time-varying bias for the exploitable biomass index, with a negative bias at the beginning of the time-series and a positive bias for the remainder of the time-series (Figure 22). The establishment of the Hawke Channel and Funk Island Deep closures were harvester-driven as these are prime fishery grounds for Snow crab. There were no time-varying biases for exploitable biomass indices in ADs 3LNO and 3Ps. In AD 3LNO, the polygons used in OgTrap for biomass estimate calculation do not overlap with any of the closures and in AD 3PS only one of the OgTrap polygons is adjacent to the Laurentian Channel MPA, however very few sets have occurred within the MPA over the time-series.

Caution should be used when interpreting the results from the CPS trap survey as there are consistent issues with coverage in the survey that affect the interpretation of stock status trends, including spatial bias and abandonment of survey areas in times of poor fishery performance. Exploitable biomass indices from trap surveys are also affected by annual variation in catchability of crab. There is uncertainty in interpreting trends from the CPS survey because it has limited spatial coverage. As well, catch rates in this survey may be affected by adverse weather and other factors that affect soak time and trap efficiency.

At present, biomass estimates are restricted to core strata (Figure 5) to conform with the past survey design which was confined to areas of commercial fishing. Since 2016 the survey design has been transitioning to the present 50% fixed and 50% random station design. Consequently, while the survey may currently take place in or near some of the closed areas, exclusion of sets does not affect the exploitable biomass estimation as this data is not used for this purpose. However, the data is presented in other aspects of the Snow crab stock assessment. Data from the random stations that may fall in these closed areas will hopefully be used in future exploitable biomass estimations as the random station time series is established.

3.5.2. Northern Shrimp Assessments

Analyses for Northern Shrimp were based on fishable biomass indices from the DFO fall RV multispecies bottom trawl survey. Only SFAs 5 and 6 were examined for this exercise. Exclusion of surveys within the Laurentian Channel area would not affect Shrimp Assessments in SFAs 5–6 given that only fall survey data is utilized for these SFAs.

While fishable biomass estimates under various exclusion scenarios result in differences from the baseline of up to 11% in SFA 5 or 9% in SFA 6, there were no statistically significant time-varying biases (Figure 23). Precautionary approach reference points are based on the geometric mean of female biomass indices. If future shrimp assessments are to be conducted on surveys that exclude sets in protected areas, then the Precautionary Approach reference points would be adjusted by up to 6% in SFA 5 and up to 5% in SFA 6.

3.6. CORALS AND SPONGES

In the NL Region, several Ecologically and Biologically Significant Areas (EBSAs), as well as many key conservation areas have been identified based on coral and sponge aggregations using DFO RV trawl data (Wareham and Edinger 2007; Kenchington et al. 2011; Guijarro et al. 2016; Kenchington et al. 2016a; 2016b; Wells et al. 2017; Wells et al. 2019). RV survey data have also been used in collaboration with non-DFO researchers and their students, leading to a considerable increase in the knowledge on coral and sponge biology and distribution in this region in recent years. Results from several of these studies have directly contributed to Science Advice (e.g., Wareham and Edinger 2007; Sherwood et al. 2007; Sherwood and Edinger 2009; Baillon et al. 2012; Gullage et al. 2017). Furthermore, DFO-NL RV survey data have been used at NAFO as input for the identification of VMEs and the delineation and re-assessment of fisheries closures outside of Canadian jurisdiction in the NW Atlantic (e.g., NAFO 2007–11; 2013; 2015–19). Despite the impressive achievements in our understanding of coral and sponge science in this region based on RV trawl data, removing trawl sets from protected areas would not prevent the future collection of data from inside the areas using less invasive gear (refer to Section 4.). Furthermore, there is no stock assessment for corals and sponges, and removing sets from inside these areas would not cause an important disruption in data collection as greater time scales are more relevant for these taxa due to their high longevities and sessile nature.

Removing RV sets from inside protected areas could potentially impact Science advice pertaining to these taxa in terms of monitoring (discussed in Section 4.), future modelling (e.g., species distributions), and/or review of closure boundaries. Removing RV sets from inside protected areas would lead to fewer new data points for modelling exercises, in the event current models are revised in the future (e.g., SiBAs; Gullage et al. 2017). Since protected areas represent sites where coral and sponge aggregations are expected to be higher than elsewhere, removing sets from these areas could potentially lead to a trend of more null sets data points and lower biomasses (Sciberras et al. 2018). If future modelling and/or review of closure boundaries can be performed by combining different sources of data (e.g., old RV data and new imagery survey data), then these constraints are less important and the removal of RV sets from inside protected areas would not have a major impact on advice relating to these taxa.

4. REVIEW OF POTENTIAL MITIGATION MEASURES FOR SCIENTIFIC SURVEYS

Benoît et al. (2020b) provided a review of mitigation measures to potentially reduce the impacts of survey activities in protected areas. These included a change in survey design, a change to less impactful gear, and a reduction in the footprint of individual sets. However, they were not able to identify alternative survey methods that can replace trawling in a multispecies context involving mobile demersal species or when a broad range of sizes of organisms must be sampled. Video surveys might have the potential to replace some types of surveys (e.g., dredge surveys) but obtaining the same level of information on individual physiological and life-history attributes could be problematic (Cryer 2015). The potential for video-surveys to replace the stations sampled in protected areas by the post-season snow crab trap survey could be explored given that only larger snow crab are sampled. However, the cost of the surveys, the fact they are conducted by industry in collaboration with DFO with vessels that may not be adapted for camera deployment, and the need to calibrate with survey densities sampled by traps outside the protected areas (Benoît et al. 2020b) render this option inviable presently. As well, much of the biological data currently collected through at-sea sampling on this survey and used in the stock assessment (shell condition, male claw height to determine maturity, female maturity, and female egg clutch) would not be possible with video surveys.

It might be possible to shorten survey trawl hauls to reduce activity footprints in protected areas, though these reductions would have to remain within the boundaries of acceptable haul durations and distances, which tend to be no less than 70% of the values for a target standard tow (e.g., Hurlbut and Clay 1990). However, systematically reducing haul duration would require extensive calibration trials as catch rates likely do not scale linearly with haul length and may be species specific (e.g., Somerton et al. 2002). Furthermore, comparisons of coral and sponge catches in research tows between Canadian and EU/Spain RV surveys, which have tow durations of 15 and 30 minutes respectively, have essentially shown no differences in the amounts caught between these surveys (NAFO 2008; 2009). This indicates that the amount caught by research trawls is more consistent with the probability of hitting a coral or sponge aggregation, which would be coarsely similar between a 15 and 30 minute research tow, than assuming catch rates linearly related to tow duration, which would be the justification for reducing current 15 minute tow durations to something in the vicinity of 10 minutes.

The cumulative footprint of multiple, spatially overlapping surveys could be reduced by limiting the number of surveys that sample the same areas. In the NL Region this would particularly apply to 3LNO, which is covered by the spring and fall DFO RV surveys, as well as the portion of this area in international waters (the NAFO Regulatory Area, which includes the nose and tail of the Grand Bank), which are surveyed by Canadian and EU/Spain RV surveys. All these surveys have the potential to impact coral and sponge aggregations in the protected areas. The Canadian surveys currently survey only to depths of 730 m in Divs. 3NO, whereas the EU-Spain survey samples down to 1,500 m. It would be a difficult task to intercalibrate all these surveys for the suite of species monitored, since it would effectively imply the integration of Canadian and EU/Spain surveys, but doing so could reduce potential impacts on sensitive benthic areas. It should also be pointed out that there is an ongoing process within NAFO to evaluate the impacts of surveys in closed areas, and that there is a voluntary agreement being followed by Canadian and EU/Spain surveys to avoid coral and sponge closures in the NRA until this process is completed.

One aspect not touched on in Benoît et al.’s (2020b) review of potential mitigation measures is the potential to slightly expand protected areas to cover more of the sensitive benthic areas as a trade-off for any potential impacts incurred from allowing bottom-contacting research activities within the protected areas. Most protected areas with benthic conservation objectives (e.g., protection of coral and sponge Significant Benthic Areas) do not encompass the entirety of the habitat identified by DFO Science. Many boundaries have been explicitly drawn to avoid impacts on commercial activities (e.g., fishing, oil and gas), leaving portions of these habitats exposed to impacts from these commercial operations. This implies that the fraction of these habitats currently exposed to commercial activities represents a de facto acceptable level of impact under current management practices. If excluding surveys from protected areas poses an unacceptable risk to the reliability/quality of the science advice, a potential mitigation measure to be considered is compensation. The impact of surveys within closed areas can be quantified, as can the impact by commercial activities on those fractions of the habitat currently without protection. Based on this information, closures can be proportionally expanded to compensate for the survey impacts within closures, while keeping the currently de facto acceptable level of impact constant. Given the substantial difference in magnitude between research surveys and, for example, commercial fishing, it can be anticipated that a modest expansion of the closures would suffice to achieve compensation.

5. METHODS / DATA SOURCES FOR MONITORING AND EVALUATING THE EFFICACY OF PROTECTED AREAS

5.1 BOTTOM-CONTACTING SCIENTIFIC SURVEYS

Monitoring and managing protected areas in the NL Region is the responsibility of DFO's Marine Planning and Conservation Branch (MPAs) and Resource Management and Indigenous Fisheries Branch (MRs). A Service Level Agreement (SLA) currently exists between these two Branches and DFO Science to provide advice on various indices for each of the areas. Based on the 2019–20 SLA, the deliverables relating to bottom-contacting surveys include analysis of data from the multispecies RV survey for focal species or groups associated with each protected area (Table 1). These include spatial distribution maps and summary statistics, which were provided for multiple species including fish, shellfish, and coral and sponges. Generally, the advice has been provided based on mean weight per tow or mean number per tow in each of the protected areas and biomass or abundance estimates are not calculated because of the lack of conformity between the DFO RV multispecies survey strata, various stock boundaries, and the protected area boundaries.

Another potential approach to the monitoring and management of these protected areas using data from the RV survey is the use of Ogmap to calculate biomass and abundance estimates based on sets that have been conducted inside each protected area. Ogmap is typically used in the NL Region for the Northern shrimp and Snow crab stock assessments as described above, however, its non-parametric approach assumes that trawl sets are independent random samples from the probability distribution at set locations and that nearby distributions are related. A Monte Carlo simulation is used to determine the probability distribution and 95% Confidence Intervals (CIs) are taken from the probability distribution (Evans et al. 2000; Orr et al. 2004). This methodology allows for the biomass and abundance estimation based on the selection of a specific area (e.g., a single protected area) and is not dependent on the underlying probability distribution within multiple underlying strata.

Ogmap estimations of biomass (thousands of tonnes) and abundance (thousands of individuals) were calculated for several of the focal species listed in Table 1 for their respective MPA or MR (Figures 28–33). This includes species listed as conservation objectives as well as other species of interest in the protected area. Data from the spring and fall RV surveys (1995–2019) were used where appropriate, however, coral and sponge groups were excluded from this analysis as Ogmap was found to be not appropriate for those data as they are not mobile species. Interpolated surfaces such as Kernel Density Estimates (KDE) would be a more appropriate method for examining coral and sponge groups.

This type of analysis is not currently being used in the NL Region and is shown here as a potential use of the RV survey data for monitoring and managing of protected areas. The main benefit is that it provides a historical view of biomass and abundance specific to each protected area and may allow for further investigation into the potential benefits of maintaining the MPA or MR. However, the influence of larger scale, population or ecosystem level influences need to be accounted for when interpreting these trends. For example, if there is an obvious shift in biomass and abundance around 2012–13, increasing for Atlantic Cod and decreasing for Northern Shrimp (see DFO 2019a; 2019c). In this case it is necessary to understand the broader scale changes in the ecosystem as opposed to looking at just the ongoing trends within the Hawke Channel closure.

It is unfortunate that it is not appropriate to use this methodology for corals and sponges since several of the protected areas have benthic habitat or communities such as corals and sponges listed as conservation objectives. Other methods will have to be used to monitor coral and sponge communities in the protected areas. Another limitation is that some of the protected areas only have a few sets along one side of the closure, for example, the 3O Coral closure. The biomass and abundance estimates for those areas do not consider the full protected area, only a portion of it that is sampled, and so those estimates may in some cases be based on a very small number of sets. Further investigation into using this analysis for monitoring protected areas is needed but it may provide some better resolution on biomass and abundance trends specific to the closed areas.

5.1.1. Benefits of Using Bottom Trawls to Monitor Protected Areas

Despite limitations, coral and sponge biomass and presence data from RV surveys have been successfully used as inputs in species distribution models (Guijarro et al. 2016; Kenchington et al. 2016a; 2016b; Gullage et al. 2017; Yesson et al. 2017; Beazley et al. 2018) and density estimations (Kenchington et al. 2014). Presence data is particularly useful, as it allows the visualization of taxa distribution, while acknowledging that null sets might not represent true absences for certain taxa (Wareham 2009). The RV dataset on coral presence in the NL Region represents an impressive dataset with an extensive geographic and bathymetric coverage (Wareham and Edinger 2007). While in this region corals have been identified to low taxonomic levels (i.e., genus, species), sponges have been mostly identified at the phylum level due to a more time-consuming sample processing and more limited taxonomic expertise, particularly at sea. RV biomass data has also helped to identify significant aggregations of corals and sponges in the region, as highlighted before (Kenchington et al. 2016a).

RV surveys represent an opportunity to collect large numbers of specimens, which can be advantageous in ecological studies. Specimen collection allows for more accurate species identifications (Beisiegel et al. 2017), and for obtaining samples for ecological analyses (Williams et al. 2015) including species associations (Baillon et al. 2012; Wareham-Hayes et al. 2017; Neves et al. 2020), reproduction (Sun et al. 2009; Sun et al. 2010; Hamel et al. 2020), genetics (Saucier 2016), stable isotopes (Sherwood et al. 2007; Salvo et al. 2018), morphometrics (Baillon et al. 2016), and coral health (Baker et al. 2019).

RV survey data have the potential to be used to obtain certain monitoring metrics. Kenchington et al. (2012) evaluated six coral and/or sponge indicators that can be calculated from trawl bycatch data: mean biomass, patch area, patch density, isolation/proximity of sponge grounds, connectivity between sponge grounds, and dispersion of sponge grounds and sea pen fields. These geospatial indicators have been suggested by these authors as a group of indicators that can use RV data with medium to high confidence. Although useful, these geospatial indicators are focused on large scale aggregations (e.g., sponge grounds and sea pens), excluding species of more sparse distribution. In the Laurentian Channel MPA, recommended direct indicators to monitor the status of sea pens include biomass, abundance and density, size distribution, geospatial indicators, taxonomic diversity and richness (DFO 2015). Abundance and density estimates have been suggested based on scientific surveys and catch rates (DFO 2015). However, see Section 5.1.2 below for limitations on the use of RV data to estimate coral abundance (and density) and size structure. Taxonomic diversity can be determined using samples collected during RV surveys, but it needs to be complemented with targeted collection and/or imagery due to low catchability of certain common sea pens (e.g., *Kophobelemnon* sp. – Section 5.1.2).

With regards to monitoring fish communities within protected areas, a bottom trawl is known to be one of the most effective ways to sample multiple species at one time and allows for the collection of specimens so various types of biological metrics can be obtained (e.g., length, weight, and diet data, genetic information, etc.). The Campelen 1800 shrimp trawl is one of the more efficient bottom trawls at catching smaller fish, allowing for a better representation of age classes and smaller-bodied species (Warren 1996).

5.1.2. Limitations of Using Bottom Trawls to Monitor Protected Areas

The most obvious limitation of RV surveys inside of protected areas is their destructive nature (Probert et al. 1997; Fosså et al. 2002; Hall-Spencer et al. 2002; Althaus et al. 2009; Neves et al. 2015b). Trawl surveys are also limited in terms of determining coral and sponge abundance (Kenchington et al. 2012; Kenchington et al. 2016a; 2016b), considering the unknown trawl catchability for selected taxa and fragile nature of specimens, which are often fragmented during the trawl process. Furthermore, corals and sponges can be patchy in their distribution, and it is difficult to determine whether specimens were found through the entire trawl path or at more specific locations. This has implications regarding our understanding of whether populations are naturally patchy or shaped by historic fishing (Watling and Norse 1998; Kulka and Pitcher 2002; Anderson and Clark 2003; Stone 2006). Kenchington et al. (2011) calculated a gear efficiency of only 5.2% for sea pen catchability with a Campelen trawl in the Laurentian Channel, in comparison to imagery data. Other studies have also highlighted the lower efficiency of other trawls and dredges in relation to camera surveys (e.g., Williams et al. 2015; Ayma et al. 2016; Chimienti et al. 2018a).

Certain sea pens common in the Laurentian Channel MPA (e.g., *Kophobelemnon* sp.) can be abundant based on imagery observations but are rarely caught or retained in the trawls due to their small size and/or behavior (Wareham 2009; V. Wareham-Hayes, unpublished data). Other sea pen species can completely withdraw in the soft sediment (*Pennatula* spp. And *Protoptilum* sp.; Langton et al. 1990; Chimienti et al. 2018b), which can limit their catchability (but see Section 2.1 on high *Pennatula aculeata* sea pen biomass). Therefore, the distribution and diversity metrics (e.g., richness) for these sea pens can be seriously underestimated in trawl catches, and alternative methods are necessary in order to properly include these taxa in monitoring plans (discussed in Section 4.).

RV trawl surveys are also limited in providing information on cold-water coral and sponge size, which can be used as a proxy for recruitment and recovery. The Campelen trawl cod-end liner mesh size is 40 mm (Walsh et al. 2009), which can allow juvenile corals and small sponges to pass through. In the case of the Redfish survey this is further complicated by the lack of a cod-end liner (Walsh et al. 2016). Furthermore, determining coral and/or sponge size is currently not part of the DFO-NL trawl surveys *at sea* protocol, and unless samples are kept for further analysis, ontogeny information is not routinely documented. Furthermore, in the case of sponges, specimens are too fragmented to be accurately counted. In the Laurentian Channel MPA, downward-looking imagery surveys have captured high densities of juvenile sea pens (*Pennatula* sp.; Miles and Edinger 2016). It is possible that under a trawl survey only, these juveniles would either not be caught by the trawl (albeit potentially removed) or be caught but not reported as juveniles, underestimating estimates of abundance based on biomass. Linney bags, small mesh bags attached to the outside portion of the net, are used in some RV surveys (e.g., Northern Shrimp Survey; Siferd 2015). These bags are used to collect animals that are too small to be retained within the net. Siferd (2015) found differences in the length frequencies of shrimp when comparing linney bag versus cod-end samples, helping to detect signatures of pre-recruit sized animals not captured in the standard trawl cod-end. The addition of linney bags to Campelen trawls might facilitate the detection of juvenile corals and sponges in an area. Nevertheless, catchability efficiency for juveniles might be even lower than for adults, and this issue has not been assessed yet.

Overall, RV trawl surveys provide restricted information on coral and sponge abundance, richness, biomass, and size structure, as the level of confidence for these parameters is low (e.g., Kenchington et al. 2011). Imagery surveys (e.g., videos, photos) are recommended for the collection of data for assessing these parameters (refer to Section 4.). RV surveys have been undoubtedly very useful in the initial reconnaissance of coral and sponge distribution in this region. However, since the beginning of the Cold-water Corals and Sponges Program at DFO-NL in 2007, our knowledge has increased considerably. Several of the current knowledge gaps cannot be necessarily assessed using RV survey samples (e.g., behavior, *in situ* studies, impacts of oil and gas exploration and aquaculture activities, understanding of their habitat, community structure, associations, etc.). A comparison of benefits and limitations of RV surveys based on DFO-NL coral and sponge samples is shown in Table 10.

With regards to sampling fish communities, the Campelen bottom trawl, like many bottom trawls, has its limitations. No trawl gear catches all the fish in its path, so density estimates provided by trawl samples do not reflect true fish densities (Fraser et al. 2007). Catchability in a trawl gear is affected by many factors and varies both between species and between different sized conspecifics, and therefore has the capacity to confound our understanding of predator-prey interactions and of the relative abundance of different species and size classes of fish at any point in time or space. Estimates of the catchability of each size class of each species sampled in a given survey would be required for more accurate trawl sample densities (Fraser et al. 2007).

5.2. OTHER POTENTIAL METHODS / DATA SOURCES

In the NL Region, the protected areas with conservation objectives to protect corals and sponges are in mean water depths of ~363–1,892 m (GEBCO 2019, bathymetry data), which causes limitations on the type of alternative gear that can be utilized for monitoring. Deep-sea cold-water coral and sponge research has been increasingly performed using imagery technology, which is a less invasive alternative in comparison to trawl surveys (Dayton et al. 2013; Wynn et al. 2014; Pirtle et al. 2015; Yoklavich et al. 2015; Ayma et al. 2016; Sward et al. 2019). The use of such technologies has also been advocated for the monitoring of deep-sea conservation areas (Huvenne et al. 2016), and to obtain cold-water coral and sponge metrics that cannot accurately be determined using trawl data, such as abundance and size (e.g., Kenchington et al. 2012). Remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), manned submersibles, towed platforms, and drop camera systems all have the potential to yield high resolution seafloor imagery, which in turn can be used to determine coral and sponge abundance and density (e.g., Langton et al. 1990; Mortensen and Buhl-Mortensen 2004; Beazley et al. 2013; Martinelli et al. 2013; Porporato et al. 2014; Long et al. 2020; Dinn et al. 2020), size (Watanabe et al. 2009; Bennecke and Metaxas 2017), and estimates of diversity (Beisiegel et al. 2017). Time-lapse image monitoring systems have also been applied in different parts of the world (e.g., Roberts et al. 2005; Juniper et al. 2019; Aguzzi et al. 2020) and can be useful for monitoring of coral and sponge growth *in situ* as well as observations of animal behavior. Some systems can offer different camera views of the seafloor (e.g., forward and downward-looking, variable distances from the seafloor), allowing for analyses at different spatial scales and resolution (e.g., Stone 2006; Lacharité and Metaxas 2017).

ROV technologies have the advantage of having high position accuracy and sample collection capabilities, including targeted specimens (or part of a specimen), surrounding sediment, and seawater. Some benthic sleds adapted with cameras can also include a cod-end net for the collection of specimens. In cases where camera systems do not have sampling capabilities, this can be overcome if associated with deployments of small bottom-contact gear, such as an Agassiz trawl, which can be towed for an average of three minutes, but with a considerable reduction in footprint in comparison to a Campelen trawl. Additionally, sediment samplers (e.g., box-cores, grabs) can also be used as a complement to obtain biodiversity metrics (e.g., Van Soest and Lavaleye 2005; Dinn et al. 2020). In their study, Van Soest and Lavaleye (2005) reported 95 species of sponges collected in 20 box-core deployments and concluded that these box-coring efforts yielded similar richness as dredging and trawling in their study area. Bottom type is a limiting factor on the choice of gear, as the use of trawls and cores in hard bottom areas is not recommended. In fact, several studies have highlighted the need for complementary types of gear in order to better assess benthic diversity, as different gear types such as cameras and benthic sleds are not interchangeable, but only complementary (e.g., Williams et al. 2015; Ayma et al. 2016; Clark et al. 2019).

Imagery technologies have been used in the monitoring of protected areas in Canada (e.g., The Gully; Allard et al. 2015), the United Kingdom (Sheehan et al. 2010; Bicknell et al. 2016; Huvenne et al. 2016; Sheehan et al. 2016), the United States (Stone 2006), and New Zealand (Tracey et al. 2019). They have also been used to investigate the effectiveness of conservation areas (e.g., Huvenne et al. 2016; Bennecke and Metaxas 2017). Therefore, camera technologies should be integrated into monitoring programs, along with a plan and budget for capacitated personnel and ship time. Despite the costs associated with these technologies, monitoring programs can be set to take place every 3, 5 or more years (e.g., Kenchington et al. 2012). It should also be mentioned that even if RV trawl surveys continue inside protected areas, imagery technologies are still recommended for better monitoring. In the Laurentian Channel MPA for example, sea pen abundance has been suggested as one of the direct indicators for monitoring (DFO 2015); however, trawls are not appropriate gear for these assessments.

There is also growing interest in the use of environmental DNA (eDNA) for monitoring of protected areas (Rees et al. 2014; Aylagas et al. 2018; Ruppert et al. 2019). However, the use of eDNA for the specific identification of corals and sponges at low taxonomic levels (i.e., high resolution) is still in its infancy (e.g., Everett and Park 2018) and more research is needed. Yet, eDNA can be used to explore changes in overall diversity trends (e.g., Aylagas et al. 2018), and should be further considered as a potential tool for the monitoring of protected areas, in combination with other sampling methods, such as the imagery technologies described above (e.g., Stat et al. 2019).

6. CONCLUDING REMARKS

It is known that bottom-contacting scientific sampling gears can have similar damaging impacts on vulnerable benthic taxa as commercial fishing gears, although at vastly reduced scales. However, the analyses presented here do not support a blanket exclusion of research surveys from all protected areas. Survey recurrence times in relation to expected recovery times suggest that bottom-contacting science surveys do not pose a major long-term threat to benthic ecosystems. In addition, any such decision to completely exclude scientific surveys would be likely to bias data sources that play a crucial role in ecosystem monitoring and resource assessments for demersal fish and shellfish stocks. These scientific surveys also play an important role in monitoring some of the conservation objectives of the protected areas. While bottom-contacting surveys are not the best option for monitoring vulnerable benthic taxa, efforts should be made to improve sampling protocols to maximize the information gathered from these surveys relating to benthic taxa in protected areas. And although the bottom-contacting scientific surveys described here may not pose long-term threats to benthic taxa, mitigation measures (e.g., avoiding smaller areas of high densities of benthic taxa within the protected areas) should be explored in order to minimize harm.

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8. TABLES

Table 1. Details regarding protected areas in the NL Region.

Protected Area	Jurisdiction	Approximate Size (km^2)	Closure Type	Monitored Focal Species/Group	Scenario
Laurentian Channel	Canada	11,580	MPA	Sea Pens**, Smooth Skate, Black Dogfish, Northern Wolffish, Porbeagle Shark***, Leatherback Turtle***	B: Sea pen Closure
Hopedale Saddle	Canada	15,411	MR	Large and Small Gorgonian Corals**, Sponges**, Northern and Spotted Wolffish, Roundnose Grenadier, Northern Shrimp, Snow Crab	A: Sponge / Gorgonian Closure
Northeast Newfoundland Slope	Canada	55,353	MR	Large and Small Gorgonian Corals**, Sponges**, Sea Pens*, Northern and Atlantic Wolffish, Greenland Halibut	A: Sponge / Gorgonian Closure
3O Coral Closure	NAFO	13,999*	NAFO	Large and Small Gorgonian Corals**, Sea Pens**, Atlantic Cod	A: Sponge / Gorgonian Closure
Hawke Channel	Canada	8,837	MR	Benthic habitat, Atlantic cod, Northern Shrimp, Northern Wolffish	C: Fish Habitat
Funk Island Deep	Canada	7,274	MR	Benthic habitat, Atlantic cod, Northern Shrimp, Smooth Skate	C: Fish Habitat
Tail of the Bank	NAFO	144	NAFO	Sponges	A: Sponge / Gorgonian Closure
Flemish Pass/Eastern Canyon	NAFO	5,417	NAFO	Sponges, Large Gorgonian Corals	A: Sponge / Gorgonian Closure
Sackville Spur	NAFO	988	NAFO	Sponges	A: Sponge / Gorgonian Closure

* A portion of the 3O Coral Closure (10,422 km2) is located within the Canadian EEZ and was designated as a Marine Refuge in 2017.
** Species excluded from Ogmap analysis in Section 5.1.
*** Species not typically captured in the RV Survey.

Table 2. Summary of current bottom-contacting surveys in the NL Region.

Survey	Target Species	Gear	Survey Design	Frequency	Mean # Sets per Survey	Mean Swept Area per haul/set (km^2)	Mean Swept Area per Survey (km^2)
Spring Multispecies RV Survey	Various	Campelen Bottom Trawl	Random-Stratified	Annual	479	0.074	35.446
Fall Multispecies RV Survey	Various	Campelen Bottom Trawl	Random-Stratified	Annual	691	0.074	51.134
Unit 2 Redfish Survey	Redfish	Campelen Bottom Trawl	Random-Stratified	Biennial	110*	0.0667	7.337
Post-Season Crab Trap Survey	Snow Crab	Crab Pots	Fixed/Random	Annual	1,085 (8,986 pots)	0.000479	0.519
Longline Halibut Survey	Atlantic Halibut	Longline	Random-Stratified	Annual	146*	0.51	74.46

* Not all sets fall into the NL Region.

Table 3. Proportion of DFO-NL RV sets (1995–2019) inside SiBAs that are located in protected areas in Canadian jurisdiction and inside VME that are located in NAFO VME Closures in the NRA. Values that are not applicable (n/a) indicate that there is no SiBA or VME identified for that area and taxon.

Protected area	Jurisdiction	Sea pens	Sponges	Large gorgonians	Small gorgonians	Total sets
Funk Island Deep Closure	Canada	n/a	n/a	n/a	n/a	174
Hawke Channel Closure	Canada	n/a	n/a	n/a	n/a	263
Hopedale Saddle Closure	Canada	0.32	49.37	40.19	0.32	316
Laurentian Channel MPA	Canada	61.08	n/a	n/a	n/a	609
Northeast Newfoundland Slope Closure	Canada	73.74	28.68	9.87	6.33	537
3O Coral Closure (complete)[1]	NAFO[1]	1.41	n/a	n/a	n/a	142
3O Coral Closure (partial, EEZ)[2]	NAFO[2]	14.71	n/a	28.68	50.74	136
Flemish Pass/Eastern Canyon	NAFO	1.46	80.29	67.88	n/a	137
Sackville Spur	NAFO	n/a	66.67*	n/a	n/a	3
Tail of the Bank	NAFO	n/a	100*	n/a	n/a	1

[1] Analyses based on entire 3O coral closure;
[2] Analyses based on only portion of 3O coral closure within Canadian EEZ
* Note very small total number of sets.

Table 4. Total area of RV survey bottom-contacting gear tracks and VMS tracks for commercial bottom otter trawl (stern) from 2005–14 in each of the protected areas. The percentage of each protected area is also included for comparison.

Protected Area	Area of RV Survey tracks (km^2)	Area of Unit 2 Redfish Survey tracks (km^2)	Area of VMS fishing tracks (bottom otter trawl [stern]) (km^2)
Laurentian Channel MPA	17.71 (0.153%)	8.452 (0.073%)	599.409 (5.164%)
3O Coral Closure	4.38 (0.031%)	0 (0%)	43.936 (0.312%)
Flemish Pass/Eastern Canyon Closure	3.48 (0.064%)	0 (0%)	2.645 (0.048%)
Northeast Newfoundland Slope Closure	15.39 (0.028%)	0 (0%)	711.942 (1.279%)
Funk Island Deep Closure	4.99 (0.068%)	0 (0%)	0 (0%)
Hawke Channel Closure	6.63 (0.075%)	0 (0%)	4.270 (0.048%)
Hopedale Saddle Closure	9.80 (0.064%)	0 (0%)	18.823 (0.122%)

Table 5. Proportion of protected areas impacted and recurrence time intervals for each survey. Spring and Fall portions of the RV survey were calculated separately then combined to get overall values for the annual survey. Na values indicate that the survey did not overlap with the corresponding protected area.

Protected Area	Jurisdiction	Spring RV Survey		Fall RV Survey		Overall RV Survey		Unit 2 Redfish Survey		Crab Trap Survey		Longline Halibut Survey	
		Prop. Impact ($year^{-1}$)	Recurrence Interval (years)	Prop. Impact ($year^{-1}$)	Recurrence Interval (years)	Prop. Impact ($year^{-1}$)	Recurrence Interval (years)	Prop. Impact ($year^{-1}$)	Recurrence Interval (years)	Prop. Impact ($year^{-1}$)	Recurrence Interval (years)	Prop. Impact ($year^{-1}$)	Recurrence Interval (years)
Funk Island Deep Closure	Canada	na	na	0.000074	13,461	0.000074	13,461	na	na	0.000002	590,047	na	na
Hawke Channel Closure	Canada	na	na	0.000087	11,508	0.000087	11,508	na	na	0.000001	924,386	na	na
Hopedale Saddle Closure	Canada	na	na	0.000069	6,705	0.000069	6,705	na	na	na	na	na	na
Laurentian Channel MPA	Canada	0.000173	5,717	na	na	0.000173	5,717	0.000066	14,916	2.63E-7	1,604,532	0.000143	6,994
Northeast Newfoundland Slope Closure	Canada	0.0000001	4,819	0.000029	9,658	0.000029	9,634	na	na	1.72E-8	1,179,123	na	na
St. Anns Bank MPA	Canada	na	na	na	na	na	na	0.000018	17,548	na	na	0.000189	5,278
Gully MPA	Canada	na	na	na	na	na	na	0.000002	12,035	na	na	0.000102	4,759
3O Coral Closure (complete)[1]	NAFO[1]	0.000003	2,757	0.000025	10,704	0.000028	9,475	na	na	na	na	0.000002	6,033
3O Coral Closure (partial, EEZ)[2]	NAFO[2]	0.000004	2,757	0.000031	10,343	0.000035	9,086	na	na	na	na	0.000002	6,033
Flemish Pass/Eastern Canyon	NAFO	0.000014	3,674	0.000058	13,322	0.000072	10,695	na	na	na	na	na	na
Sackville Spur	NAFO	na	na	0.000003	11,612	0.000003	11,612	na	na	na	na	na	na
Tail of the Bank	NAFO	na	na	0.000024	11,891	0.000024	11,890	na	na	na	na	na	na

[1] Analyses based on entire 3O coral closure;
[2] Analyses based on only portion of 3O coral closure within Canadian EEZ

Table 6. Summary of survey area overlapping each protected area and the cumulative proportion of impact and recurrence time intervals for all surveys combined.

Protected Area	Jurisdiction	Total Area (km^2)	Redfish Survey Overlap (km^2)	Crab Trap Survey Overlap (km^2)	RV Survey Overlap (km^2)	Longline Halibut Survey Overlap (km^2)	Cumulative Survey Area Overlap (km^2)	Prop. Survey Overlap	Cumulative Prop. Impact ($years^{-1}$)	Cumulative Recurrence Interval (years)
Funk Island Deep Closure	Canada	7,284.3	na	7,162.9	7,284.3	na	7,287.3	1.00	0.000076	13,171
Hawke Channel Closure	Canada	8,838.3	na	8,678.7	8,838.3	na	8,850.9	1.00	0.000088	11,385
Hopedale Saddle Closure	Canada	15,374.5	na	na	7,138.2	na	7,138.2	0.46	0.000069	6,705
Laurentian Channel MPA	Canada	11,607.9	11,513.1	4,882.2	11,489.9	11,607.9	11,607.9	1.00	0.000383	2,612
Northeast Newfoundland Slope Closure	Canada	55,654.9	na	1,128.7	15,699.8	na	15,680.0	0.28	0.000029	9,616
St. Anns Bank MPA	Canada	4,363.2	1,414.9	na	na	4,361.4	4,361.8	1.00	0.000208	4,810
Gully MPA	Canada	2,362.9	62.7	na	na	1,144.9	1,182.3	0.50	0.000104	4,810
3O Coral Closure (complete)[1]	NAFO[1]	14,091.1	na	na	3,716.9	156.9	3,716.9	0.26	0.000030	8,884
3O Coral Closure (partial, EEZ)[2]	NAFO[2]	10,453.2	na	na	3,464.8	156.9	3,464.8	0.33	0.000038	8,734
Flemish Pass / Eastern Canyon	NAFO	5,471.8	na	na	4,196.6	na	4,196.6	0.77	0.000072	10,695
Sackville Spur	NAFO	1,005.8	na	na	30.0	na	30.0	0.03	0.000003	11,612
Tail of the Bank	NAFO	144.9	na	na	40.7	na	40.7	0.28	0.000024	11,891

[1] Analyses based on entire 3O coral closure;
[2] Analyses based on only portion of 3O coral closure within Canadian EEZ.

Table 7. Summary of percentage of survey area, strata that intersect, and sets within protected areas in each scenario, by EPU.

EPU	Scenario	Percentage of EPU in protected areas	Percentage of strata that intersect protected areas	Percentage of sets within protected areas
2H	A	17.6%	57.1%	23.7%
2J3K	A	6.1%	21.3%	13.5%
-	C	7.5%	20.0%	7.0%
-	ABC	16.6%	41.3%	20.5%
3LNO	A	0.2%	4.7%	Spring – 1.4% Fall – 1.4%
3Ps	B	18.8%	24.2%	16.8%

Table 8. List of demersal fish stocks for which stratified estimates were recalculated by omitting RV multi-species bottom trawl data that were collected from within protected areas.

Species	Stock/ Divs[1]	Jurisdiction	Survey/Time Series
American plaice	2J3K	DFO	Fall
American plaice	3LNO	NAFO	Fall, Spring
American plaice	3Ps	DFO	Spring
Atlantic cod	2J3KL	DFO	Fall
Atlantic cod	3NO	NAFO	Fall, Spring
Atlantic cod	3Ps	DFO	Spring
Redfish	2J3K	DFO	Fall
Redfish	3LN	NAFO	Fall, Spring
Redfish	3O	NAFO	Fall, Spring
Redfish	3Ps	DFO	Spring
Greenland halibut[2]	2J3K	NAFO	Fall
Greenland halibut[2]	3LNO	NAFO	Fall, Spring
Greenland halibut	3Ps	DFO	Spring
Witch flounder	2J3KL	DFO	Fall
Witch flounder	3NO	NAFO	Fall, Spring
Witch flounder	3Ps	DFO	Spring
Yellowtail flounder	3LNO	NAFO	Fall, Spring
Yellowtail flounder	3Ps	DFO	Spring
Thorny skate	2J3K	DFO	Fall
Thorny skate	3LNOP	DFO/NAFO	Fall, Spring
Smooth skate	2J3K	DFO	Fall
Smooth skate	3LNOP	DFO	Fall, Spring
White hake	3NOPs	NAFO	Fall, Spring
Striped wolffish	2J3K	DFO	Fall
Striped wolffish	3LNO	DFO	Fall, Spring
Striped wolffish	3Ps	DFO	Spring
Spotted wolffish	2J3K	DFO	Fall
Spotted wolffish	3LNO	DFO	Fall, Spring
Spotted wolffish	3Ps	DFO	Spring
Haddock	3LNO	DFO	Fall, Spring
Haddock	3Ps	DFO	Spring
Roughhead grenadier	2J3K	NAFO	Fall
Monkfish	3NOPs	DFO	Fall, Spring

[1] In some cases the Divs. used to assess the stock do not equate to the total stock area;
[2] The assessment for this stock uses the Canadian survey data split into two division groupings.

Table 9. Summary of Multi-species RV Survey strata used in STRAP that were merged, and number of merged strata broken down by protected area.

Jurisdiction	Protected Area	Number of strata merged	Number of new strata
DFO	Division 3O Coral and Sponge Conservation Closure	14	5
DFO	Funk Island Deep Closure	5	2
DFO	Hawke Channel Closure	7	2
DFO	Hopedale Saddle Closure	18	3
DFO	Laurentian Channel MPA	9	3
DFO	Northeast Newfoundland Slope Closure	23	5
NAFO	Flemish Pass/Eastern Canyon	13	5
NAFO	Sackville Spur	3*	1*
NAFO	Tail of the Bank	2*	1*

* The merged strata that overlaps the Sackville Spur also overlaps with Northeast Newfoundland Slope Closure, similarly the merged strata that overlap with the Tail of the Bank overlaps with the Flemish Pass/Eastern Canyon. Both are reflected in counts for both protected areas.

Table 10. Benefits and limitations of RV scientific trawl surveys for cold-water coral and sponge research and advice in the NL Region.

RV samples	**Benefits**	**Limitations**
Abundance	• Indication of potential hotspots, or areas of significant concentrations.	• Due to low trawl catchability for these taxa, data on abundance can represent underestimations of true abundance.
Distribution	• Large spatial coverage.	• Limited to presence data. • Limited to depths <1,500 m.
Taxonomy and species richness	• Large number of samples available for species identification (dissection, genetics, exchanges with other researchers). • Additional sampling along with sponge spp. Sampled from within/on the *K. flexibilus* thickets (Dinn and Leys 2018; Dinn et al. 2020).	• Difficult to determine species morphology (fragmented pieces, deflated, constricted). • No information on *in situ* morphology and habitat. • Trawl catchability limits collection of certain species (e.g., sea pens with withdrawing behavior) and is limited to trawlable bottoms.
Identification of key areas	• Surveys can provide information on areas of significant concentrations (e.g., *Keratoisis flexibilus*. Disko Fan, SE Baffin Bay (Neves et al. 2015a). • *Geodia*-type sponge grounds.	• Community partly wiped out. • Community level impacts unknown. • Not capturing diverse sponge communities that are comprised of 'lighter' sponge species.
Behaviour	• Limited. Possible if specimens are examined immediately after collection and kept alive for a certain period (taxa-dependent).	• Most of the time specimens are not kept alive.
Ecology	• Ecological studies (reproduction, growth) possible, large number of specimens available advantageous.	• Specimens mixed with others in trawl (contamination for certain studies such as microbiomes).
Functional role(s) • Provision of habitat • Ecosystem functioning • Benthic-pelagic coupling	• Samples drew our attention to the relationship. • Limited. Possible for endobionts, embedded, encompassed, or firmly attached specimens.	• Difficult to quantify because of fragmented material. • Challenging for mobile associates, which might escape during trawling.

9. FIGURES

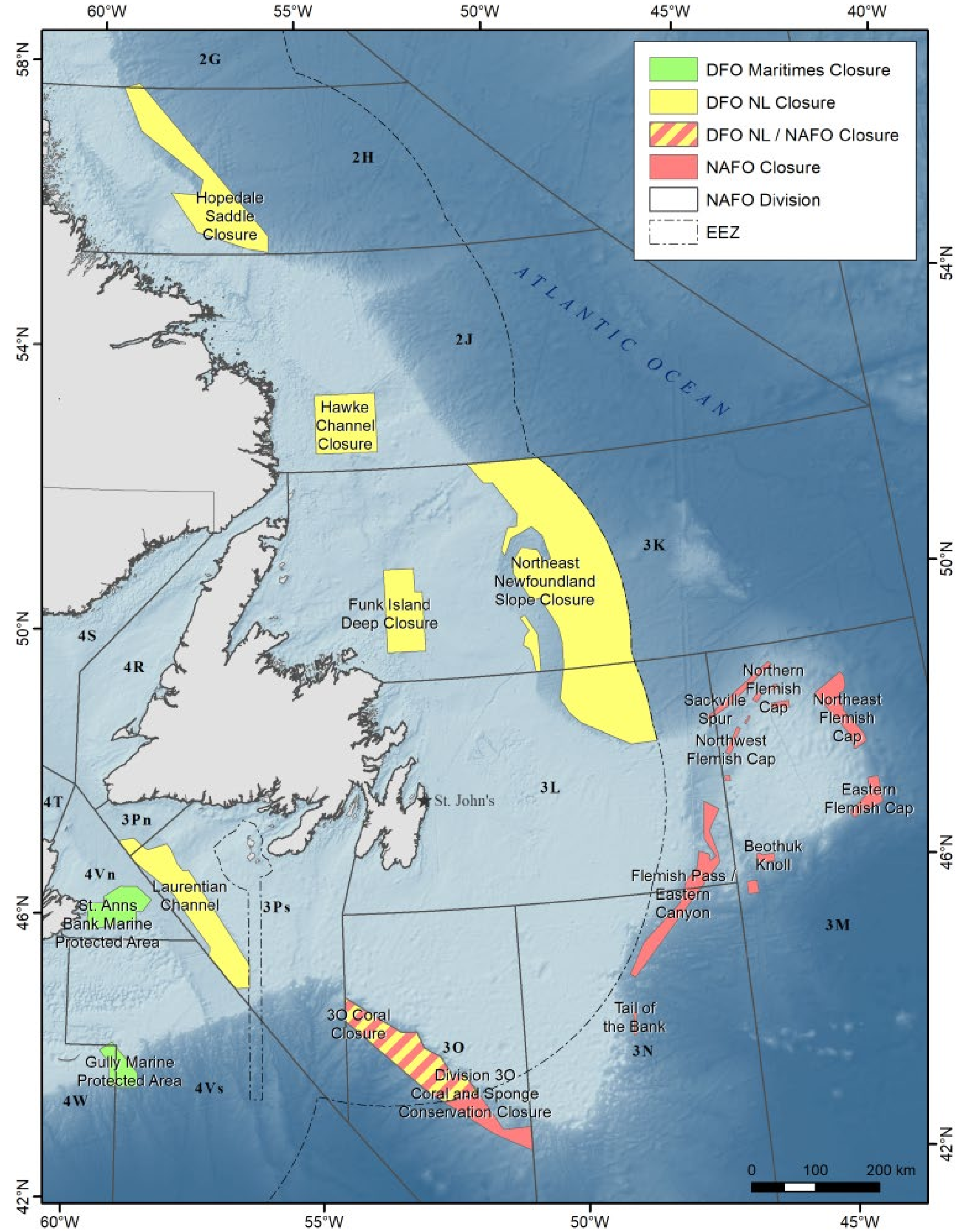


Figure 1. Map of the MRs, MPAs, and NAFO closures in which one or more ongoing scientific surveys employing bottom-contacting gear occurs.

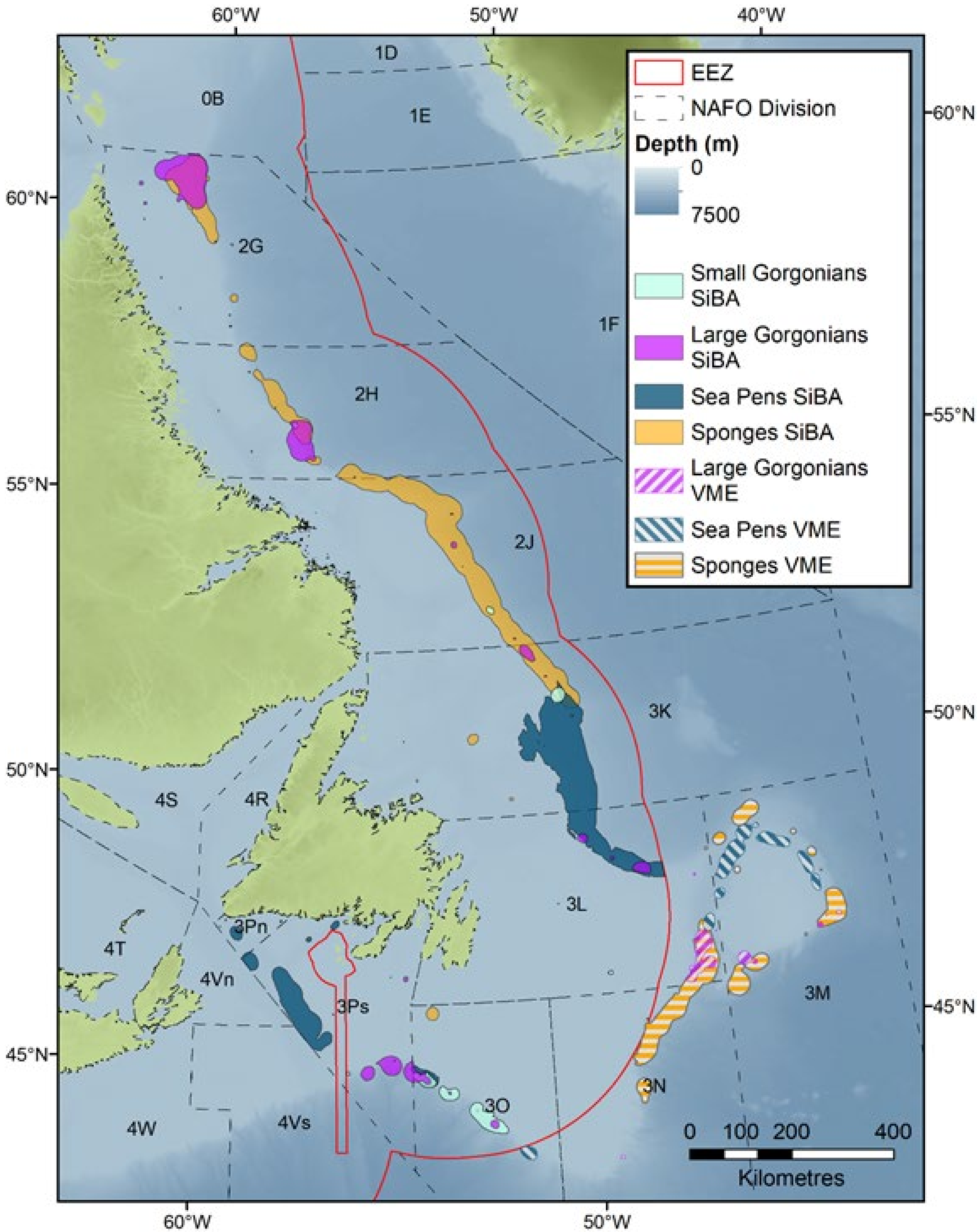


Figure 2. Location of SiBAs and VME habitats currently defined in the NL Region.

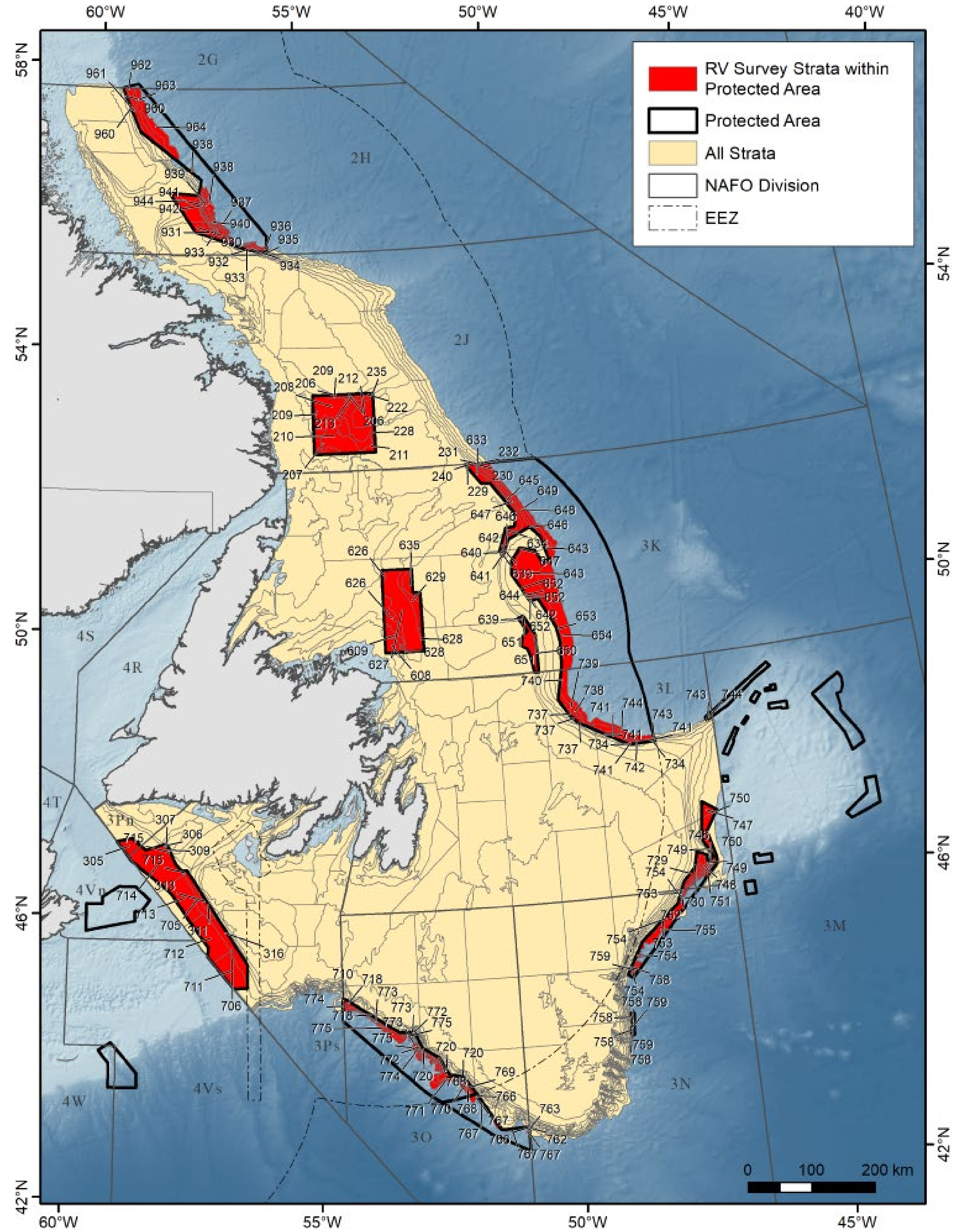


Figure 3. Map demonstrating the survey stratification scheme for Newfoundland and Labrador multi-species bottom trawl surveys in relation to protected areas in the region. The fall survey covers Divs. 2HJ3KLNO. The spring survey covers Divs. 3LNOPs. The overlap between the survey footprint and the closed areas is highlighted red and the strata that overlap all or partially with the protected areas are labelled.

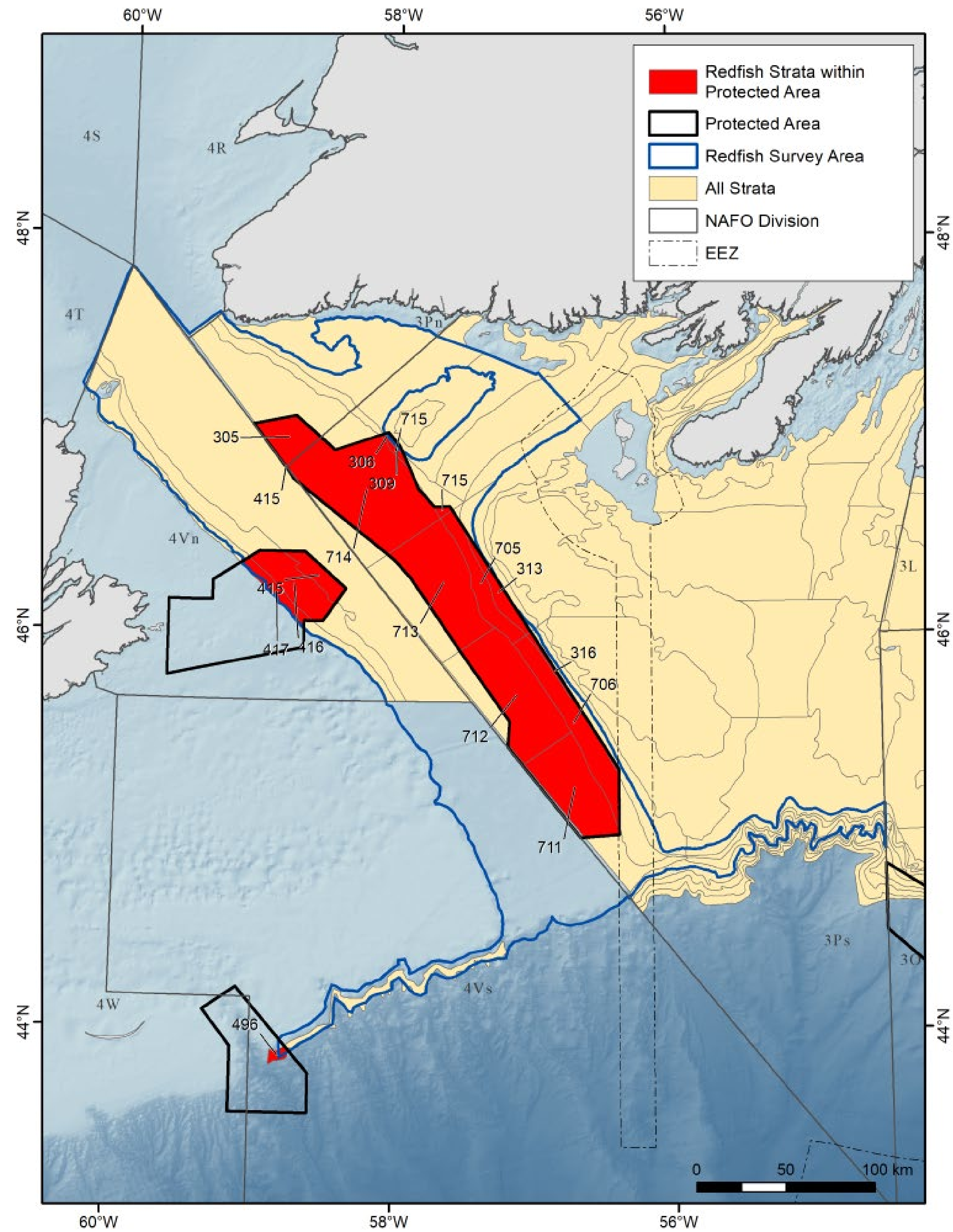


*Figure 4. Strata for the Unit 2 redfish survey. *Note that this is not a complete picture of the strata for this survey as a file containing all the stratum spatial polygons was not available at the time that these analyses were performed. Four strata outside the NL Region were included here which contain survey sets within the boundaries of the relevant protected areas.*

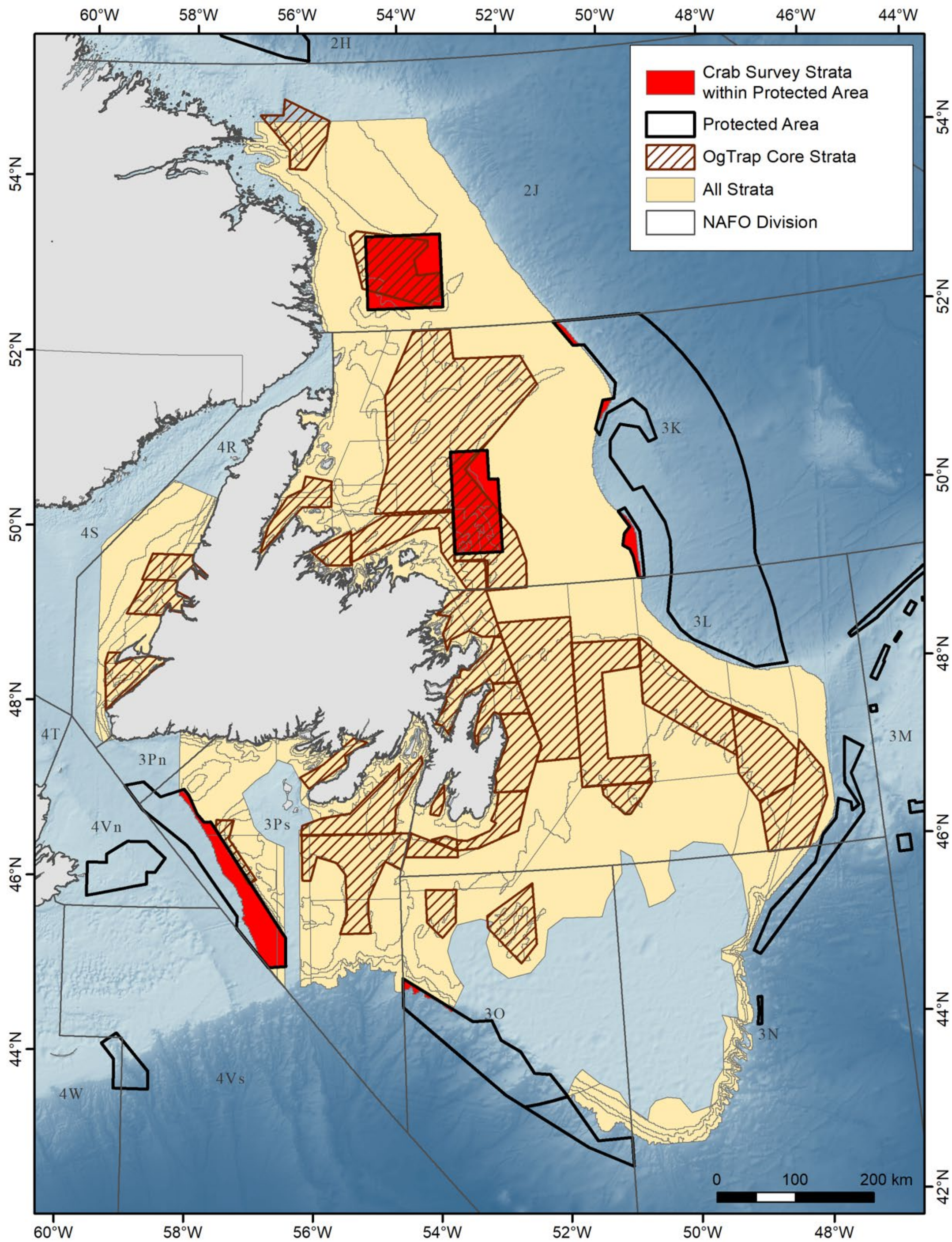


Figure 5. Map demonstrating the survey stratification scheme for the CPS crab survey in relation to protected areas in the NL Region. The overlap between the survey footprint and the closed areas is highlighted red. The hatched areas represent the core strata that are used for exploitable biomass estimation in OgTrap.

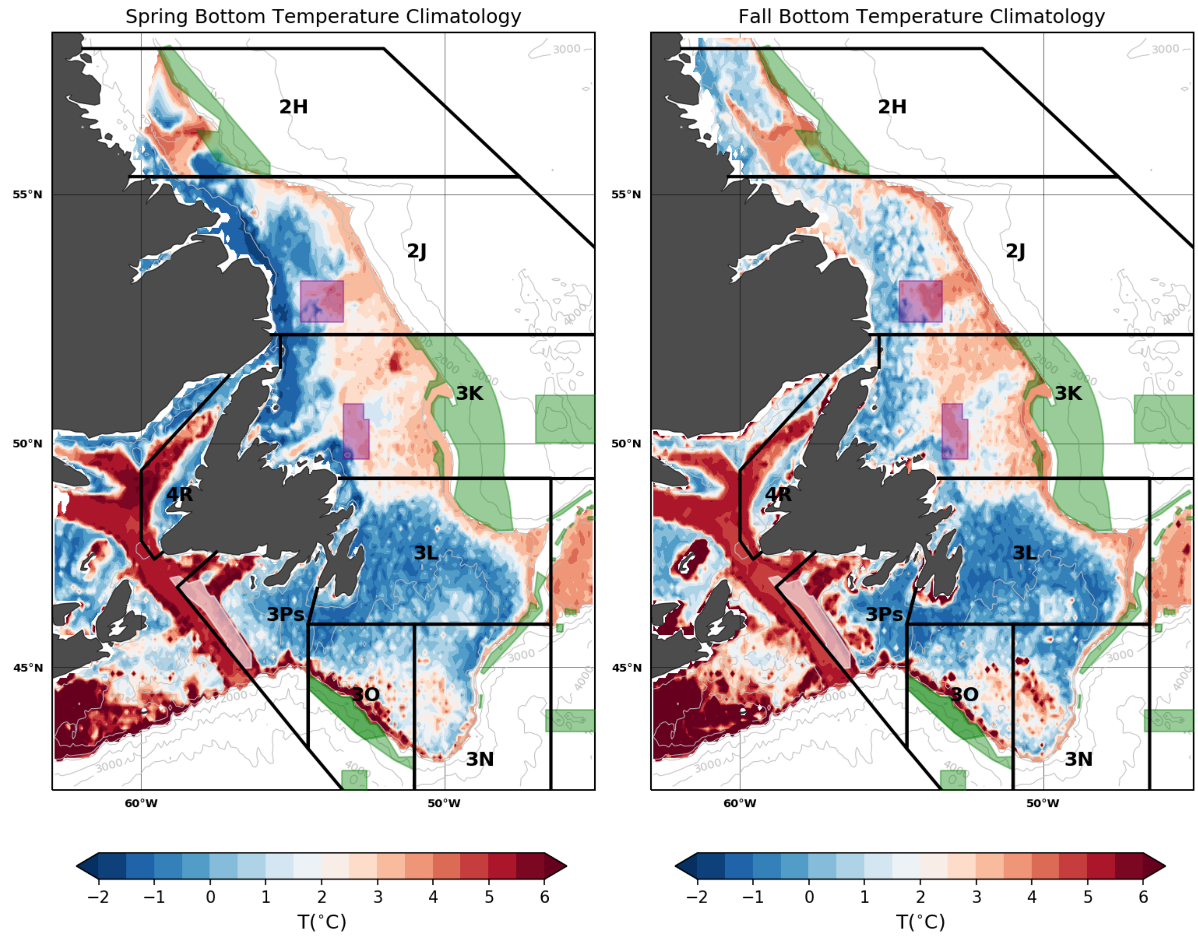


Figure 6. Maps of the mean 1981–2010 spring (left) and fall (right) bottom temperature. The closures group are drawn in translucid green (group A; gorgonian and sponge closures), white (group B; sea pen closure) and purple (group C; fish habitat closures). NAFO divisions are also drawn for reference. Bottom temperatures are only calculated for depths shallower than 1,000 m.

< -3.0	-3.0 to -2.5	-2.5 to -2.0	-2.0 to -1.5	-1.5 to -1.0	-1.0 to -0.5	-0.5 to 0.0	0.0 to 0.5	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	> 3.0

Figure 7. Color scale used for the presentation of normalized anomalies presented in Figures 8 and 9. Color levels are incremented by 0.5 SD, where blue is below normal and red above normal. Values between 0 and ±0.5 SD remain white indicating normal conditions.

	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	x̄	sd
-- NAFO division 3LNO --																																
T_{bot} (°C) – Reference	-0.1	-0.1	0.1	0.4	0.2		1.1	0.6	1.4	1.8	1.4	1.1	1.0	0.5	1.8	1.4	1.4	1.2	1.2	1.2	1.6	2.3	1.9	1.7	0.8	1.0	0.8	1.0	1.2	1.2	1.0	0.6
T_{bot} (°C) – Scenario A	-0.1	-0.1	0.1	0.4	0.2		1.1	0.6	1.4	1.8	1.4	1.1	1.0	0.5	1.8	1.4	1.4	1.2	1.2	1.2	1.6	2.3	1.9	1.7	0.8	1.0	0.8	1.0	1.2	1.2	1.0	0.6
T_{bot} (°C) – Scenario B	-0.1	-0.1	0.1	0.4	0.2		1.1	0.6	1.4	1.8	1.4	1.1	1.0	0.5	1.8	1.4	1.4	1.2	1.2	1.2	1.6	2.3	1.9	1.7	0.8	1.0	0.8	1.0	1.2	1.2	1.0	0.6
T_{bot} (°C) – Scenario AB	-0.1	-0.1	0.1	0.4	0.2		1.1	0.6	1.4	1.8	1.4	1.1	1.0	0.5	1.8	1.4	1.4	1.2	1.2	1.2	1.6	2.3	1.9	1.7	0.8	1.0	0.8	1.0	1.2	1.2	1.0	0.6
T_{bot} (°C) – Scenario ABC	-0.1	-0.1	0.1	0.4	0.2		1.1	0.6	1.4	1.8	1.4	1.1	1.0	0.5	1.8	1.4	1.4	1.2	1.2	1.2	1.6	2.3	1.9	1.7	0.8	1.0	0.8	1.0	1.2	1.2	1.0	0.6
Sc. A (% change)	-0.6	-0.3	-2.0	0.0	-2.6		-0.2	0.1	0.0	-0.1	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	-0.4	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.2	0.6
Sc. B (% change)	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Sc. AB (% change)	-0.6	-0.3	-2.0	0.0	-4.0		-0.2	0.1	0.0	-0.1	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	-0.1	-0.4	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.3	0.8
Sc. ABC (% change)	-1.6	-0.2	-1.9	0.0	-4.0		-0.2	0.1	-0.2	-0.1	0.0	-0.1	-0.3	-0.2	0.0	0.0	0.0	0.0	-0.1	-0.4	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	-0.2	0.4	0.8
-- NAFO division 3Ps --																																
T_{bot} (°C) – Reference				1.8	1.8	2.0	2.3	1.8	2.3	2.8	2.9	1.8	2.1	1.4	2.2	2.6		1.7	2.3	2.5	2.6	3.0	2.9	2.7	2.5	2.6	3.1	2.5	2.9	2.7	2.2	0.4
T_{bot} (°C) – Scenario A				1.8	1.8	2.0	2.3	1.8	2.3	2.8	2.9	1.8	2.1	1.4	2.2	2.6		1.7	2.3	2.5	2.6	3.0	2.9	2.7	2.5	2.6	3.1	2.5	2.9	2.7	2.2	0.4
T_{bot} (°C) – Scenario B				1.8	1.8	2.0	2.3	1.8	2.2	2.8	2.9	1.8	2.1	1.4	2.2	2.6		1.7	2.1	2.5	2.6	3.0	2.9	2.7	2.5	2.6	3.0	2.5	2.9	2.6	2.1	0.4
T_{bot} (°C) – Scenario AB				1.8	1.8	2.0	2.3	1.8	2.2	2.8	2.9	1.8	2.1	1.4	2.2	2.6		1.7	2.1	2.5	2.6	3.0	2.9	2.7	2.5	2.6	3.0	2.5	2.9	2.6	2.1	0.4
T_{bot} (°C) – Scenario ABC																																
Sc. A (% change)				0.0	-1.2	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2
Sc. B (% change)				-1.1	-0.8	0.6	0.2	-3.6	-1.6	-0.1	-0.2	-2.1	0.0	-2.4	-2.6	-0.2		-2.2	-8.7	-1.1	-1.2	-0.2	-1.3	0.3	-2.4	-0.5	-2.5	-1.6	0.4	-3.2	1.6	1.9
Sc. AB (% change)				-1.2	-1.9	0.6	0.0	-3.6	-1.6	-0.1	-0.2	-2.1	0.0	-2.4	-2.6	-0.2		-2.2	-8.7	-1.1	-1.2	-0.2	-1.3	0.3	-2.4	-0.5	-2.5	-1.6	0.4	-3.2	1.6	1.9
Sc. ABC (% change)																																

Figure 8. Scorecards of mean spring bottom temperature for NAFO divisions 3LNO (top) and 3Ps (bottom). The top row of each panel represents the reference scenario (no removal) and is followed by the four exclusion scenarios studied here. These cells are color-coded according to their normalized anomaly compared to the 1980–2010 climatology (color-code of Figure 7). The climatological average and SD appear in the last two columns. The bottom four lines of each panel (in bold) represent the percentage change of each scenario compared to the reference. For these rows, only the values lower/greater than ±5% are colored and the last two columns correspond to the average absolute value percentage change and its SD. Gray cells indicate an absence of data.

	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	x	sd
-- NAFO division 2H --																																
T_{bot} (°C) – Reference		1.4						2.2	2.2	2.4		2.1			2.8		2.2		2.3		3.0	3.1	2.4	2.1	2.2	2.0	2.1	1.7	2.4	2.4	2.3	0.5
T_{bot} (°C) – Scenario A		1.4						2.2	2.2	2.4		2.0			2.6		2.1		2.2		3.0	3.0	2.5	2.1	2.3	2.1	2.0	1.6	2.4	2.3	2.2	0.4
T_{bot} (°C) – Scenario B																																
T_{bot} (°C) – Scenario AB																																
T_{bot} (°C) – Scenario ABC																																
Sc. A (% change)		0.0						0.0	0.0	0.0		-4.8			-7.1		-4.5		-4.3		0.0	-3.2	4.2	0.0	4.5	5.0	-4.8	-5.9	0.0	-4.2	2.9	3.6
Sc. B (% change)																																
Sc. AB (% change)																																
Sc. ABC (% change)																																
-- NAFO division 2J --																																
T_{bot} (°C) – Reference	1.3	1.5	1.1	1.1	1.5		2.4	2.3	2.2	2.4	2.0	2.5	2.3	2.6	2.8	2.9	2.0	2.9	2.2	2.3	3.1	3.2	2.2	2.3	1.9	1.9	2.4	2.1	2.7	2.7	2.2	0.6
T_{bot} (°C) – Scenario A	1.3	1.5	1.1	1.1	1.5		2.4	2.3	2.2	2.4	2.0	2.6	2.3	2.6	2.8	2.9	2.0	2.9	2.2	2.3	3.1	3.1	2.2	2.3	1.9	1.9	2.4	2.1	2.7	2.7	2.2	0.6
T_{bot} (°C) – Scenario B																																
T_{bot} (°C) – Scenario AB																																
T_{bot} (°C) – Scenario ABC	1.2	1.5	1.1	1.1	1.4		2.4	2.3	2.2	2.4	2.0	2.6	2.2	2.6	2.8	2.9	2.0	2.9	2.2	2.3	3.1	3.2	2.2	2.2	2.0	1.9	2.4	2.1	2.7	2.7	2.2	0.6
Sc. A (% change)	-0.3	0.0	0.0	0.0	-0.7		-0.1	0.0	0.0	0.0	-0.2	0.7	-0.1	0.0	-0.2	0.0	0.0	0.1	0.0	-0.1	0.0	0.0	0.0	0.1	-0.2	0.0	-0.1	-0.3	-0.1	-0.4	0.1	0.2
Sc. B (% change)																																
Sc. AB (% change)																																
Sc. ABC (% change)	-5.2	-2.4	0.4	1.1	-2.5		-1.2	-0.7	0.3	0.0	-0.2	0.6	-3.0	-2.1	-1.1	0.6	-1.9	-0.5	0.3	-1.1	-0.3	0.1	-0.3	-0.7	1.3	0.6	-0.6	0.2	-1.1	0.0	1.0	1.4
-- NAFO division 3K --																																
T_{bot} (°C) – Reference	1.6	2.0	1.7	1.7	1.8		2.4	2.8	2.7	2.9	2.7	2.5	2.8	2.8	3.2	2.9	2.6	2.9	2.8	2.6	3.2	3.5	2.7	2.7	2.4	2.5	2.4	2.2	2.8	2.9	2.5	0.5
T_{bot} (°C) – Scenario A	1.6	2.0	1.7	1.7	1.8		2.4	2.8	2.7	2.9	2.7	2.5	2.8	2.8	3.2	2.9	2.6	2.9	2.8	2.6	3.2	3.5	2.7	2.7	2.4	2.5	2.4	2.2	2.8	2.9	2.5	0.5
T_{bot} (°C) – Scenario B																																
T_{bot} (°C) – Scenario AB																																
T_{bot} (°C) – Scenario ABC	1.7	2.1	1.7	1.7	1.8		2.4	2.8	2.7	2.9	2.7	2.5	2.7	2.8	3.2	2.9	2.6	2.9	2.9	2.6	3.2	3.5	2.7	2.7	2.4	2.5	2.4	2.2	2.8	2.9	2.5	0.5
Sc. A (% change)	-0.4	-0.1	0.1	0.4	-1.5		0.1	0.0	-0.1	0.0	-0.1	0.0	-0.1	0.0	-0.1	0.1	0.1	-0.1	0.6	0.0	0.0	-0.1	0.0	-0.1	0.1	0.0	-0.3	-0.2	-0.1	-1.0	0.2	0.4
Sc. B (% change)																																
Sc. AB (% change)																																
Sc. ABC (% change)	3.7	0.2	-0.4	0.7	-2.2		0.7	0.1	-1.9	1.3	-1.3	-0.7	-2.8	-2.4	-0.2	0.0	0.4	-0.7	0.8	-0.5	-0.4	0.0	-0.2	-0.3	0.3	0.0	0.0	0.1	0.3	-0.6	0.8	1.2
-- NAFO division 3LNO --																																
T_{bot} (°C) – Reference	0.6	0.4	0.4	0.1	0.4		1.2	1.1	1.5	2.0	1.0	1.2	1.1	1.0	1.6	1.3	1.4	1.1	0.8	1.4	1.8	2.3	1.4	1.3	0.7	1.0	1.0	0.7	1.3	1.2	1.1	0.5
T_{bot} (°C) – Scenario A	0.6	0.4	0.4	0.1	0.4		1.2	1.1	1.5	2.0	1.0	1.2	1.1	1.0	1.5	1.3	1.4	1.1	0.8	1.4	1.8	2.3	1.4	1.3	0.7	1.0	1.0	0.7	1.3	1.2	1.1	0.5
T_{bot} (°C) – Scenario B																																
T_{bot} (°C) – Scenario AB																																
T_{bot} (°C) – Scenario ABC																																
Sc. A (% change)	-0.2	0.1	0.2	-0.4	-2.0		-0.1	-0.1	-0.2	-0.1	-1.1	-1.5	-1.6	-1.1	-1.7	-1.0	-0.9	-1.9	-1.9	-1.4	-0.3	-0.2	0.0	0.1	-0.1	-0.4	0.2	-1.6	0.0	-0.4	0.7	0.7
Sc. B (% change)																																
Sc. AB (% change)																																
Sc. ABC (% change)																																

Figure 9. Scorecards of mean fall bottom temperature for NAFO divisions 2H (top), 2J (second), 3K (third) and 3LNO (bottom). The top row of each panel represents the reference scenario (no removal) and is followed by the four exclusion scenarios studied here. These cells are color-coded according to their normalized anomaly compared to the 1980–2010 climatology (color-code of Figure 7). The climatological average and SD appear in the last two columns. The bottom four lines of each panel (in bold) represent the percentage change of each scenario compared to the reference. Only values greater than ±5% are colored. For these rows, the last two columns correspond to the average absolute value percentage change and its SD. Gray cells indicate an absence of data.

2H_Fall

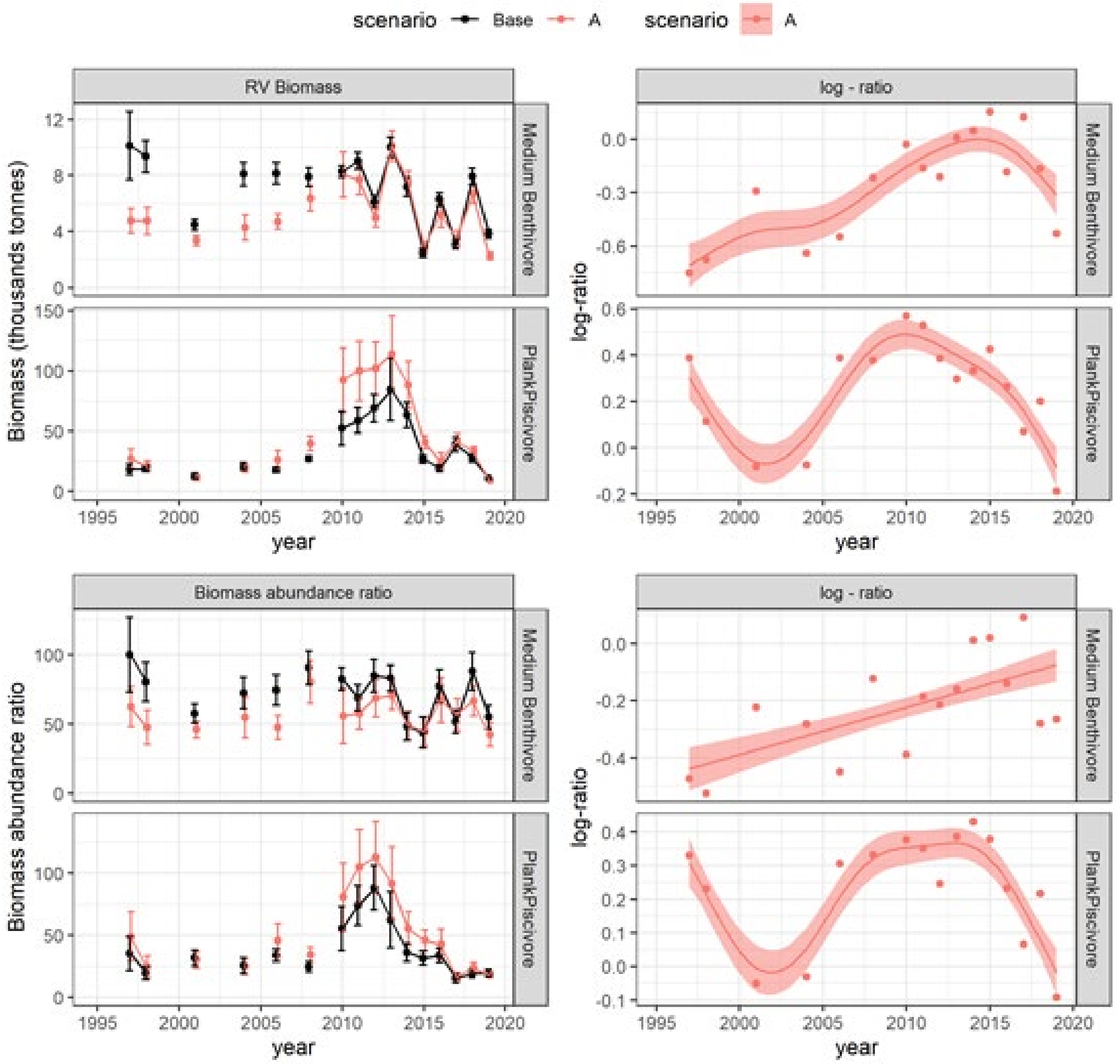


Figure 10. Summary of potential impact on scaled biomass and BA-ratio indices in 2H Fall for plankpiscivores when excluding RV Survey activity from coral and sponge closures (A) across fish functional group from 1995 to 2019. Plots on the left represent time series of scaled biomass (top) and BA-ratio (bottom) indices including all sets (Base, black points) and excluding sets under coral and sponge closures (A, red) with one SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the 95% CI and smoother of a GAM when the smoother was statistically significant.

2J3K_Fall

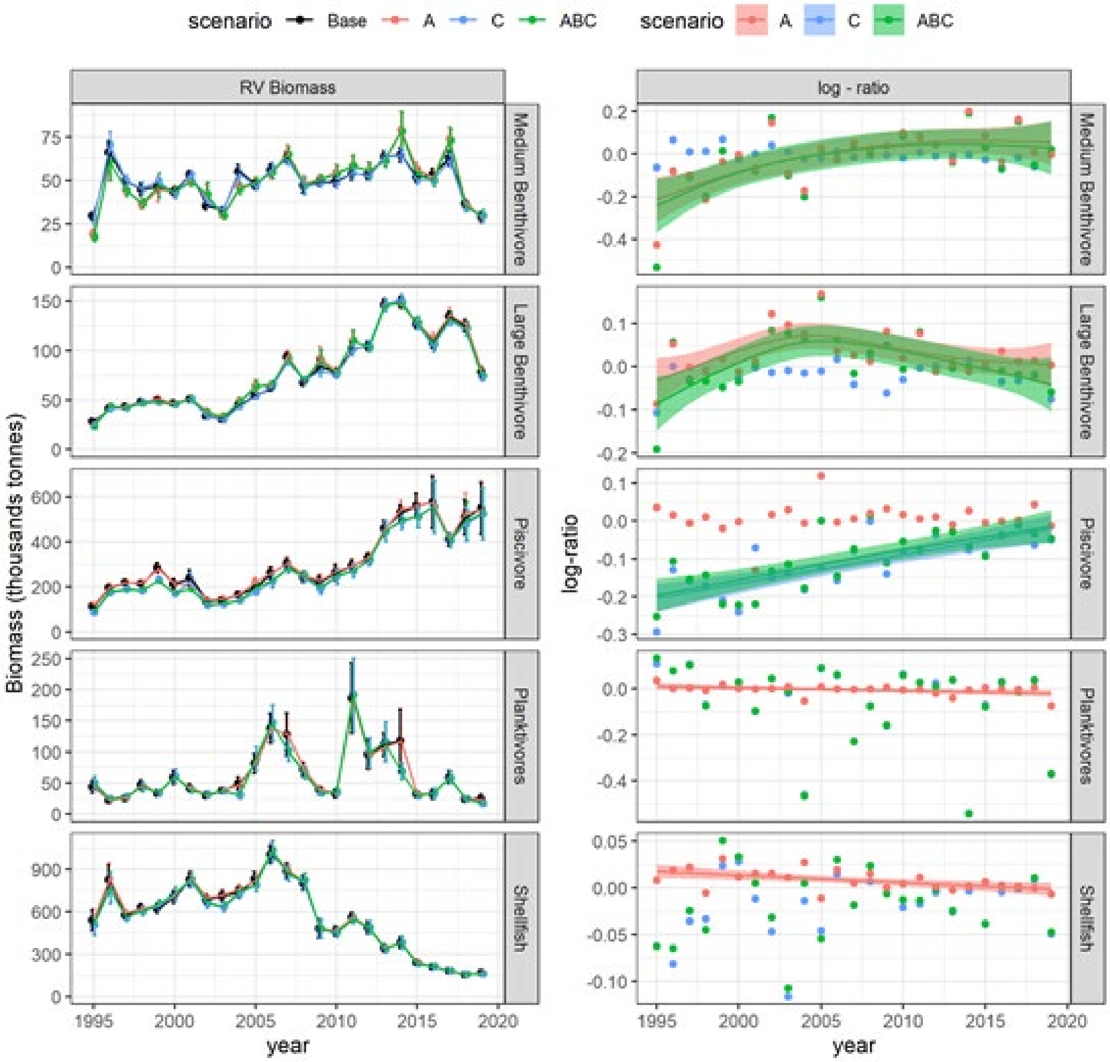


Figure 11. Summary of potential impact on scaled biomass index in 2J3K Spring when excluding RV Survey activity from coral and sponge closures (A), closures for groundfish breeding habitat (C), and combination of the two (ABC) across five fish functional group from 1995 to 2019. Plots on the left represent time series of scaled biomass indices including all sets (Base, black points) and excluding sets under each scenario, coral and sponge closures (A, red), closures for groundfish breeding habitat (C, blue), and combination of the two (ABC, green) with one SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the 95% CI and smoother of a GAM when the smoother was statistically significant. Each row represents a fish functional group.

3Ps_Spring

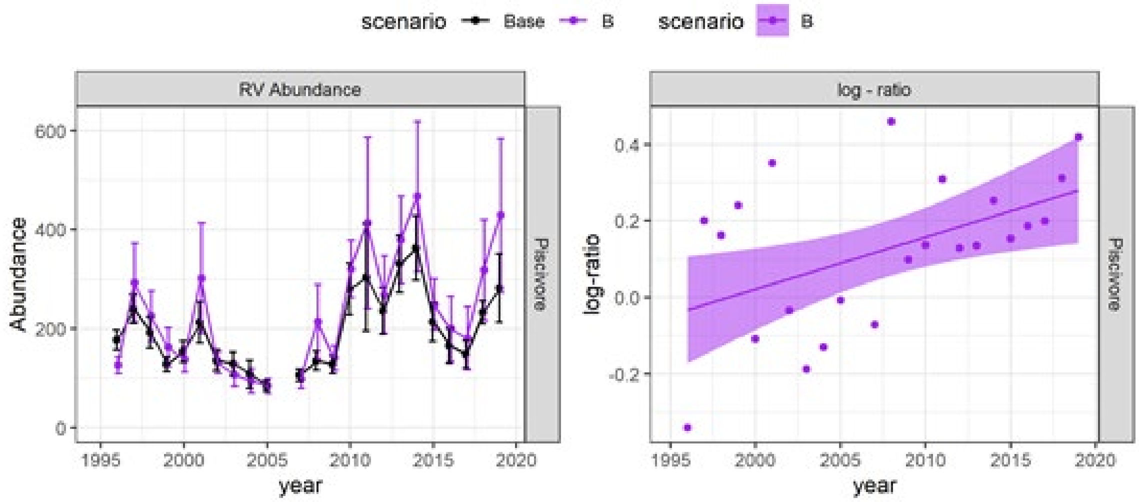


Figure 12. Summary of potential impact on abundance index in 3Ps Spring when excluding RV Survey activity from sea pen closures (B) across fish functional group from 1995 to 2019. The plot on the left represent time series of abundance indices including all sets (Base, black points) and excluding sets under each scenario, sea pen closures (B, purple) with one SD. The plot on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values, and the line and ribbon are the 95% CI and smoother of a GAM when the smoother was statistically significant.

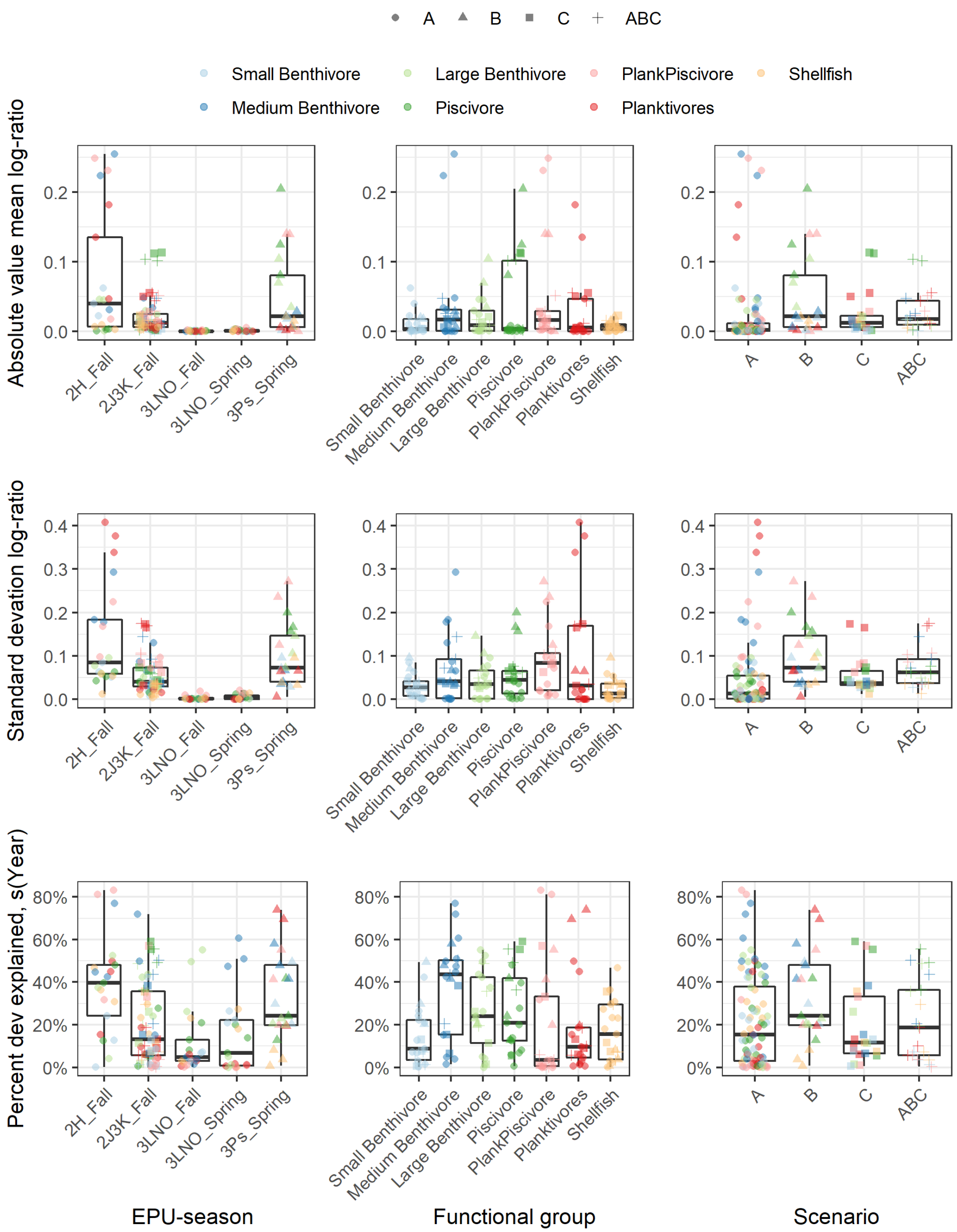


Figure 13. Summary of absolute mean value of log-ratio, SD of log-ratio, and percent deviance explained by year smooth in GAMs for each analysis, broken down by EPU-season, fish functional groups, and closure scenario. Boxplots describe the distribution, points for each analysis are presented with color representing fish functional group, and shape closure scenario.

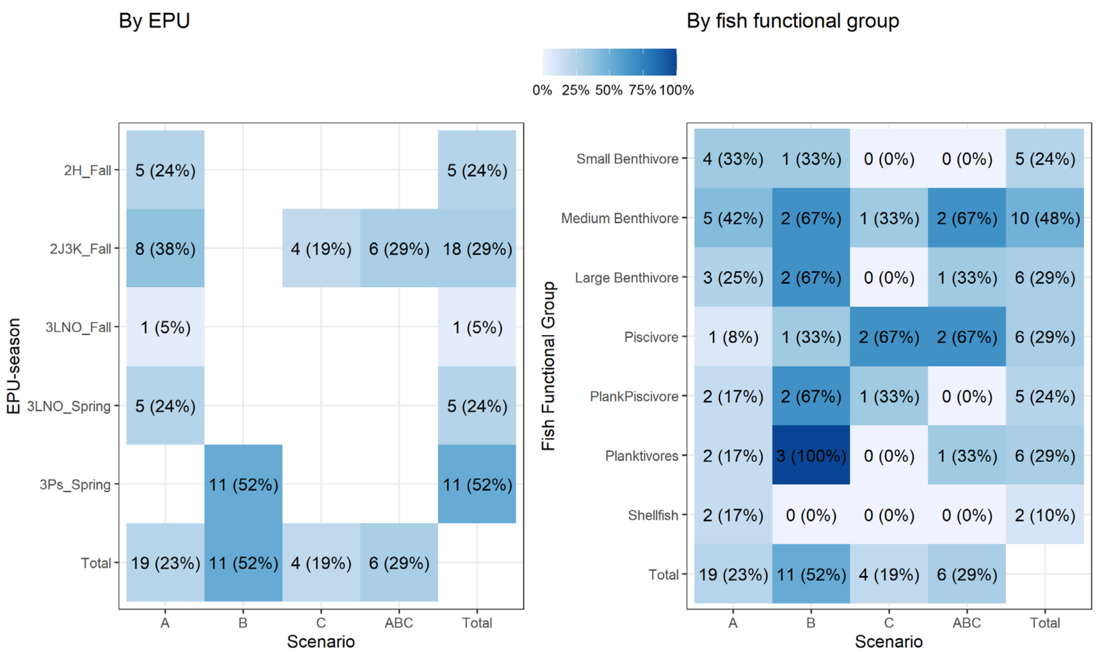


Figure 14. Summary of the number of relationships of log-ratio and year that have significant patterns, summarized by EPU-season and fish functional group, broken down by scenario. Patterns include all indices (biomass, abundance, and ba-ratio) and include a total summary for all EPU-season or functional group along the bottom, total summary for all scenario along the right. The percentage of patterns that are significant is presented in brackets and color of block.

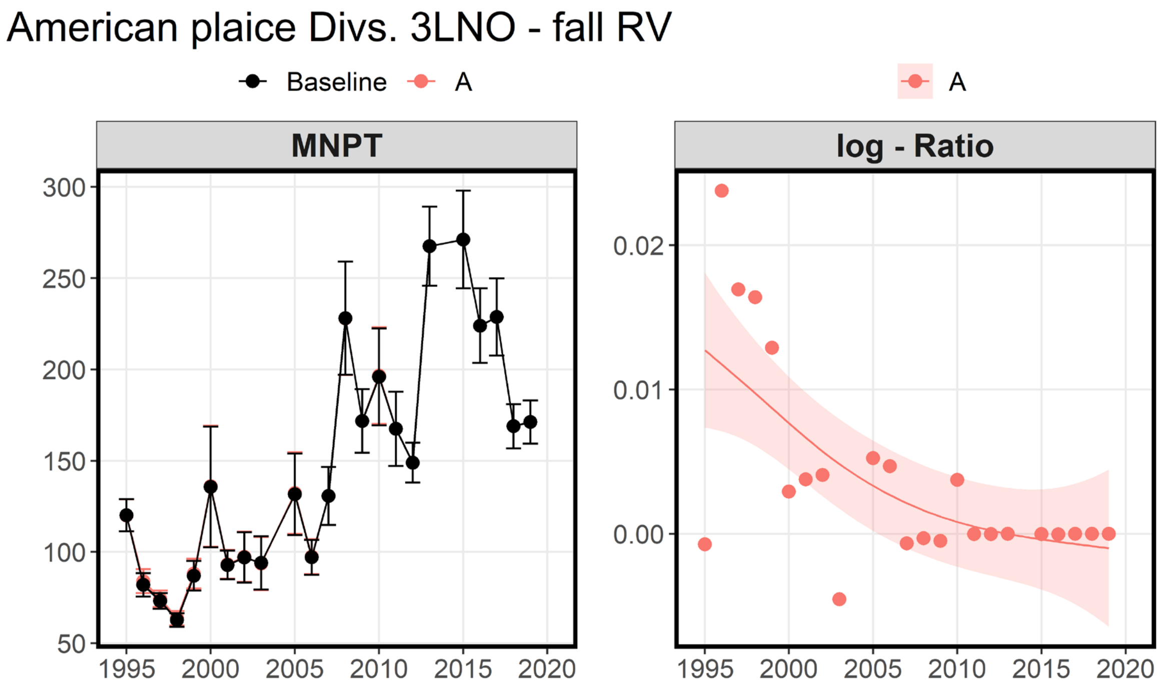


Figure 15. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Fall survey indices for American Plaice in Divs. 3LNO. The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

Witch flounder Divs. 2J3KL - fall RV

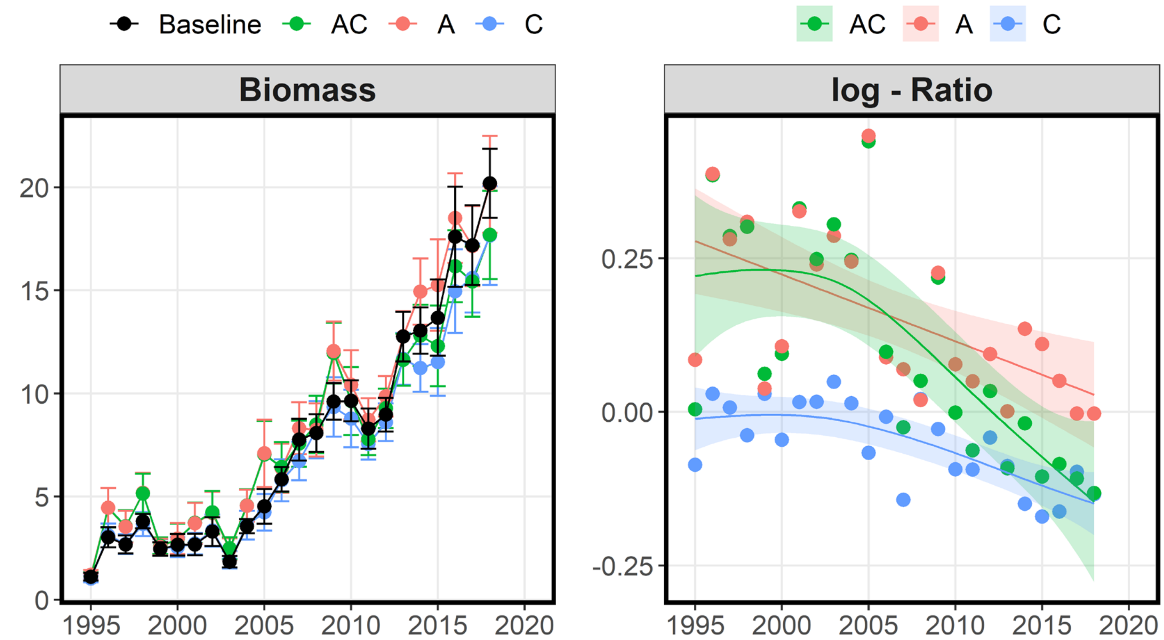


Figure 16. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Fall survey indices for Witch Flounder in Divs. 2J3KL. The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

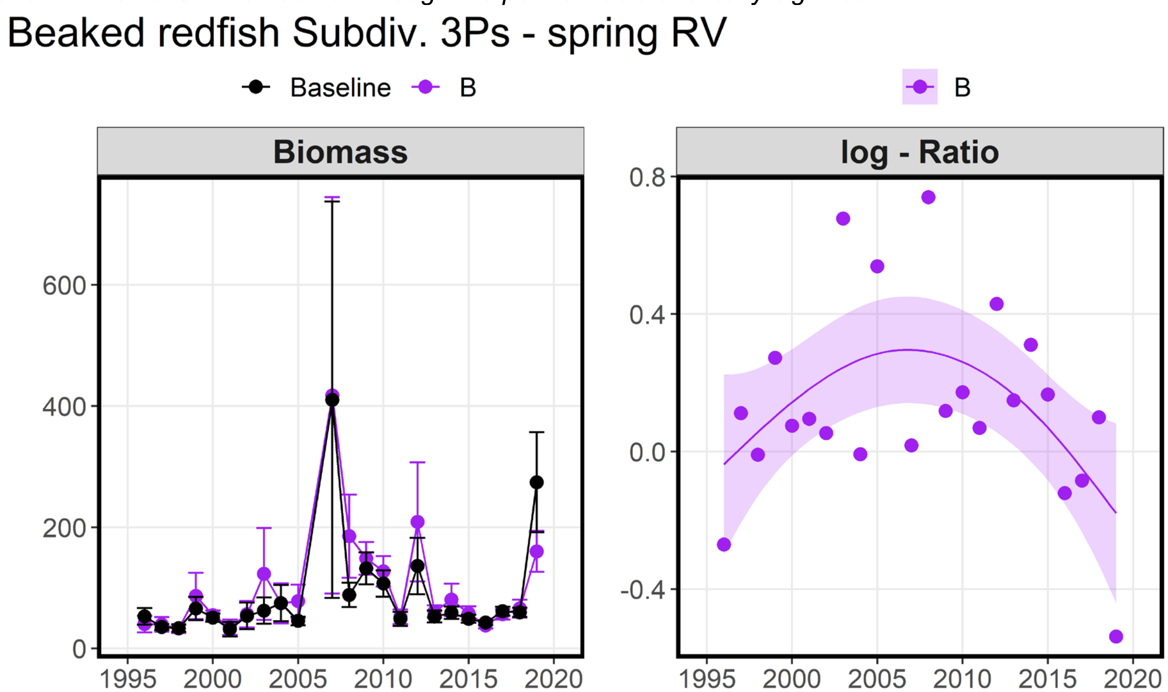


Figure 17. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Spring survey indices for Redfish in Subdiv. 3Ps. The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

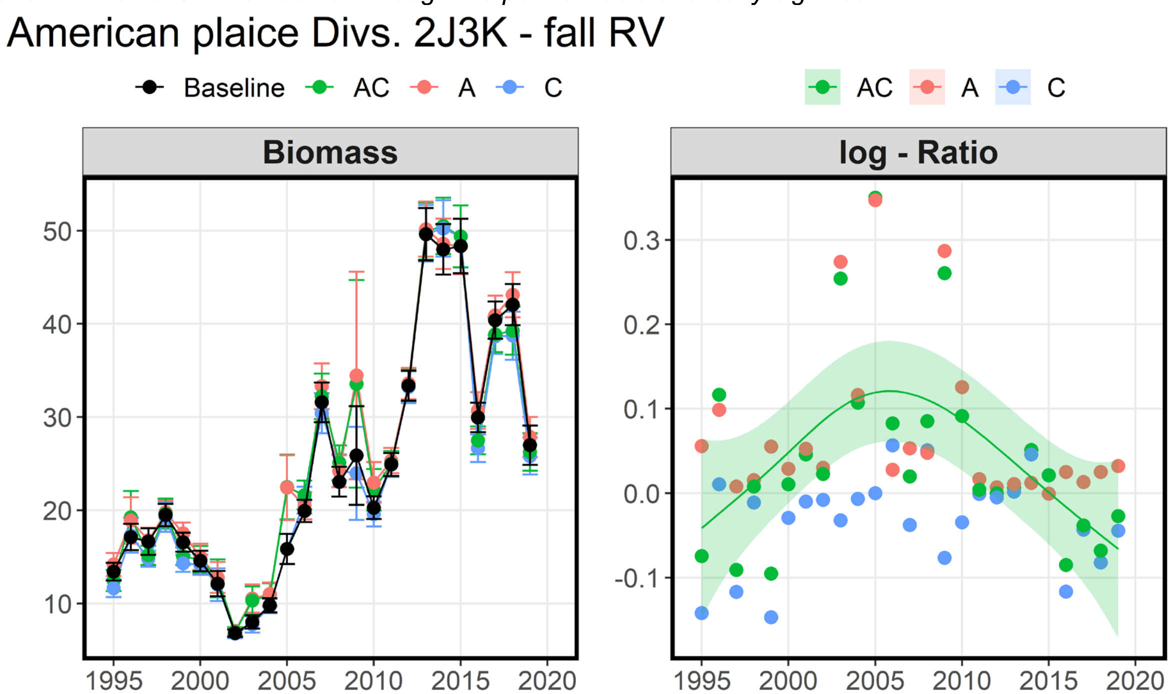


Figure 18. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Fall survey indices for Greenland Halibut in Divs. 2J3K. The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

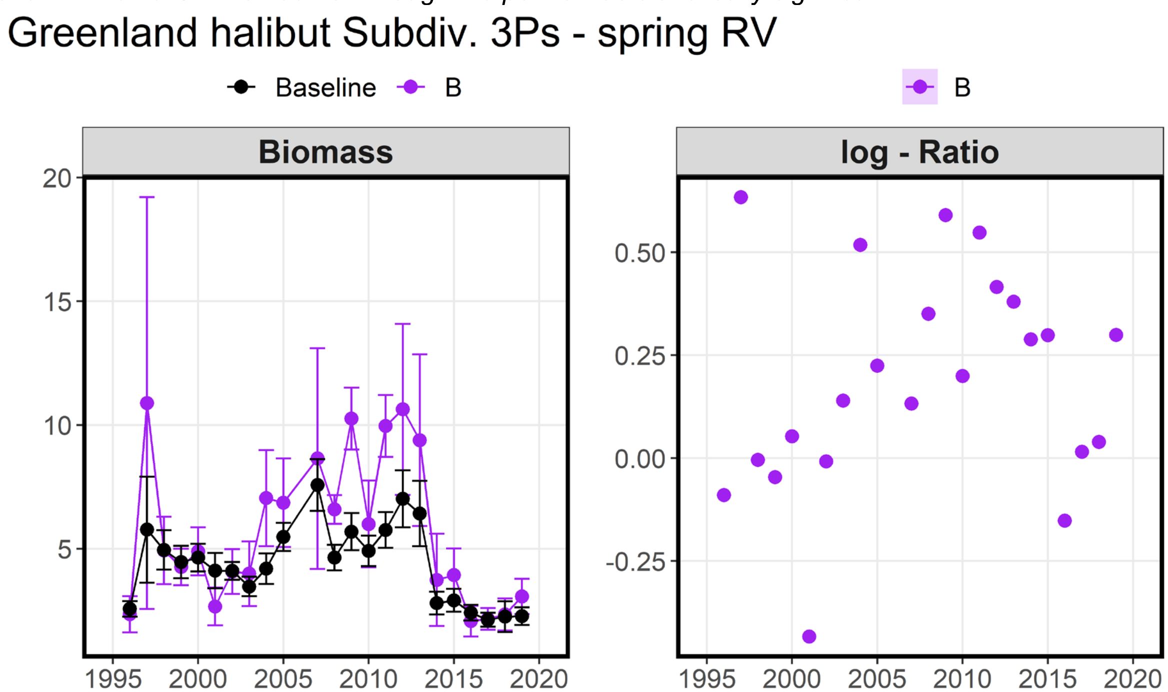


Figure 19. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Spring survey indices for Greenland halibut in Subdiv. 3Ps. The survey indices presented are those currently used in the respective assessments. The ‘Baseline’ scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

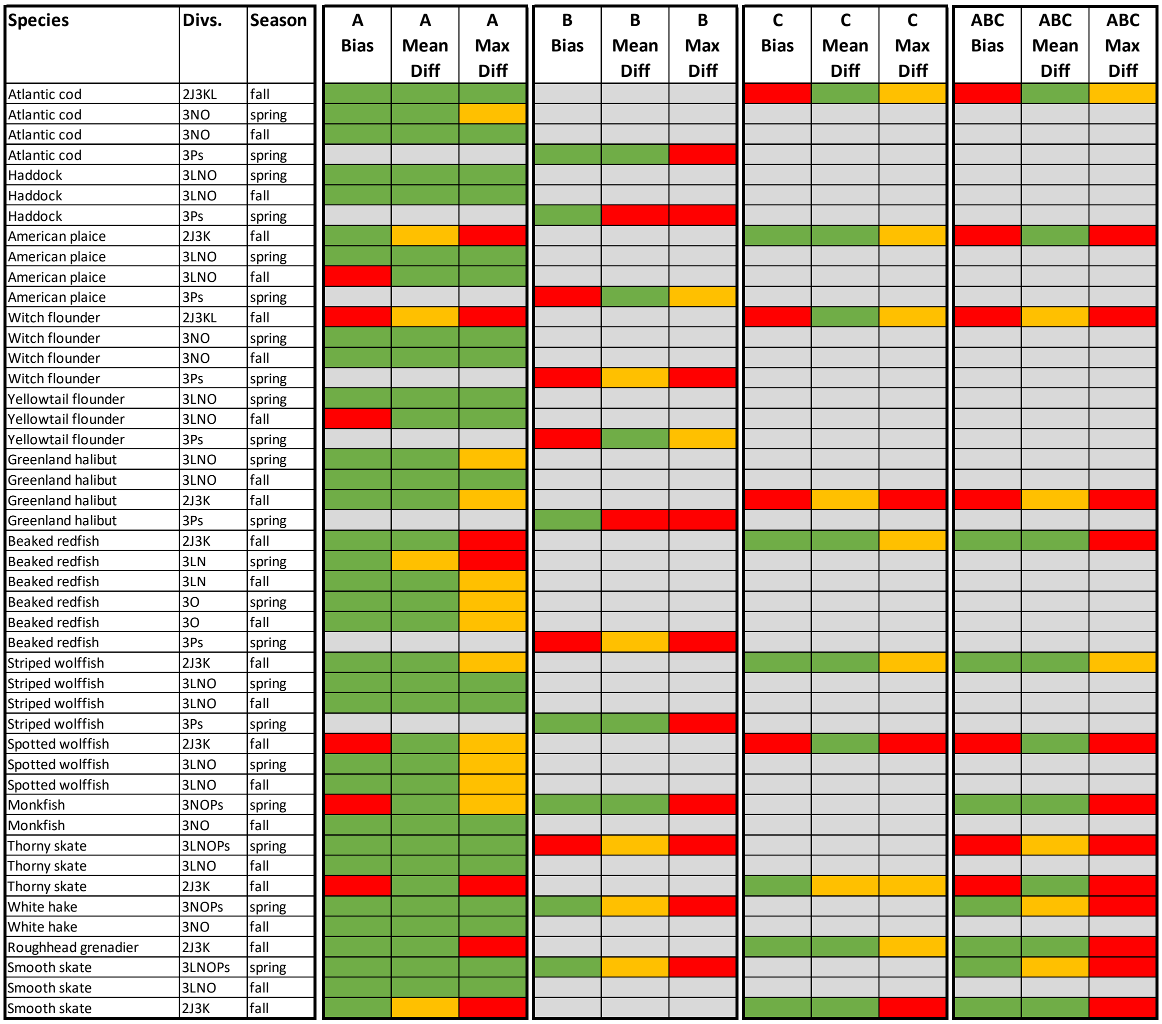


Figure 20. Scorecard of the impacts on stock-specific indices of excluding RV bottom-trawl surveys from protected areas in the NL Region. Scenario A is the exclusion of surveys from coral and sponge protection areas, Scenario B is the exclusion of surveys from sea pen protection areas, Scenario C is the exclusion of surveys from fish habitat protection areas, and Scenario ABC is the exclusion of surveys from all protection areas. Bias represents p-values for GAM smoothers fit through annual log-ratios of the scenario vs. the baserun (red=signif, green=non-signif). Mean ratio represents the average ratio of indices over the entire time series and max ratio represents the largest observed departure of the scenario from the baserun (green = a difference of less than 5%, yellow = 5–20%, red = >20%).

Snow crab - RV trawl survey

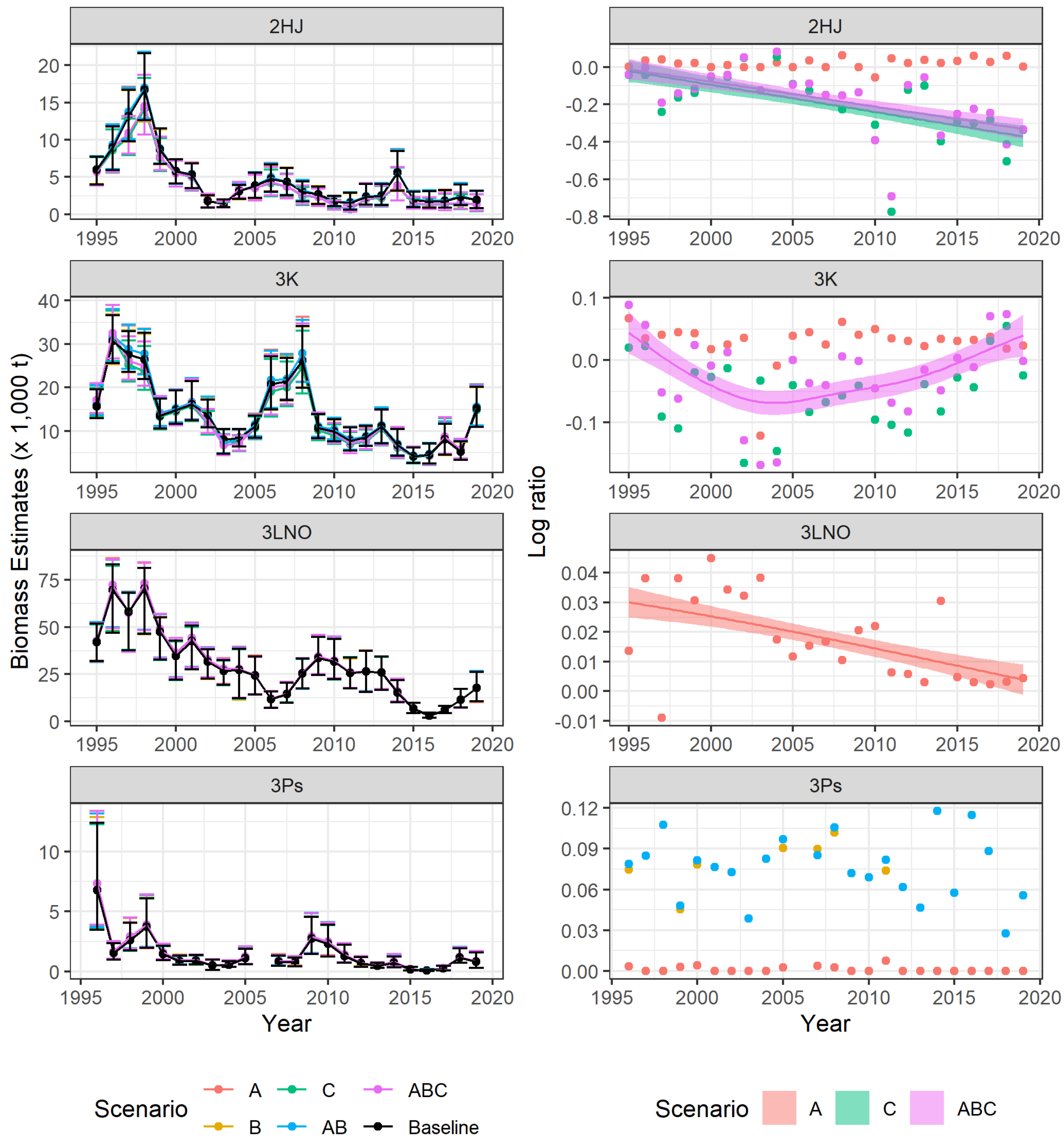


Figure 21. Snow crab exploitable biomass estimates with 95% CIs (left) and bias (right) in ADs 2HJ, 3K, 3LNO, and 3Ps from multispecies bottom trawl surveys. The black line represents biomass estimates based on current survey coverage, while different colours represent the exclusion of different protected areas. Only smoothers (coloured ribbon) with a p-value of ≤0.05 are displayed.

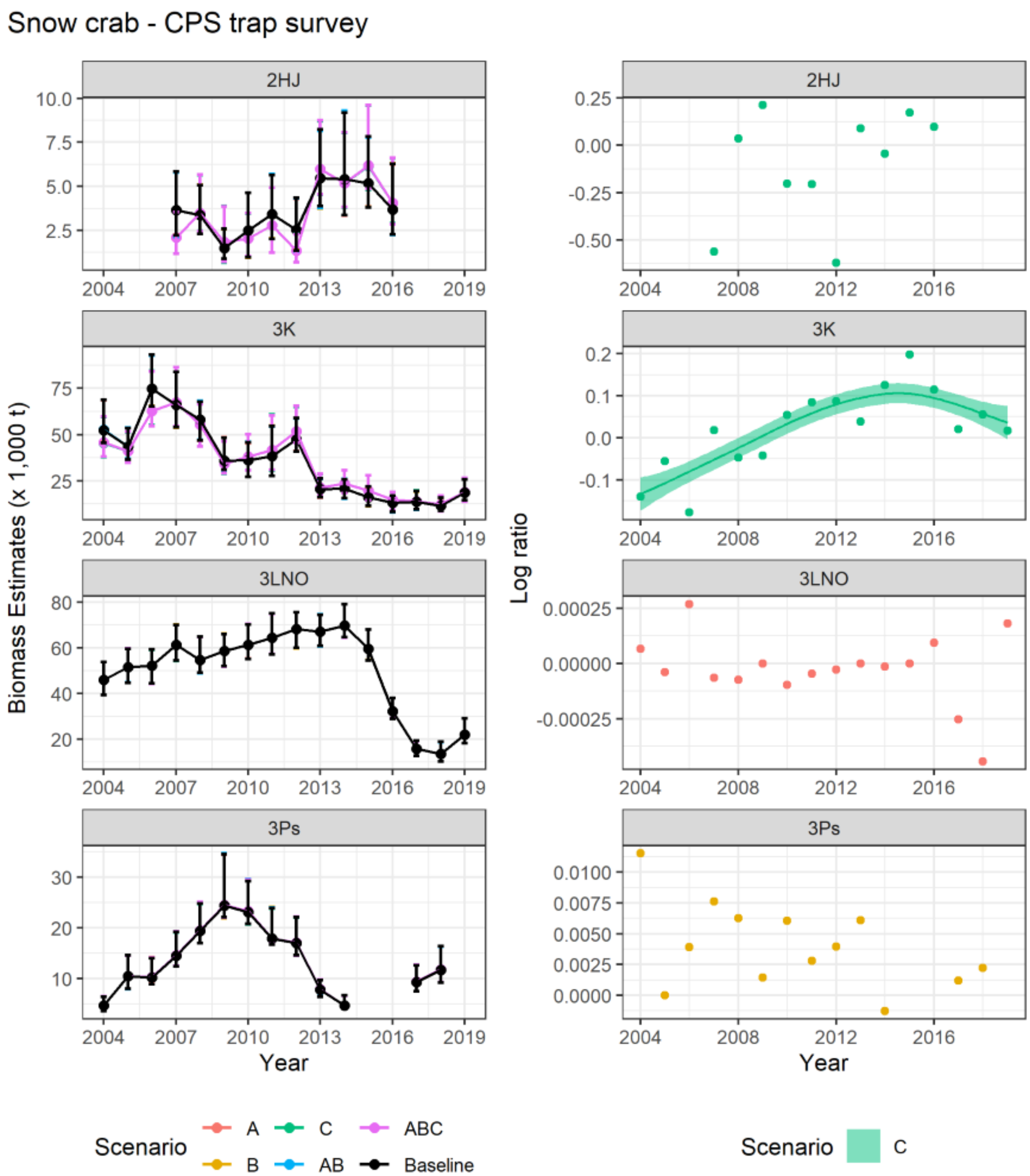


Figure 22. Snow crab exploitable biomass estimates with 95% CIs (left) and bias (right) in ADs 2HJ, 3K, 3LNO, and 3Ps from CPS Trap surveys. The black line represents biomass estimates based on current survey coverage, while different colours represent the exclusion of different MRs and/or VMEs. Only smoothers (coloured ribbon) with a p-value of ≤0.05 are displayed.

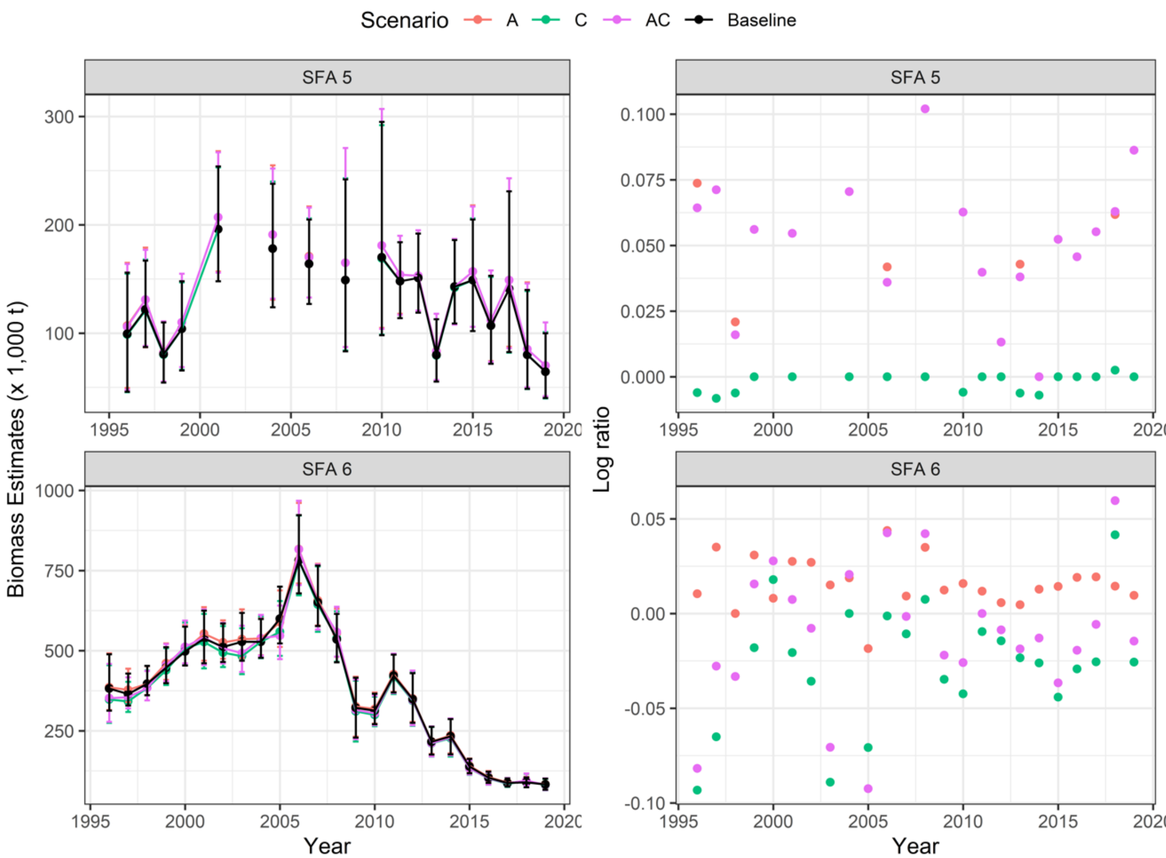


Figure 23. Northern Shrimp fishable biomass estimates with 95% CIs (left) and bias (right) for SFA 5 (top) and 6 (bottom). The black line represents biomass estimates based on current survey coverage, while different colours represent the exclusion of different MRs and/or VMEs (A: Exclusion of Hopedale Saddle, Northeast Avalon Slope, 3O Coral Box and NAFO VMEs, C: Exclusion of Hawke Box and Funk Island Deep Box, AC: Exclusion of both A and C). None of the trends in relative bias were significant, hence smoothers are not displayed.

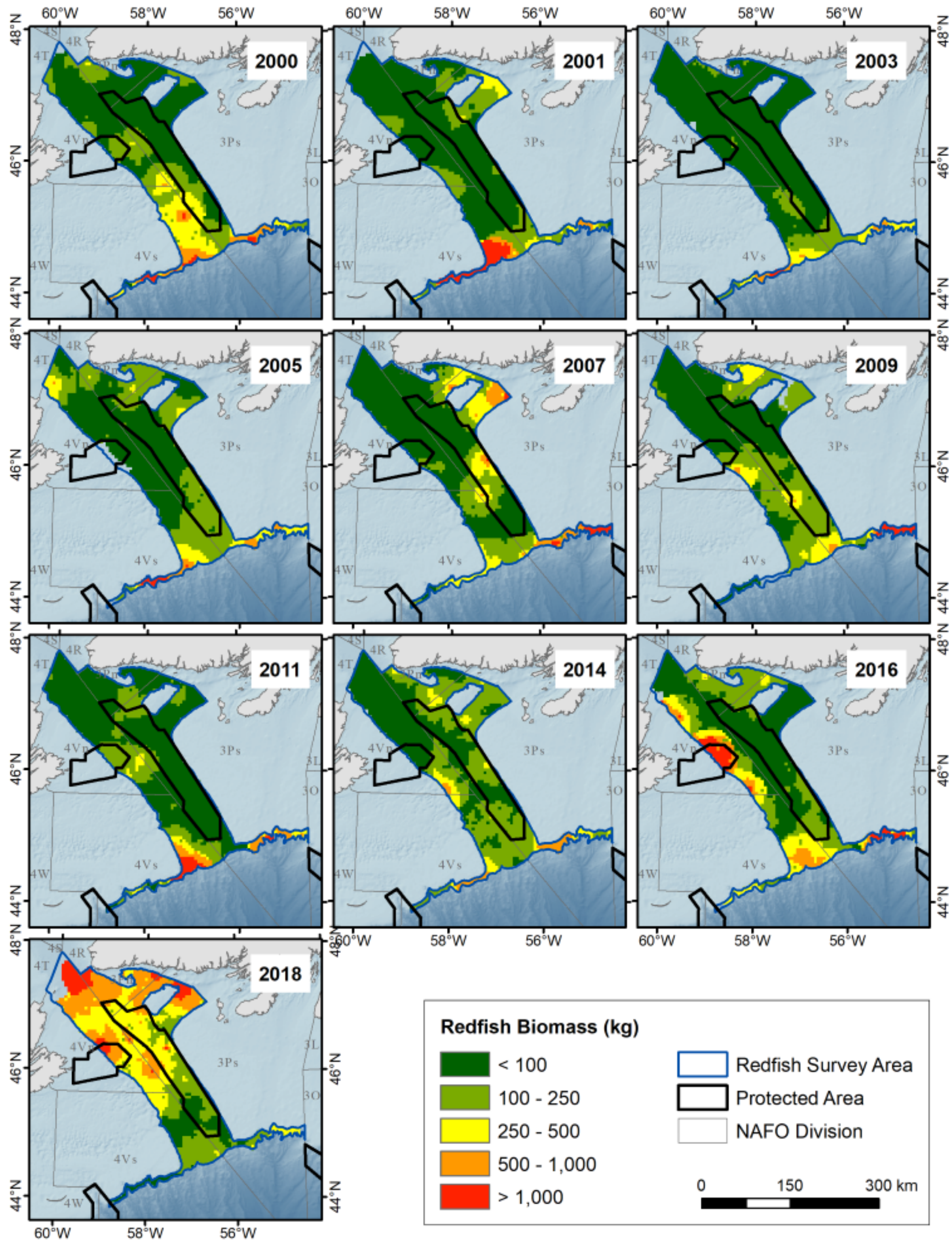


Figure 24. IDW interpolated biomass for the Unit 2 redfish survey by year.

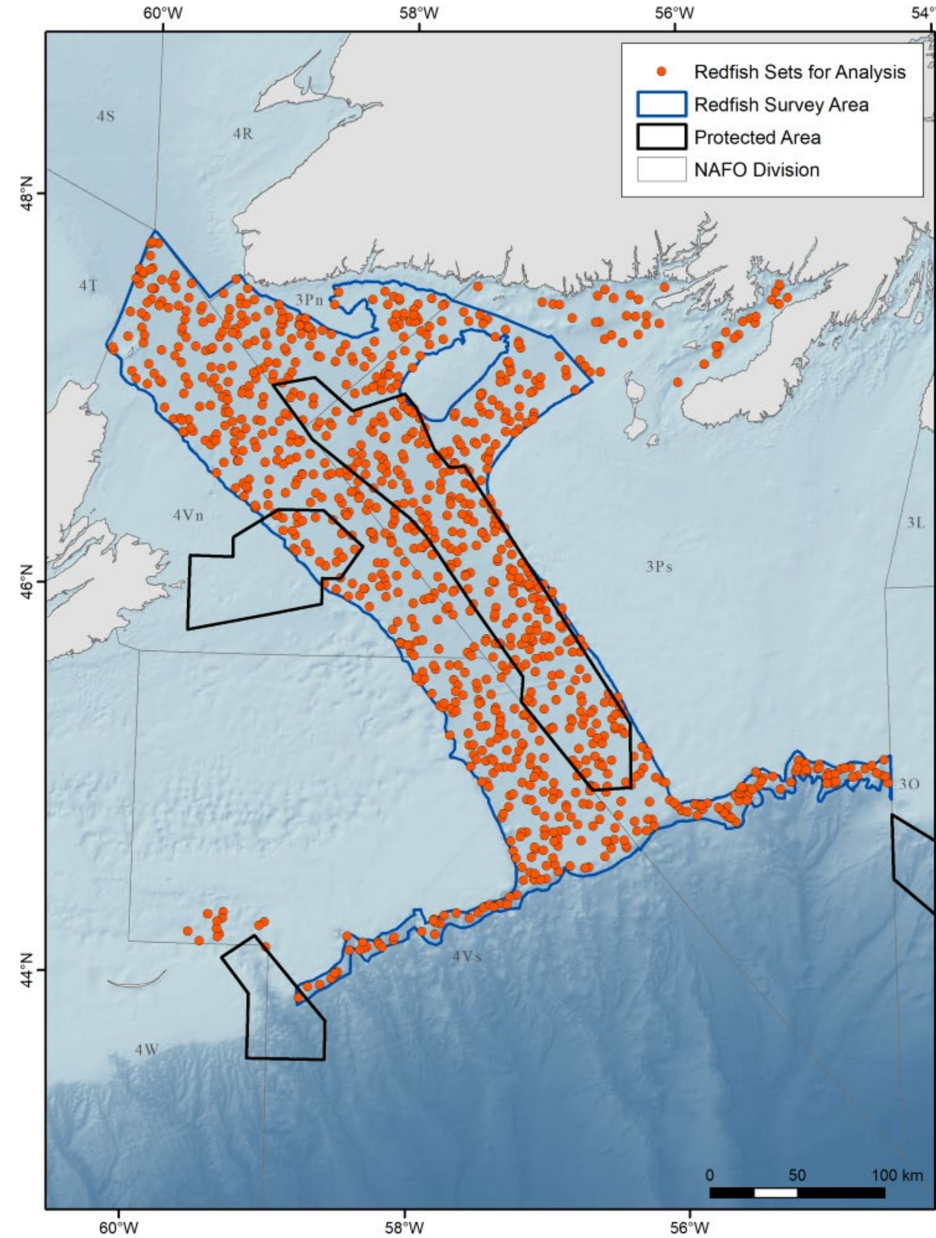


Figure 25. Map of Unit 2 redfish survey area with all sets (2000–18) illustrating which sets fall outside the study area and were subsequently clipped from the annual IDW interpolation rasters.

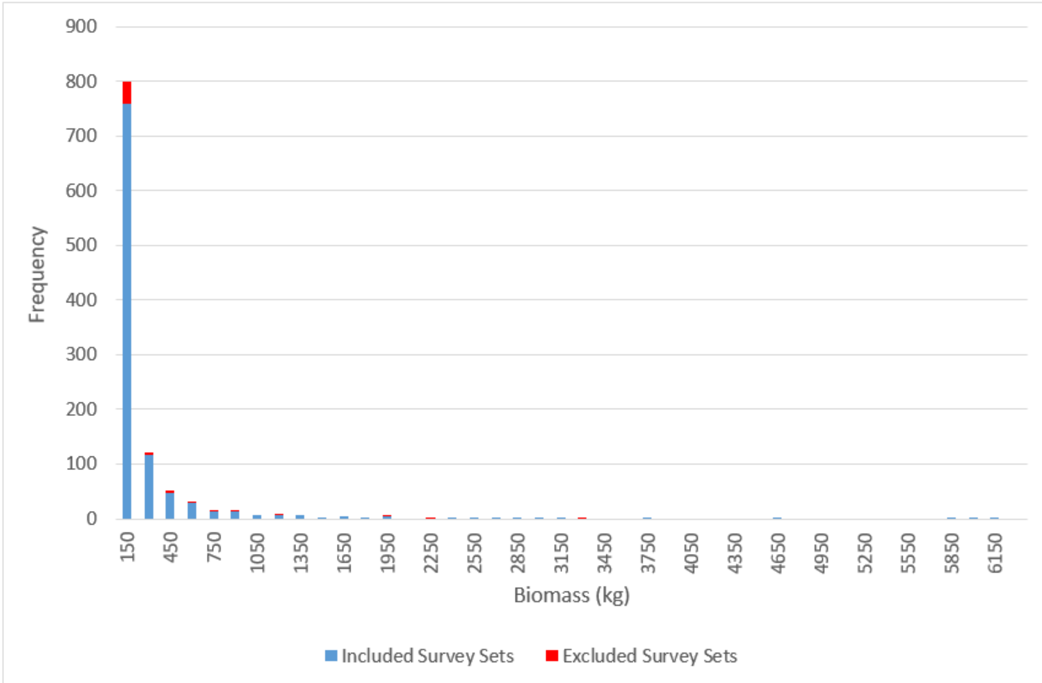


Figure 26. Frequency histogram of all Unit 2 redfish survey sets showing those included in the analysis (inside the survey area; see Figure 25 above) and those sets excluded when the interpolated rasters were clipped to the study area polygon.

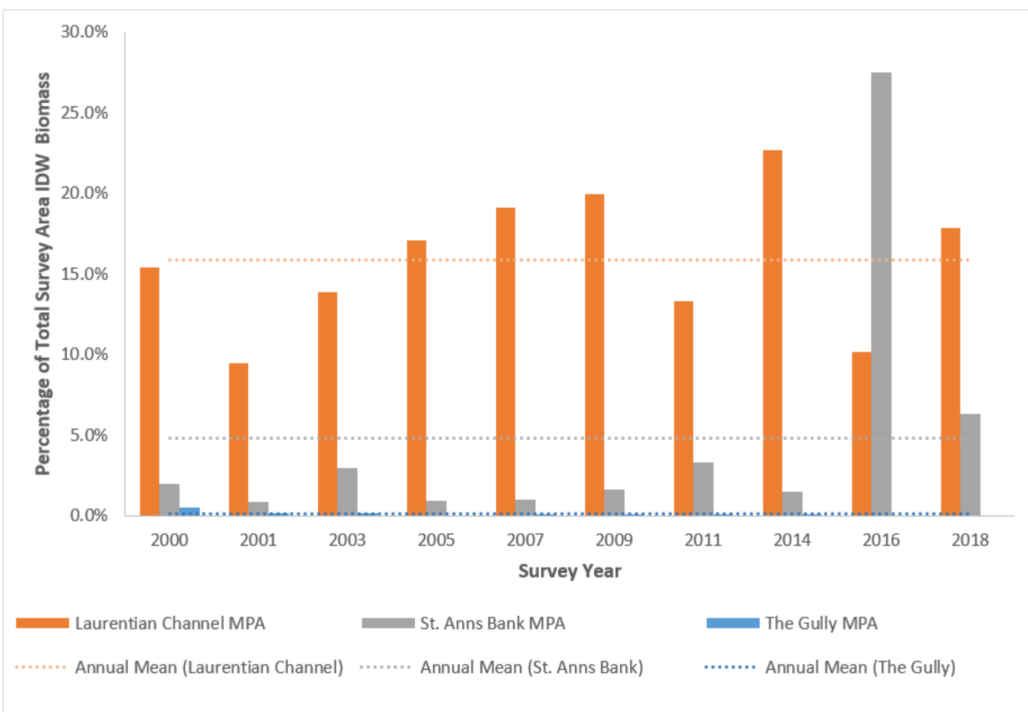


Figure 27. Annual percentages of biomass from the Unit 2 redfish survey. Annual mean values are shown as dashed lines to indicate annual deviations from the mean over the full survey time series.

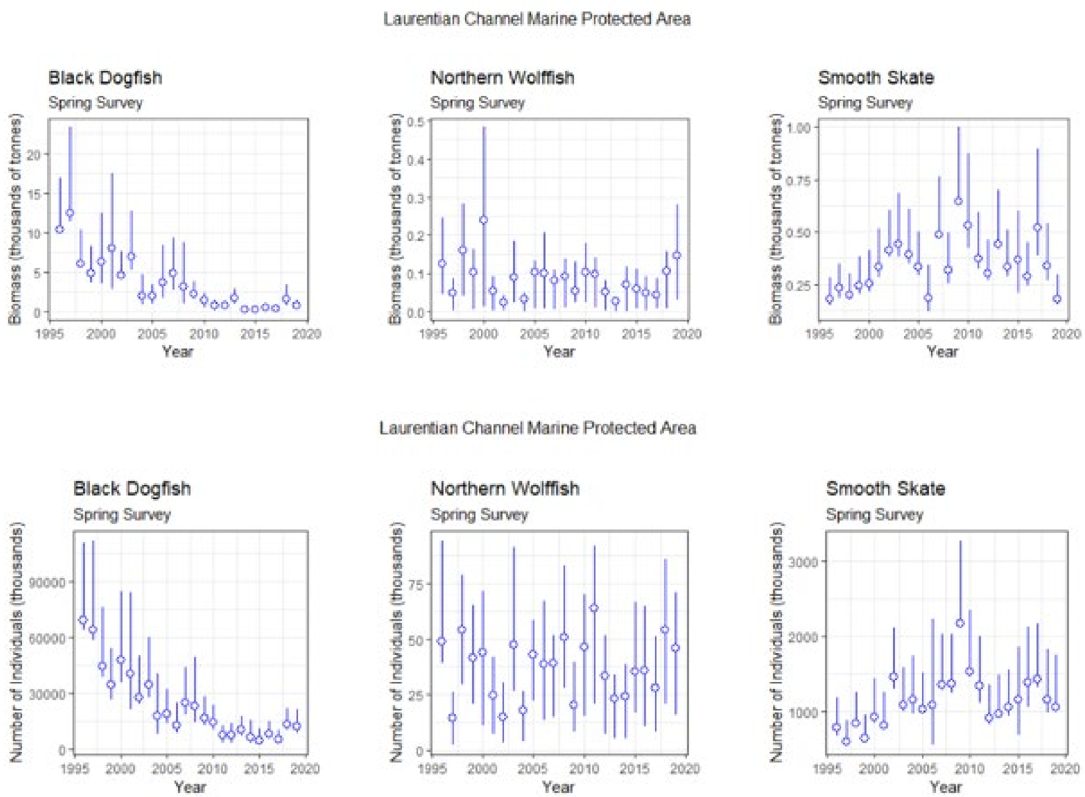


Figure 28. Ogmap biomass (top) and abundance (bottom) estimates with 95% CIs for Black Dogfish, Northern Wolffish, and Smooth Skate in the Laurentian Channel MPA.

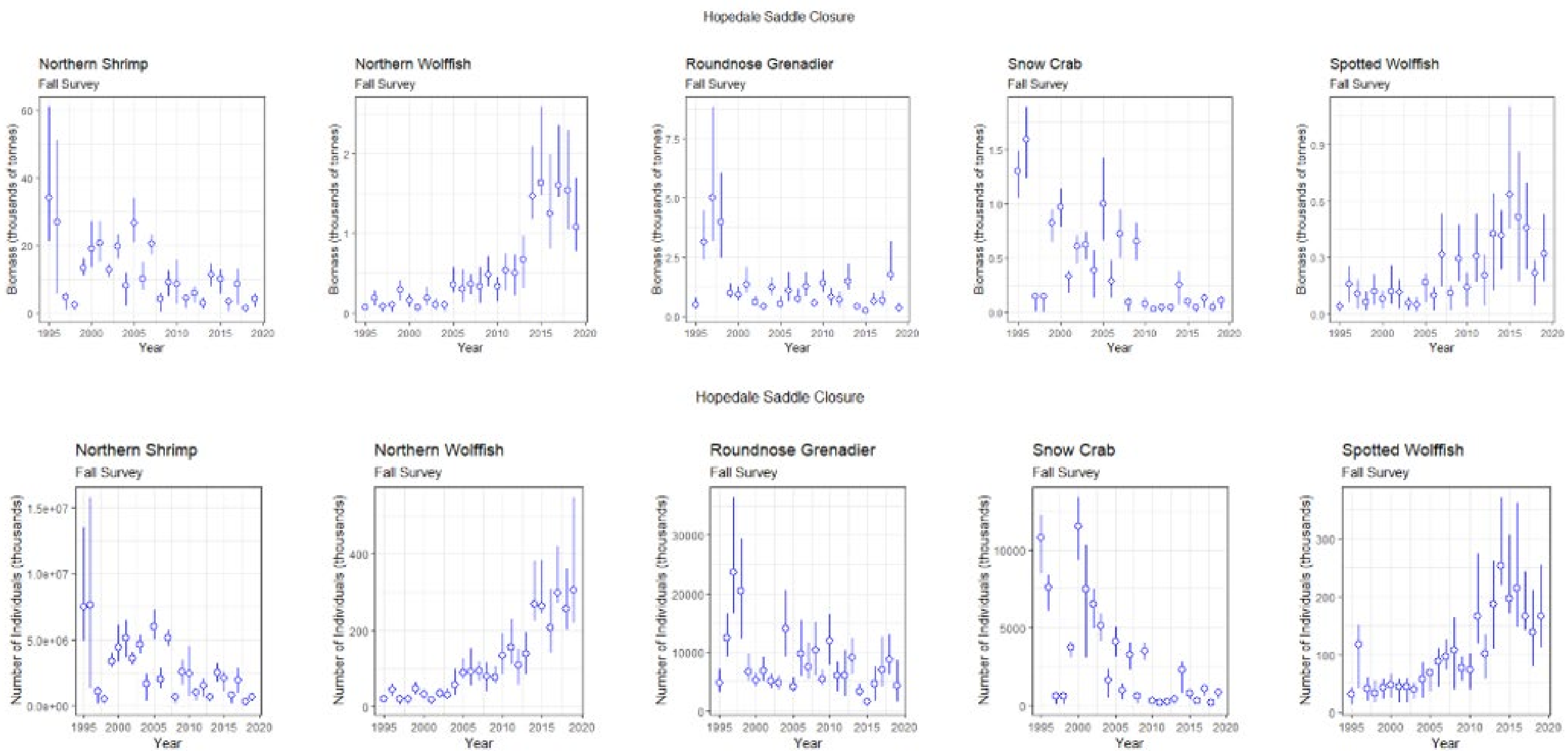


Figure 29. Ogmap biomass (top) and abundance (bottom) estimates with 95% CIs for Northern Shrimp, Northern Wolffish, Roundnose Grenadier, Snow Crab, and Spotted Wolffish in the Hopedale Saddle Closure.

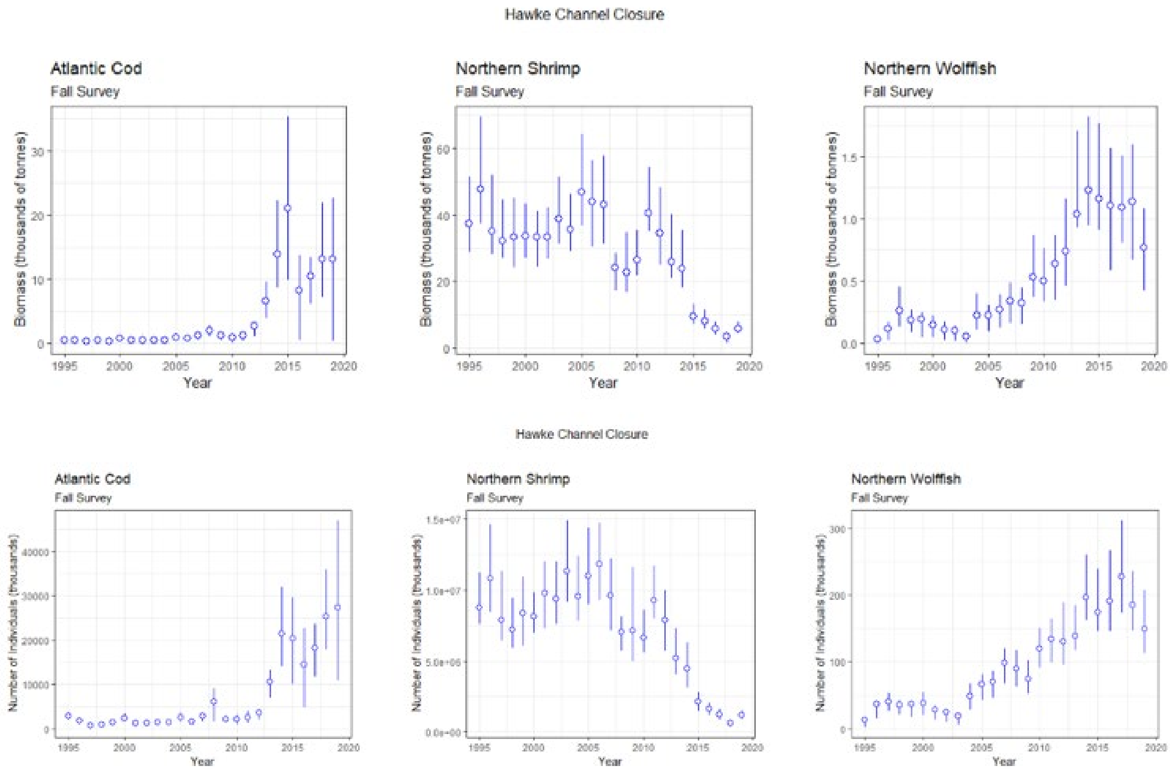


Figure 30. Ogmap biomass (top) and abundance (bottom) estimates with 95% CIs for Atlantic Cod, Northern Shrimp, and Northern Wolffish in the Hawke Channel Closure.

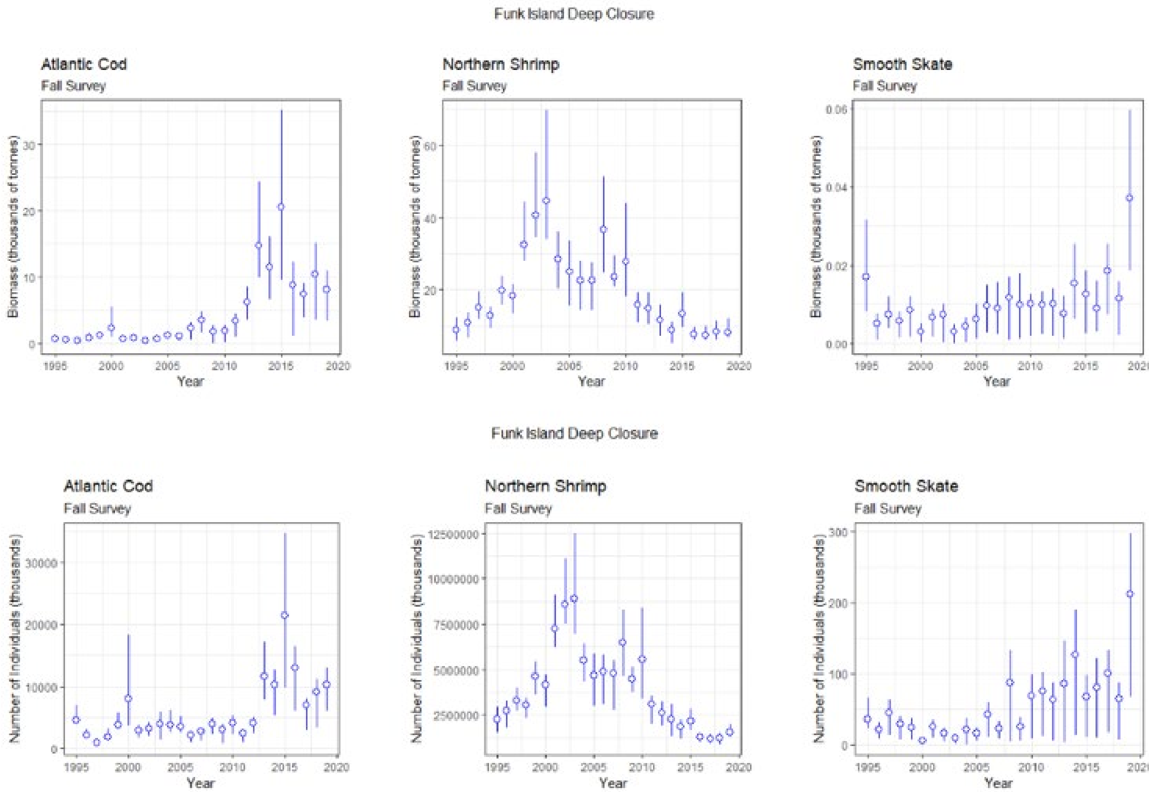
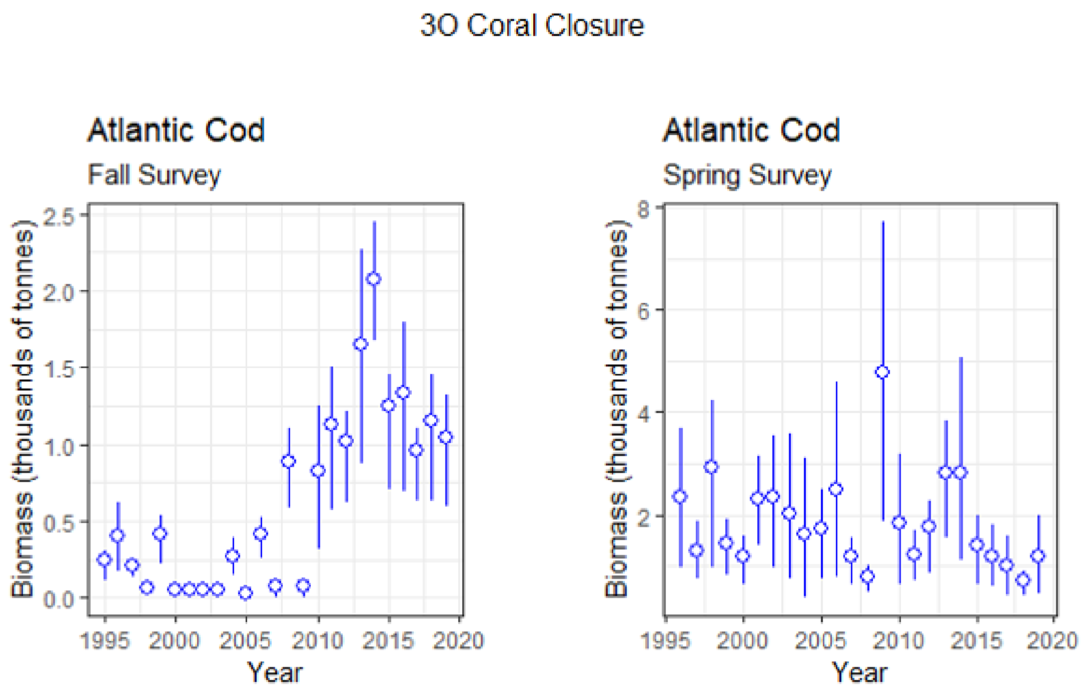


Figure 31. Ogmap biomass (top) and abundance (bottom) estimates with 95% CIs for Atlantic Cod, Northern Shrimp, and Smooth Skate in the Funk Island Deep Closure.



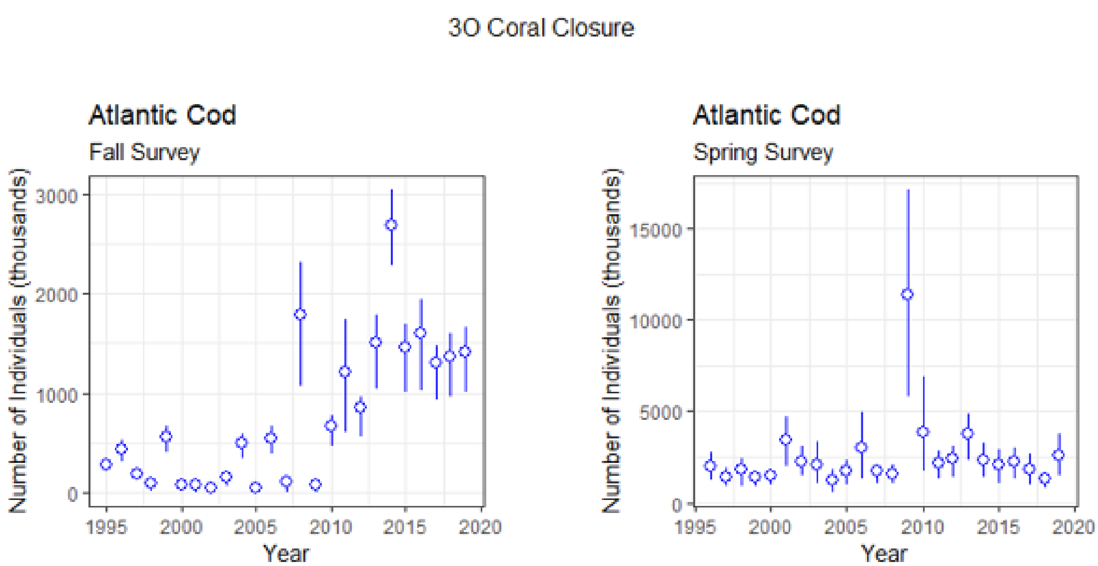


Figure 32. Ogmap biomass (top) and abundance (bottom) estimates with 95% CIs for Atlantic Cod (fall survey), and Atlantic Cod (spring survey) in the 3O Coral Closure.

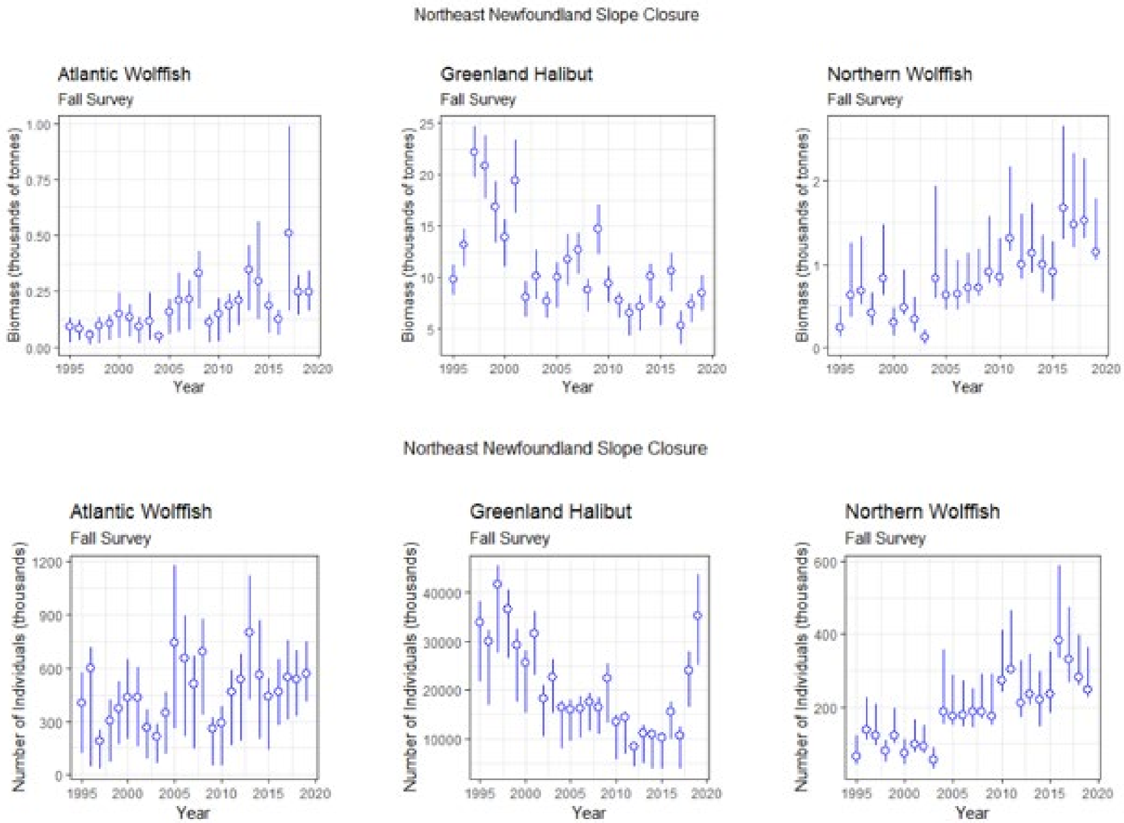


Figure 33. Ogmap biomass (top) and abundance (bottom) estimates with 95% CIs for Atlantic Wolffish, Greenland Halibut, and Northern Wolffish in the Northeast Newfoundland Slope Closure.

10. APPENDIX A – LIST OF ACRONYMS

Acronym	Definition
AD	Assessment Division
AOI	Area of Interest
AUV	Autonomous Underwater Vehicle
BCD	Bitter Crab Disease
CMA	Crab Management Area
CPS	Collaborative Post-Season
CTD	Conductivity-Temperature-Depth sensor
DFO	Fisheries and Oceans Canada
EBSA	Ecologically and Biologically Significant Area
EEZ	Exclusive Economic Zone
GIS	Geographic Information System
NAFO	Northwest Atlantic Fisheries Organization
NL	Newfoundland and Labrador
NRA	NAFO Regulatory Area
MPA	Marine Protected Area
MR	Marine Refuge
OEABCM	Other Effective Area-Based Conservation Measure
ROPOS	Remotely Operated Platform for Ocean Sciences
ROV	Remotely Operated Vehicle
RV	Research Vessel
SFA	Shrimp Fishing Area
SiBA	Significant Benthic Area
SDM	Species Distribution Model
VME	Vulnerable Marine Ecosystem

11. APPENDIX B – ECOSYSTEM PLOTS

2H_Fall

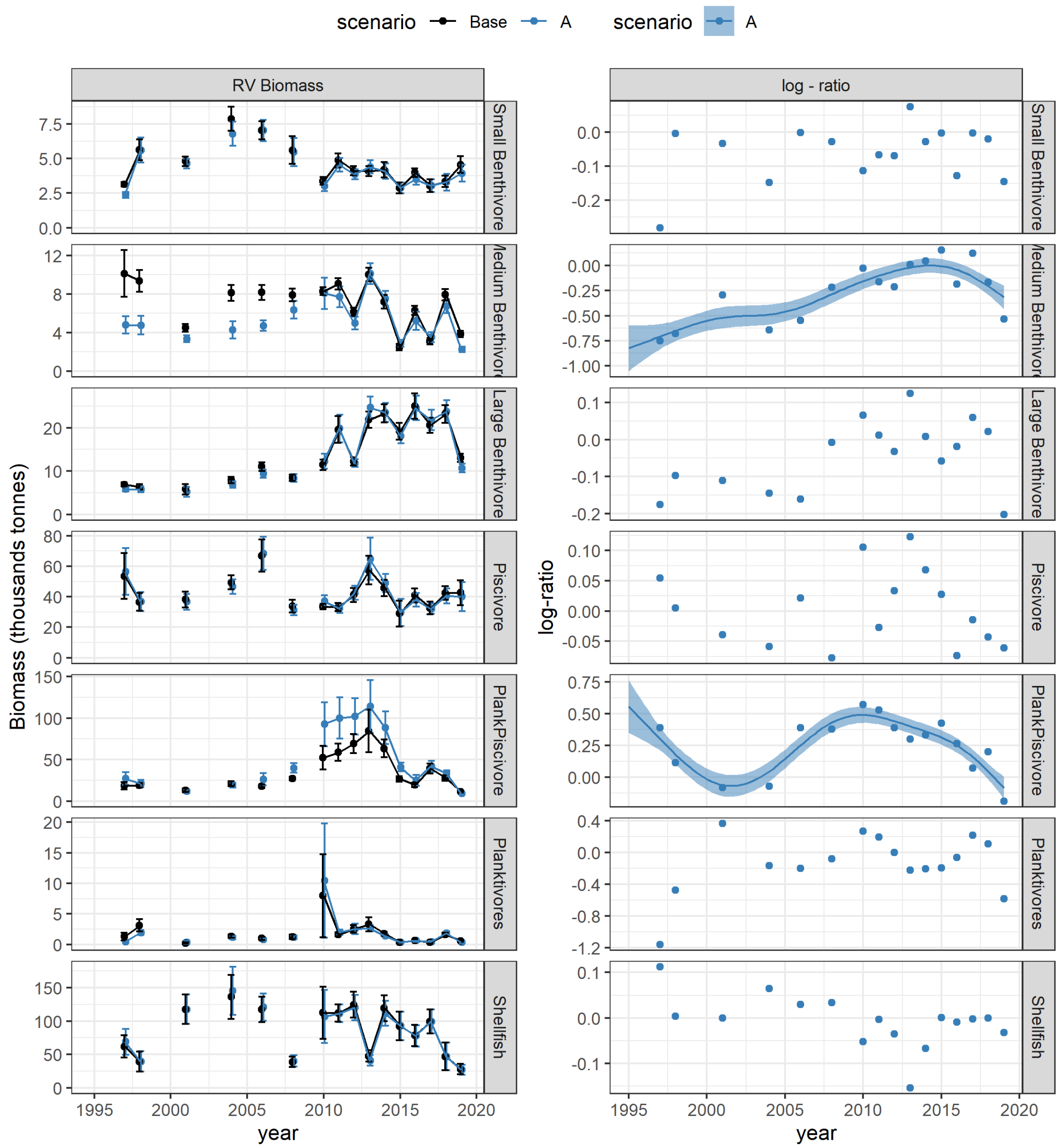


Figure B1. Summary of potential impact on RV Biomass index in 2H Fall when excluding RV Survey activity from coral and sponge closures (A) across fish functional group from 1997 to 2019. Plots on the left represent time series of RV Biomass indices including all sets (Base, black points) and excluding sets under the scenario with coral and sponge closures (A, blue) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

2H_Fall

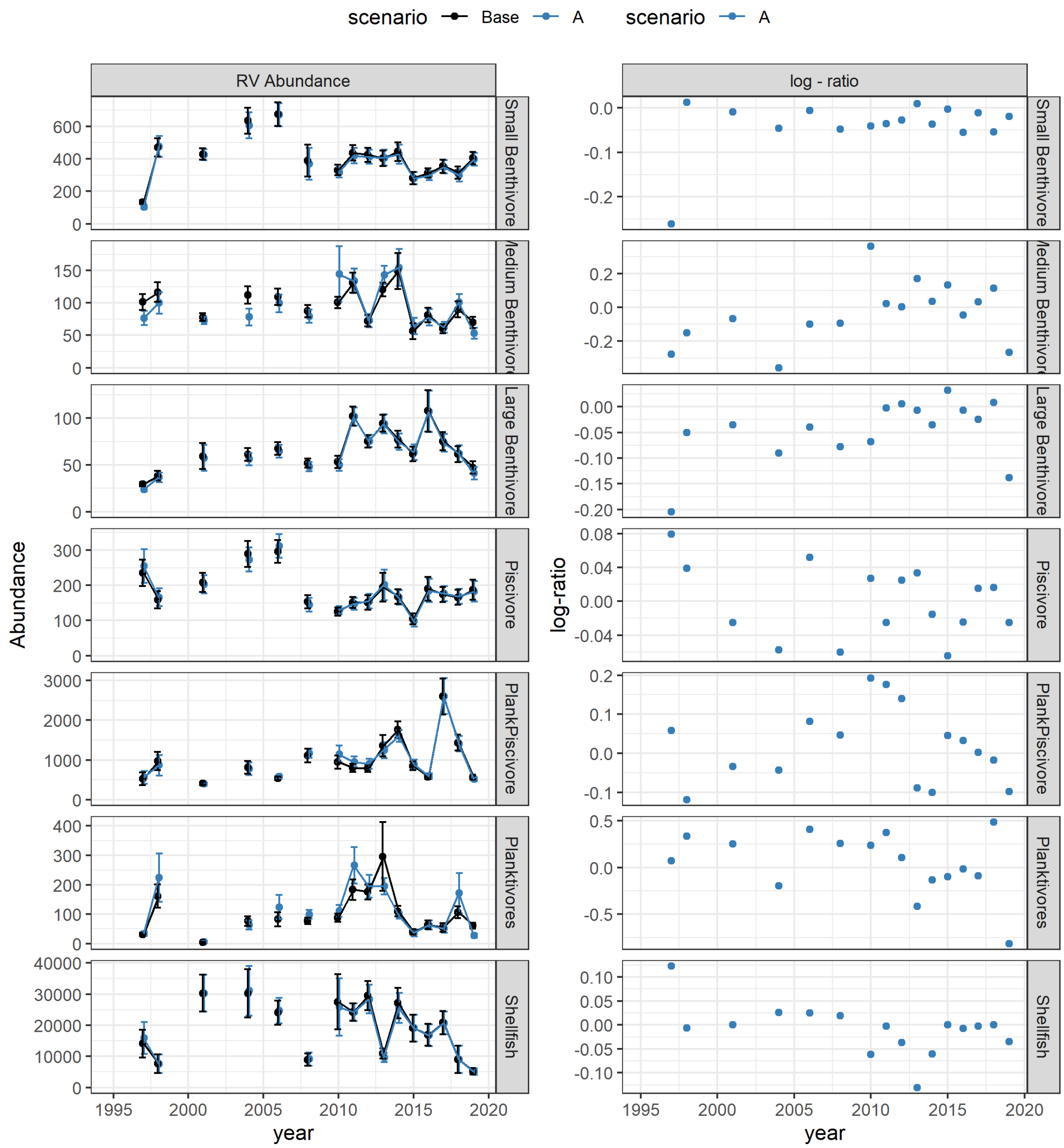


Figure B2. Summary of potential impact on RV Abundance index in 2H Fall when excluding RV Survey activity from coral and sponge closures (A) across fish functional group from 1997 to 2019. Plots on the left represent time series of RV Abundance indices including all sets (Base, black points) and excluding sets under the scenario with coral and sponge closures (A, blue) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

2H_Fall

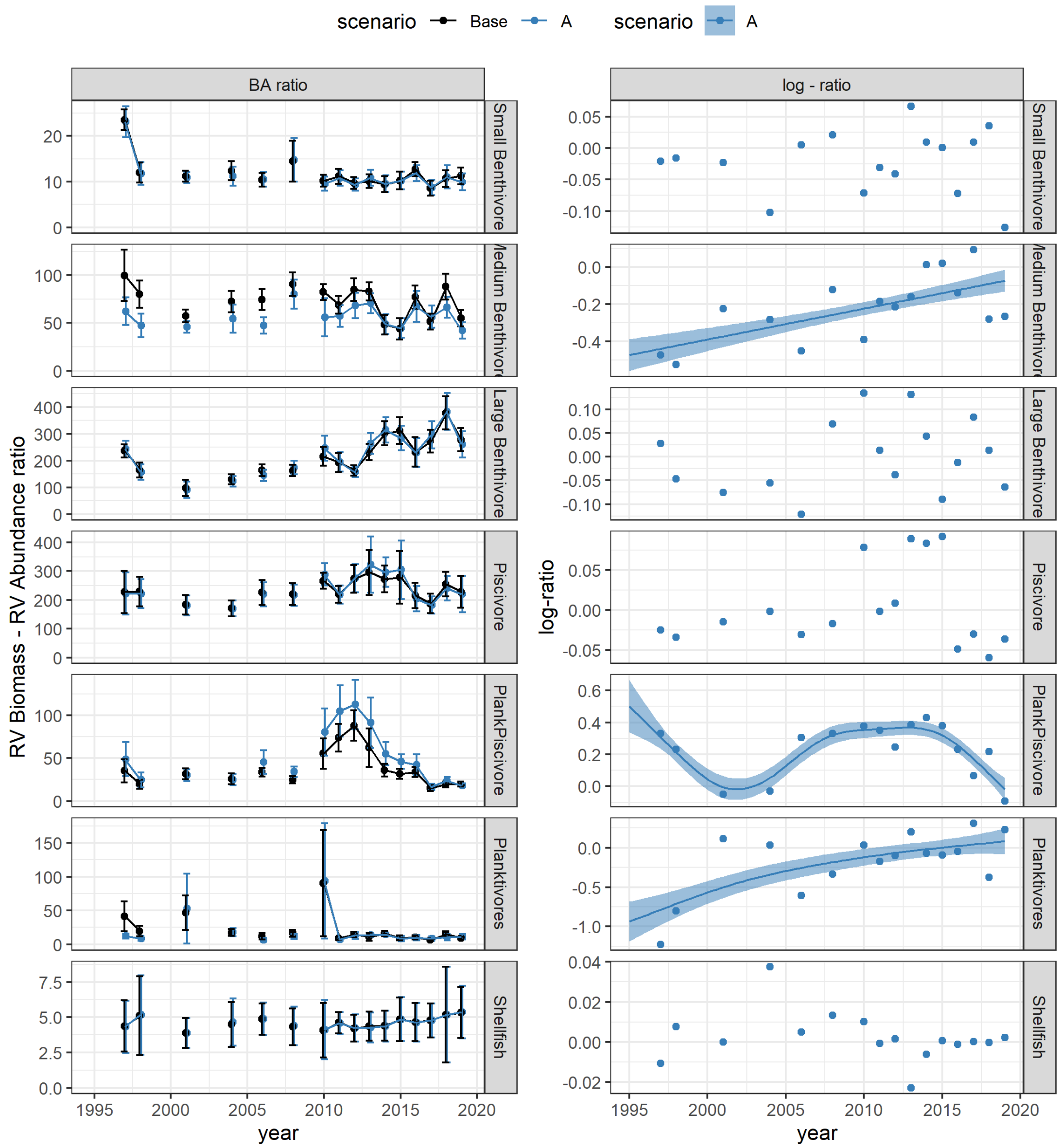


Figure B3. Summary of potential impact on ba ratio index in 2H Fall when excluding RV Survey activity from coral and sponge closures (A) across fish functional group from 1997 to 2019. Plots on the left represent time series of ba ratio indices including all sets (Base, black points) and excluding sets under the scenario with coral and sponge closures (A, blue) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

2J3K_Fall

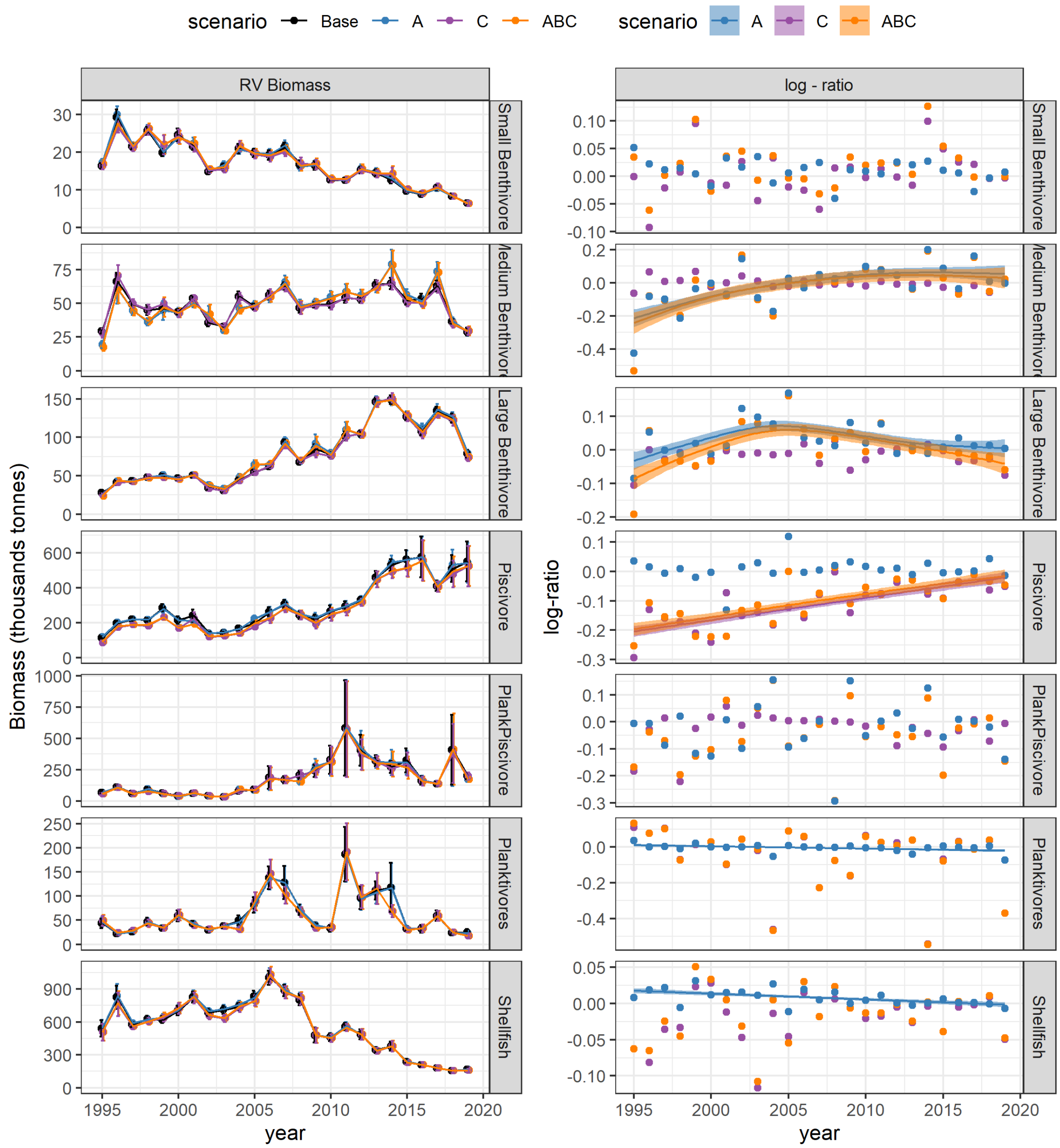


Figure B4. Summary of potential impact on RV Biomass index in 2J3K Fall when excluding RV Survey activity from coral and sponge closures (A), closures for groundfish breeding habitat, and combination of the two (ABC) across fish functional group from 1995 to 2019. Plots on the left represent time series of RV Biomass indices including all sets (Base, black points) and excluding sets under each scenario: coral and sponge closures (A, blue), closures for groundfish breeding habitat, and combination of the two (ABC, orange) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

2J3K_Fall

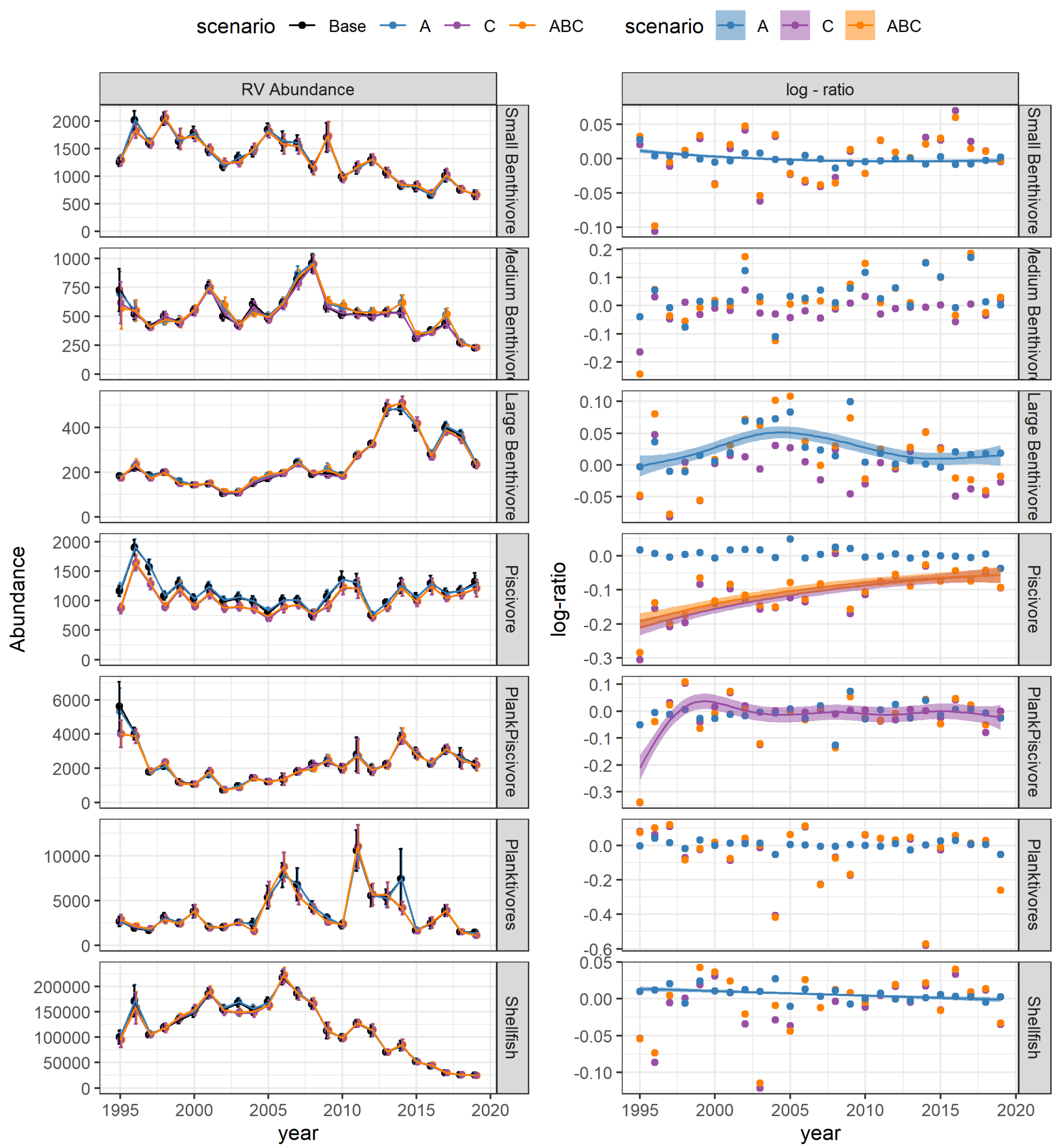


Figure B5. Summary of potential impact on RV Abundance index in 2J3K Fall when excluding RV Survey activity from coral and sponge closures (A), closures for groundfish breeding habitat, and combination of the two (ABC) across fish functional group from 1995 to 2019. Plots on the left represent time series of RV Abundance indices including all sets (Base, black points) and excluding sets under each scenario: coral and sponge closures (A, blue), closures for groundfish breeding habitat, and combination of the two (ABC, orange) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

2J3K_Fall

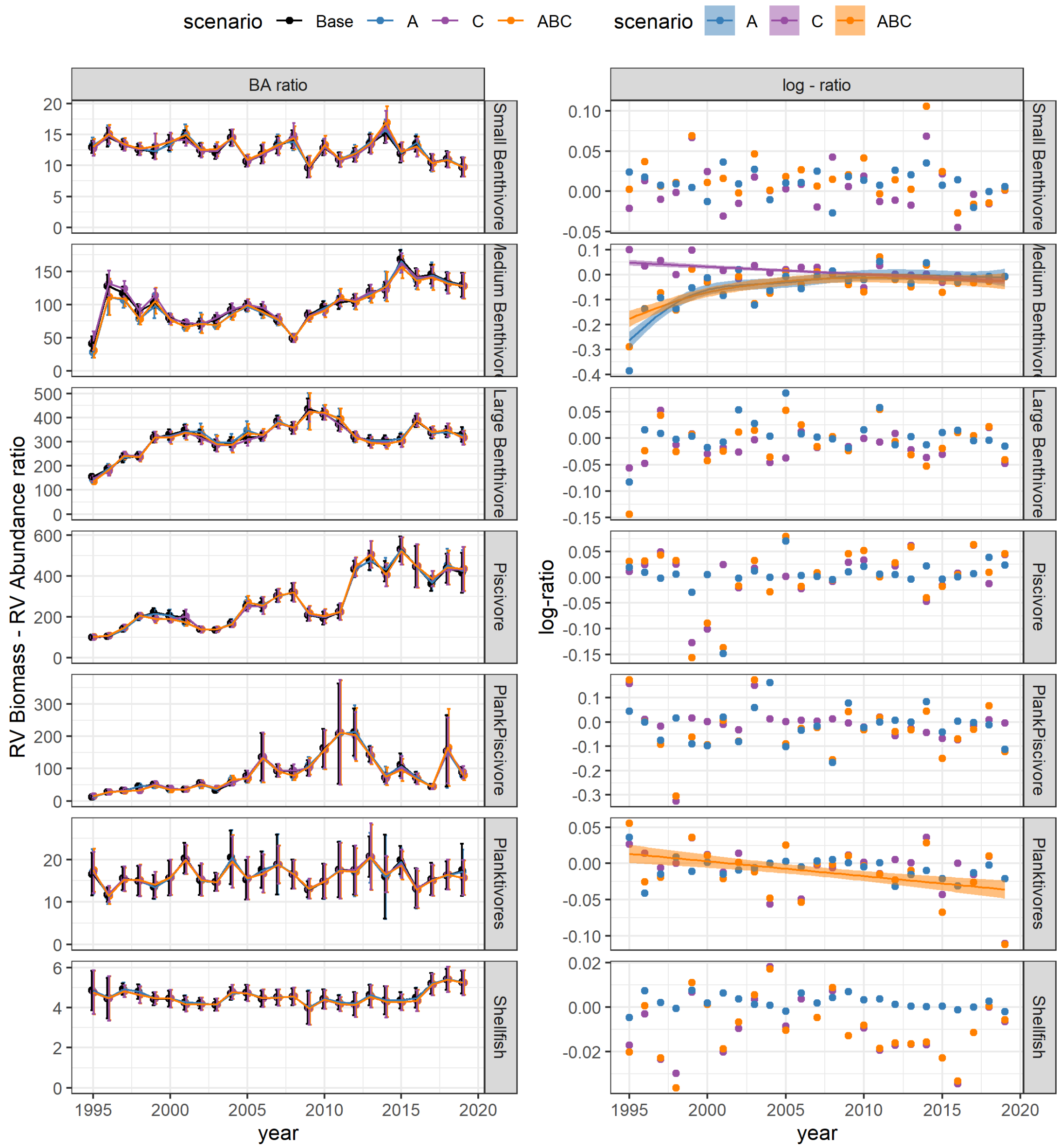


Figure B6. Summary of potential impact on ba ratio index in 2J3K Fall when excluding RV Survey activity from coral and sponge closures (A), closures for groundfish breeding habitat, and combination of the two (ABC) across fish functional group from 1995 to 2019. Plots on the left represent time series of ba ratio indices including all sets (Base, black points) and excluding sets under each scenario: coral and sponge closures (A, blue), closures for groundfish breeding habitat, and combination of the two (ABC, orange) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

3LNO_Fall

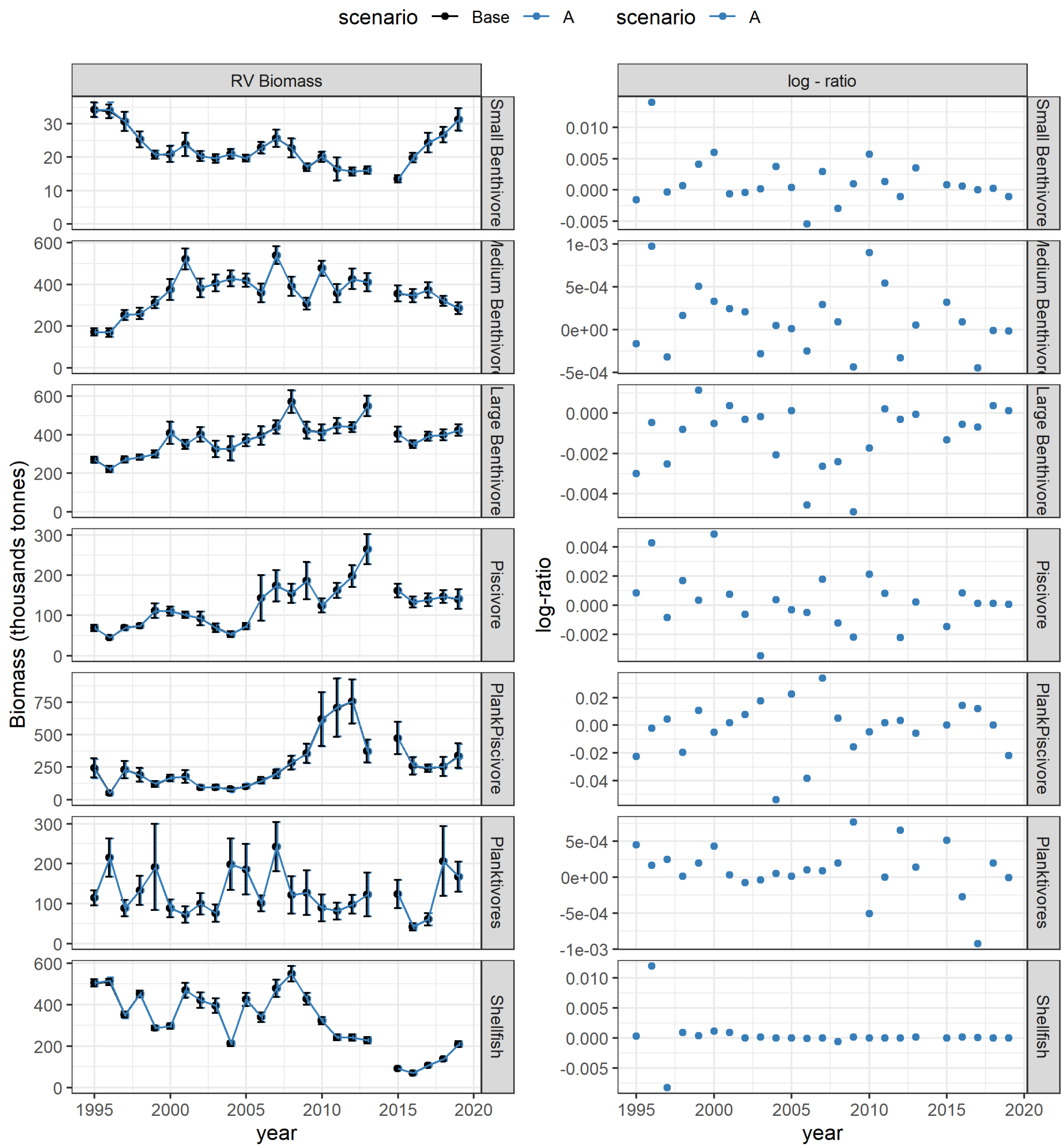


Figure B7. Summary of potential impact on RV Biomass index in 3LNO Fall when excluding RV Survey activity from coral and sponge closures (A) across fish functional group from 1995 to 2019. Plots on the left represent time series of RV Biomass indices including all sets (Base, black points) and excluding sets under the scenario with coral and sponge closures (A, blue) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

3LNO_Fall

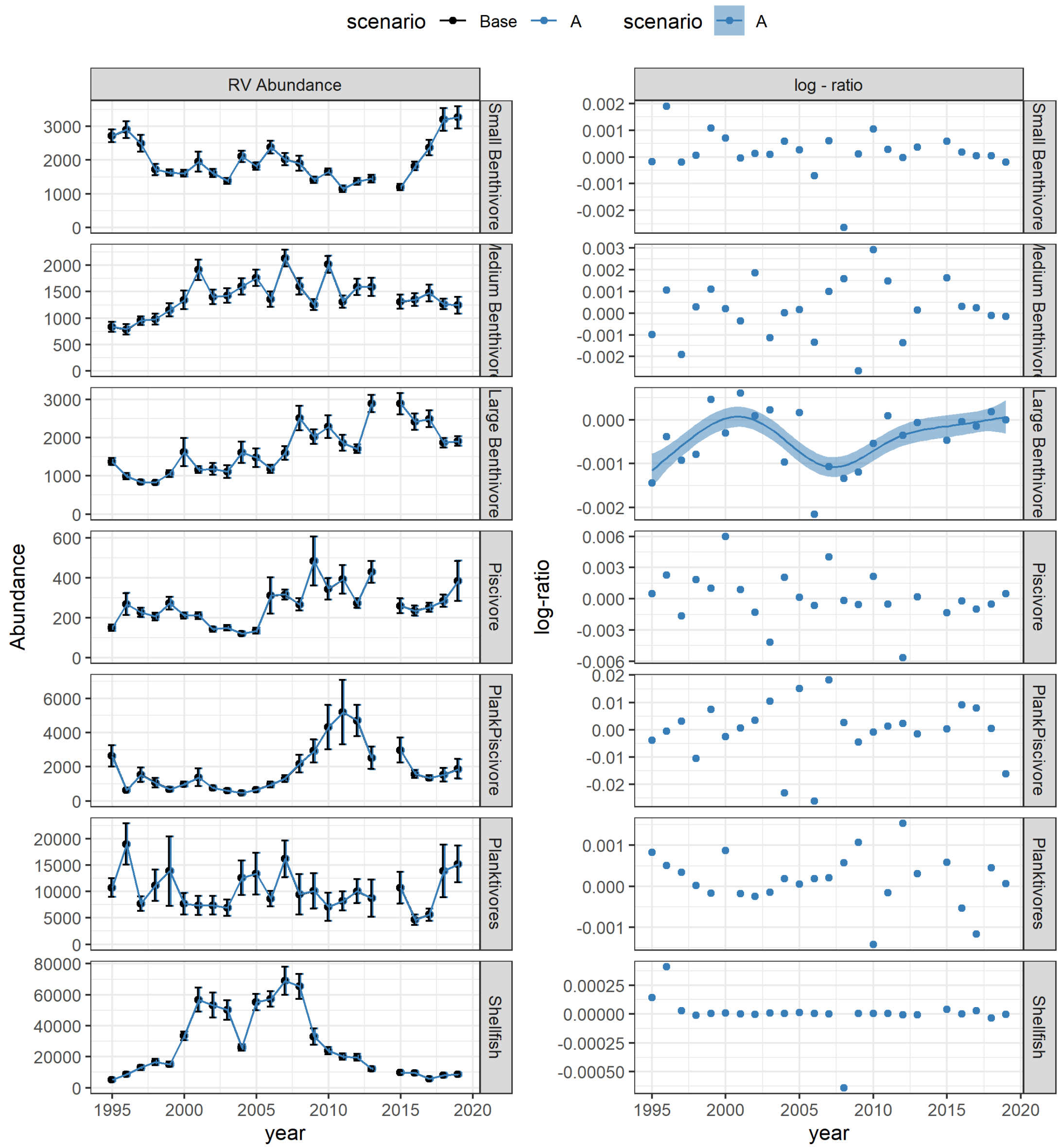


Figure B8. Summary of potential impact on RV Abundance index in 3LNO Fall when excluding RV Survey activity from coral and sponge closures (A) across fish functional group from 1995 to 2019. Plots on the left represent time series of RV Abundance indices including all sets (Base, black points) and excluding sets under the scenario with coral and sponge closures (A, blue) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

3LNO_Fall

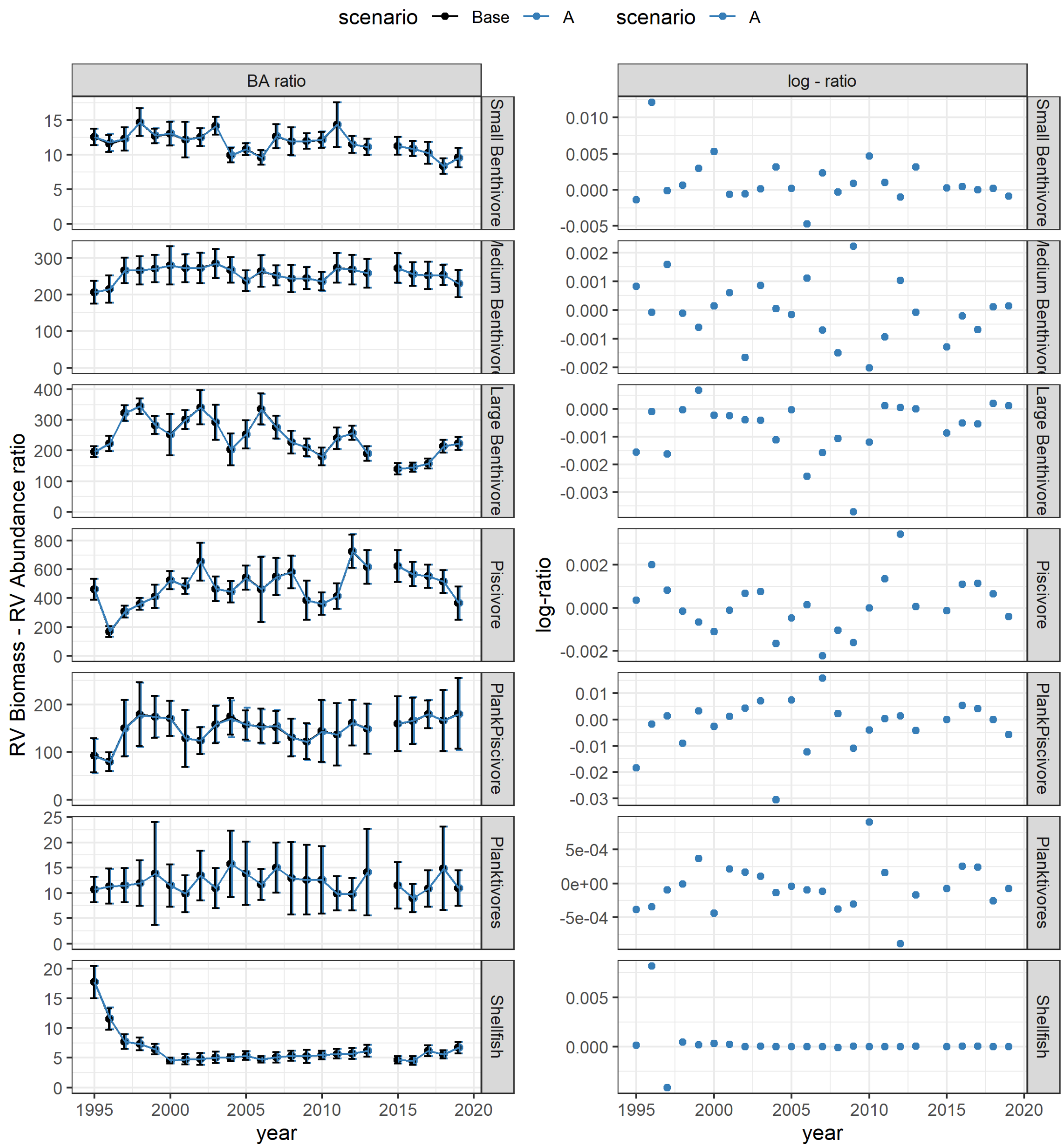


Figure B9. Summary of potential impact on ba ratio index in 3LNO Fall when excluding RV Survey activity from coral and sponge closures (A) across fish functional group from 1995 to 2019. Plots on the left represent time series of ba ratio indices including all sets (Base, black points) and excluding sets under the scenario with coral and sponge closures (A, blue) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

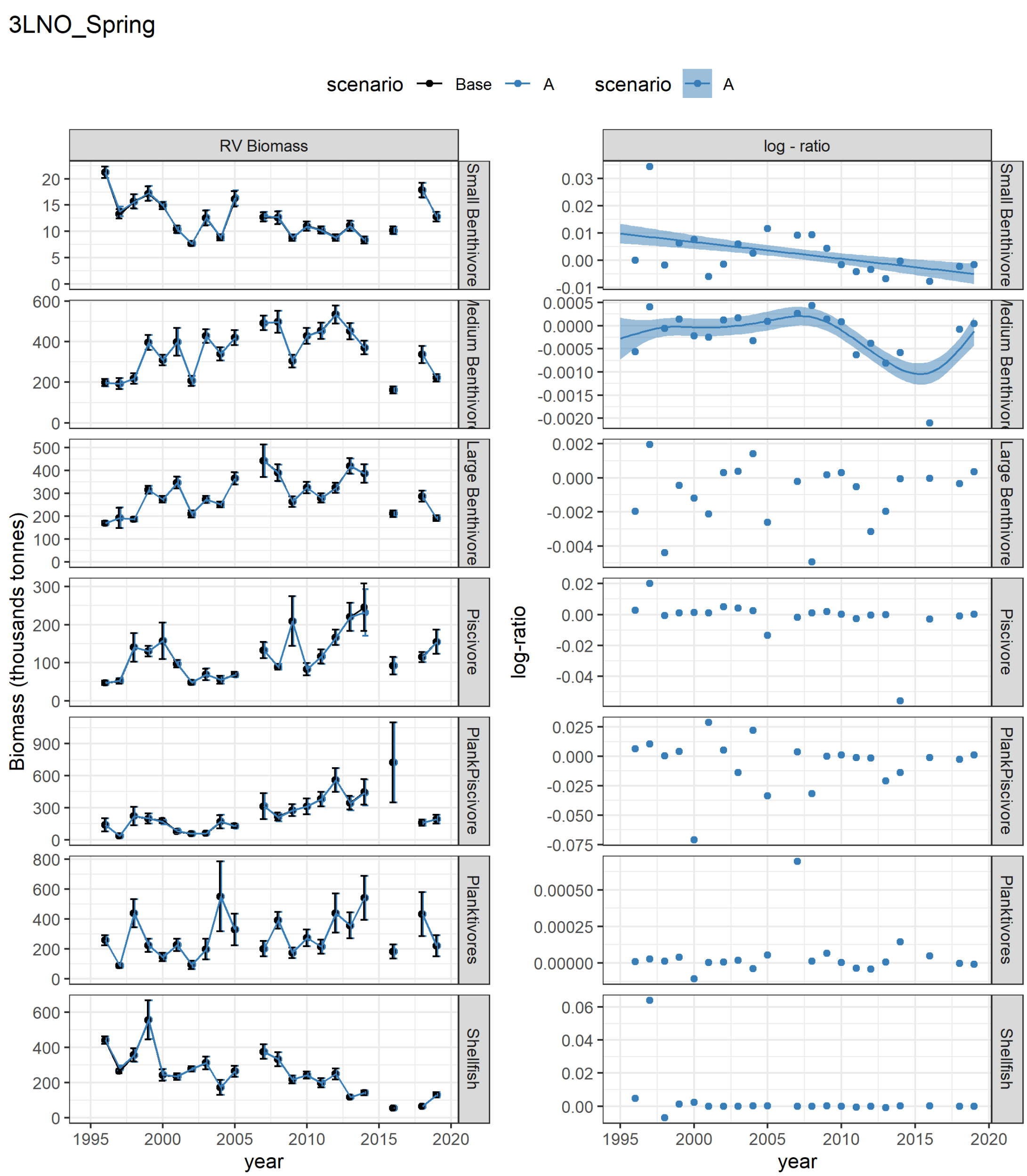


Figure B10. Summary of potential impact on RV Biomass index in 3LNO Spring when excluding RV Survey activity from coral and sponge closures (A) across fish functional group from 1996 to 2019. Plots on the left represent time series of RV Biomass indices including all sets (Base, black points) and excluding sets under the scenario with coral and sponge closures (A, blue) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

3LNO_Spring

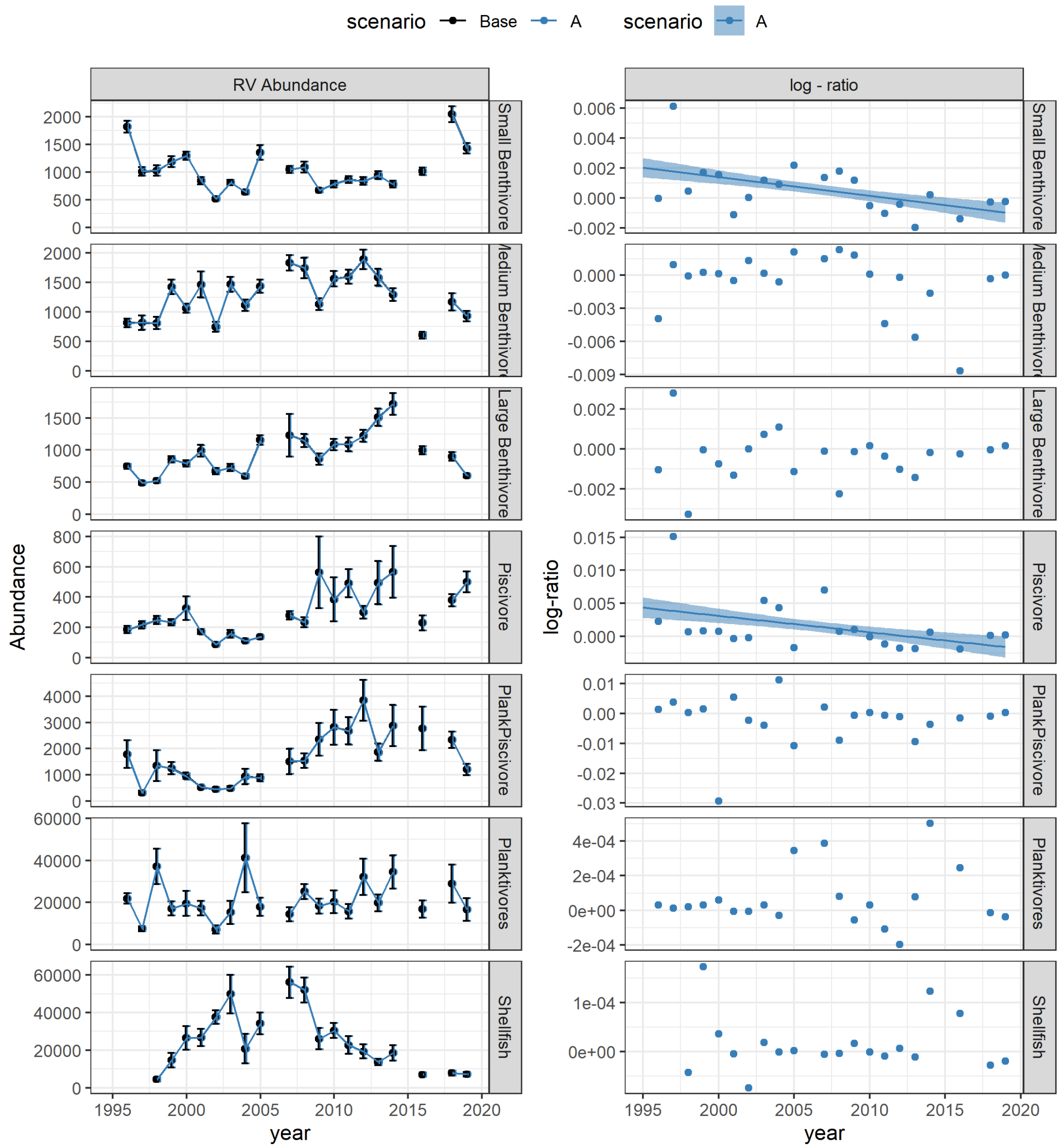


Figure B11. Summary of potential impact on RV Abundance index in 3LNO Spring when excluding RV Survey activity from coral and sponge closures (A) across fish functional group from 1996 to 2019. Plots on the left represent time series of RV Abundance indices including all sets (Base, black points) and excluding sets under the scenario with coral and sponge closures (A, blue) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

3LNO_Spring

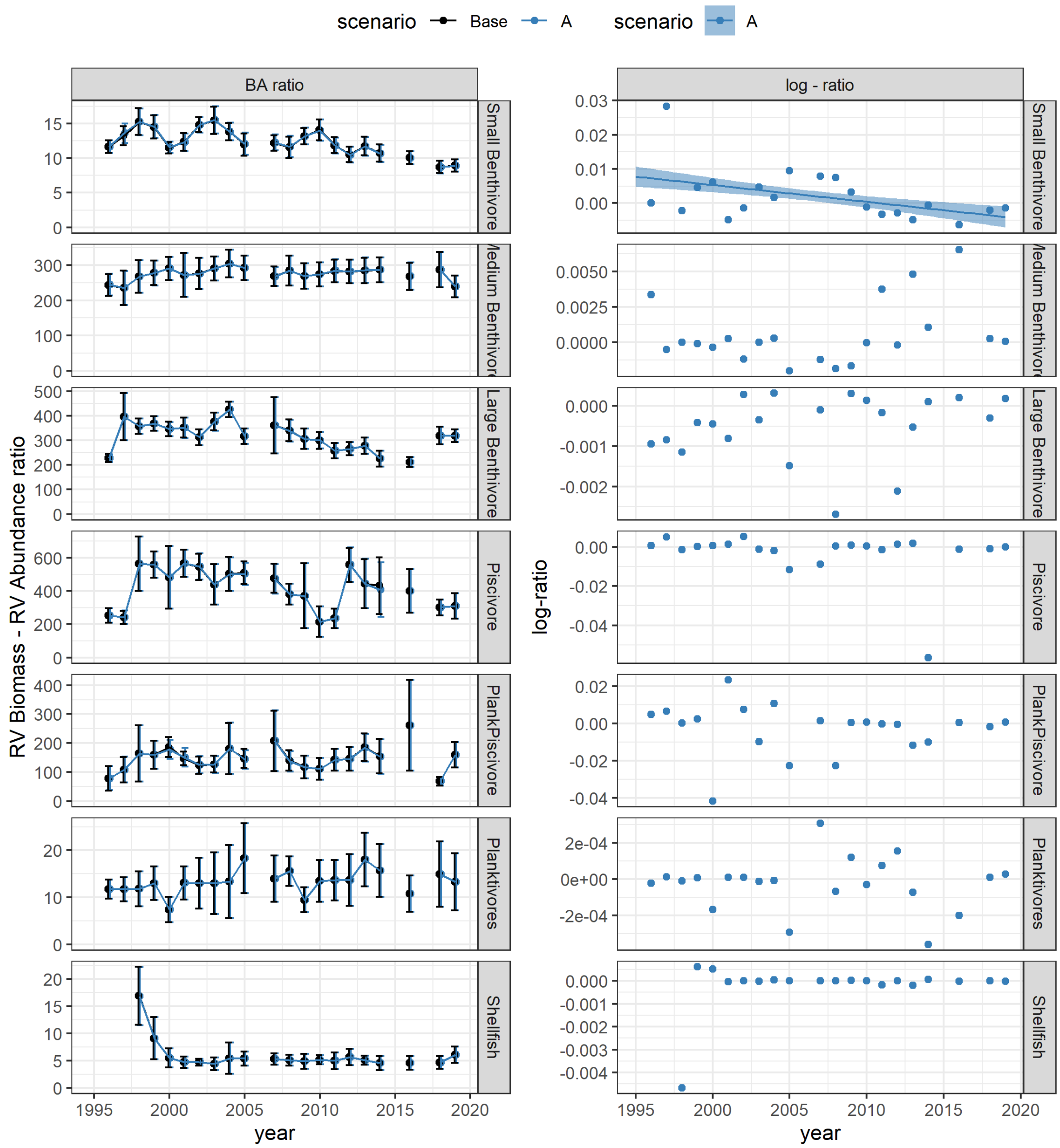


Figure B12. Summary of potential impact on ba ratio index in 3LNO Spring when excluding RV Survey activity from coral and sponge closures (A) across fish functional group from 1996 to 2019. Plots on the left represent time series of ba ratio indices including all sets (Base, black points) and excluding sets under the scenario with coral and sponge closures (A, blue) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

3Ps_Spring

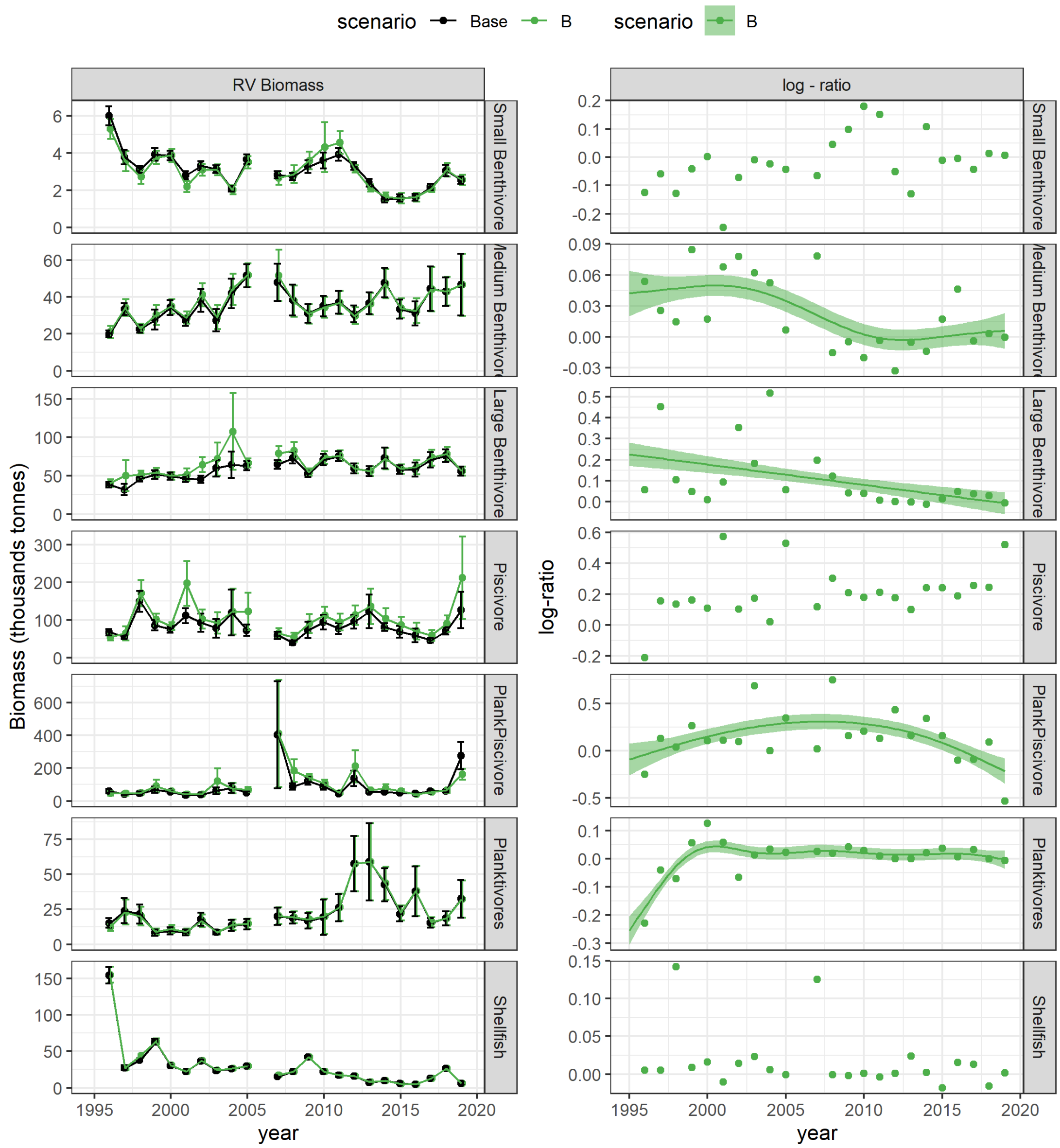


Figure B13. Summary of potential impact on RV Biomass index in 3Ps Spring when excluding RV Survey activity from the seapen closure (B) across fish functional group from 1996 to 2019. Plots on the left represent time series of RV Biomass indices including all sets (Base, black points) and excluding sets under the scenario with the seapen closure (B, green) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

3Ps_Spring

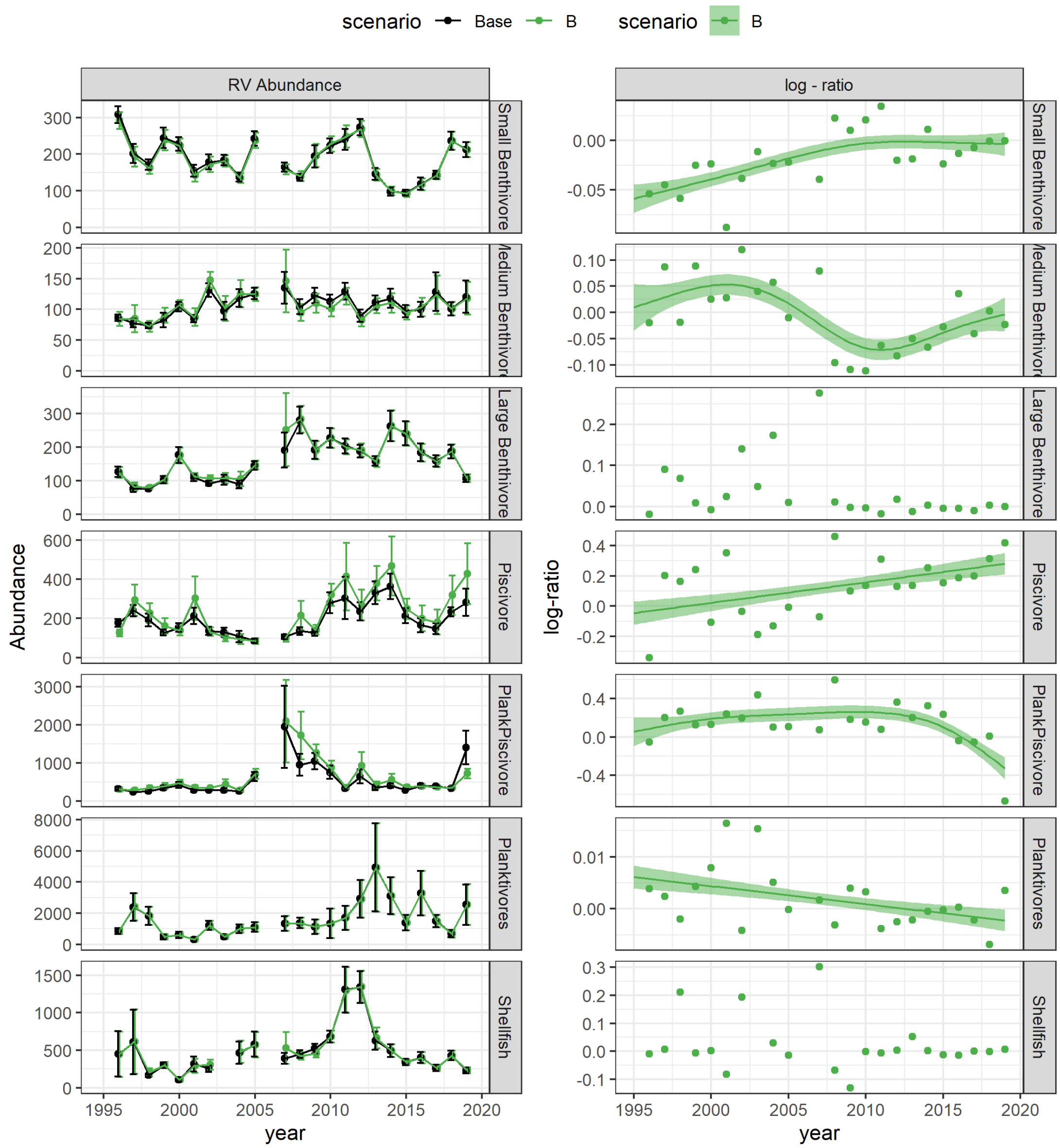


Figure B14. Summary of potential impact on RV Abundance index in 3Ps Spring when excluding RV Survey activity from the seapen closure (B) across fish functional group from 1996 to 2019. Plots on the left represent time series of RV Abundance indices including all sets (Base, black points) and excluding sets under the scenario with the seapen closure (B, green) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

3Ps_Spring

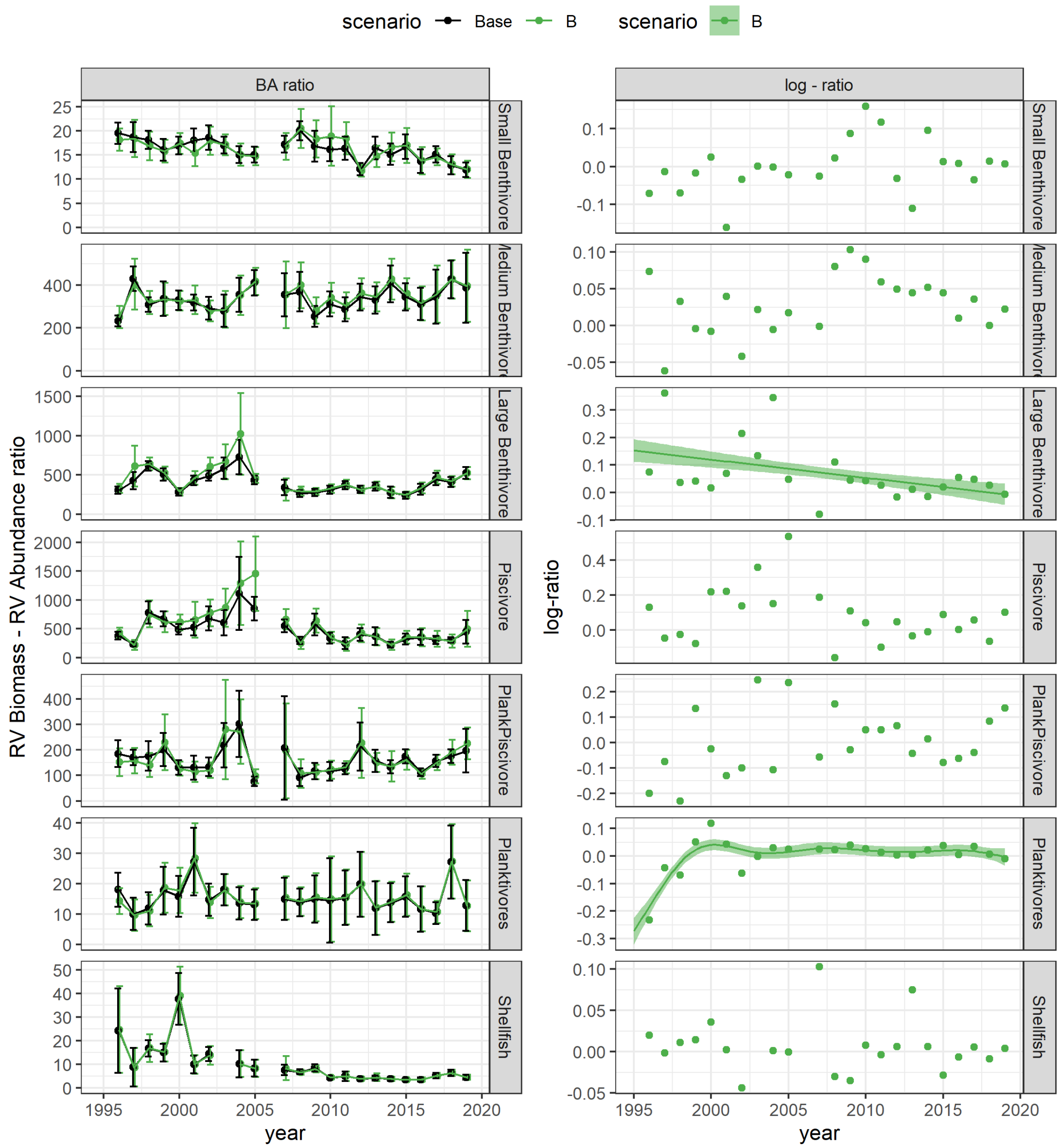


Figure B15. Summary of potential impact on ba ratio index in 3Ps Spring when excluding RV Survey activity from the seapen closure (B) across fish functional group from 1996 to 2019. Plots on the left represent time series of ba ratio indices including all sets (Base, black points) and excluding sets under the scenario with the seapen closure (B, green) with SD. Plots on the right represent relative bias, log-ratio (log of index excluding sets over base), where the points are data values and the line and ribbon are the smoother and SD of a GAM when year was statistically significant. Each row represents a fish functional group.

12. APPENDIX C – DEMERSAL FISH PLOTS

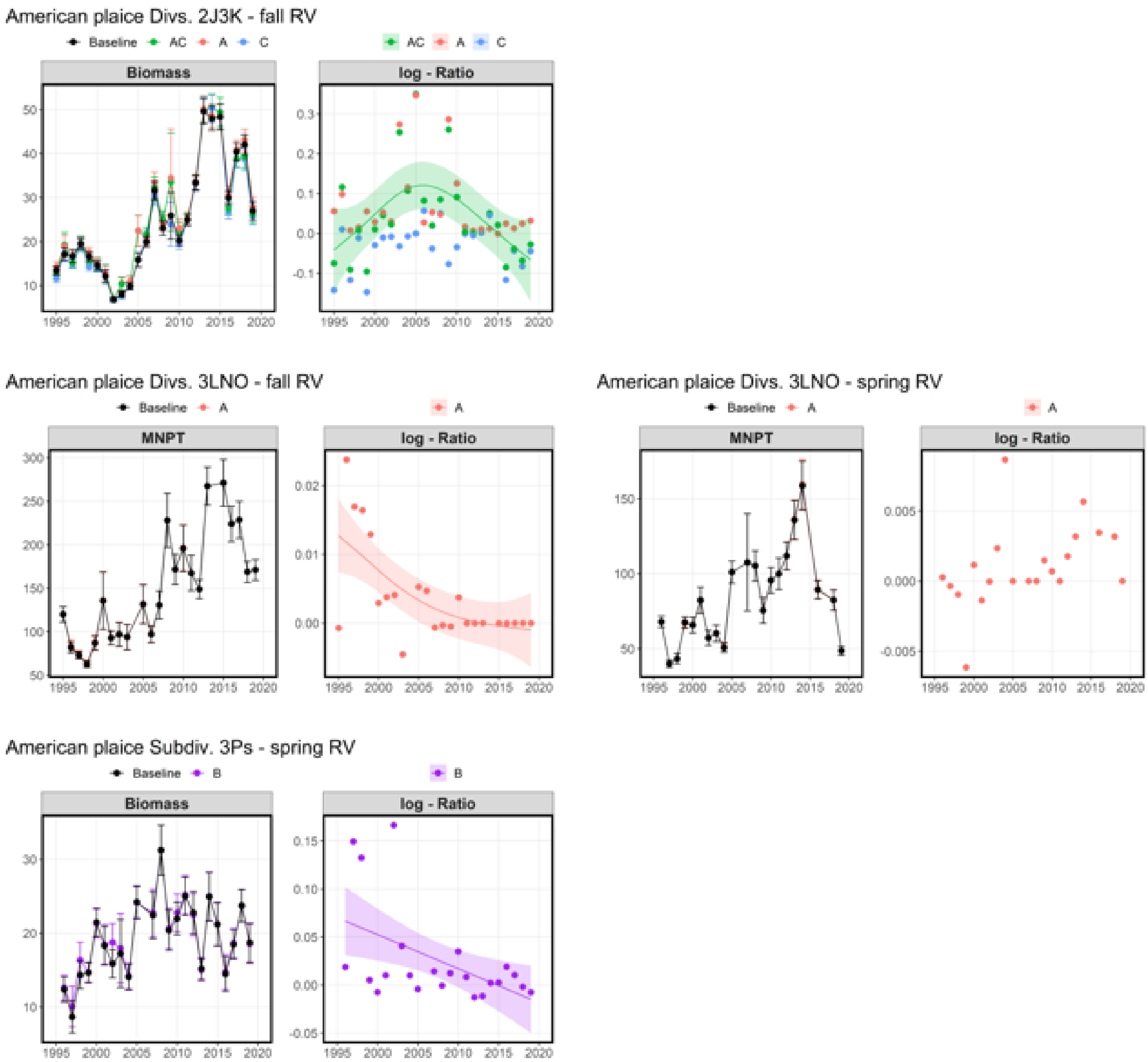


Figure C1. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: American Plaice (Divs. 2J3K, Divs. 3LNO, Subdiv. 3Ps). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

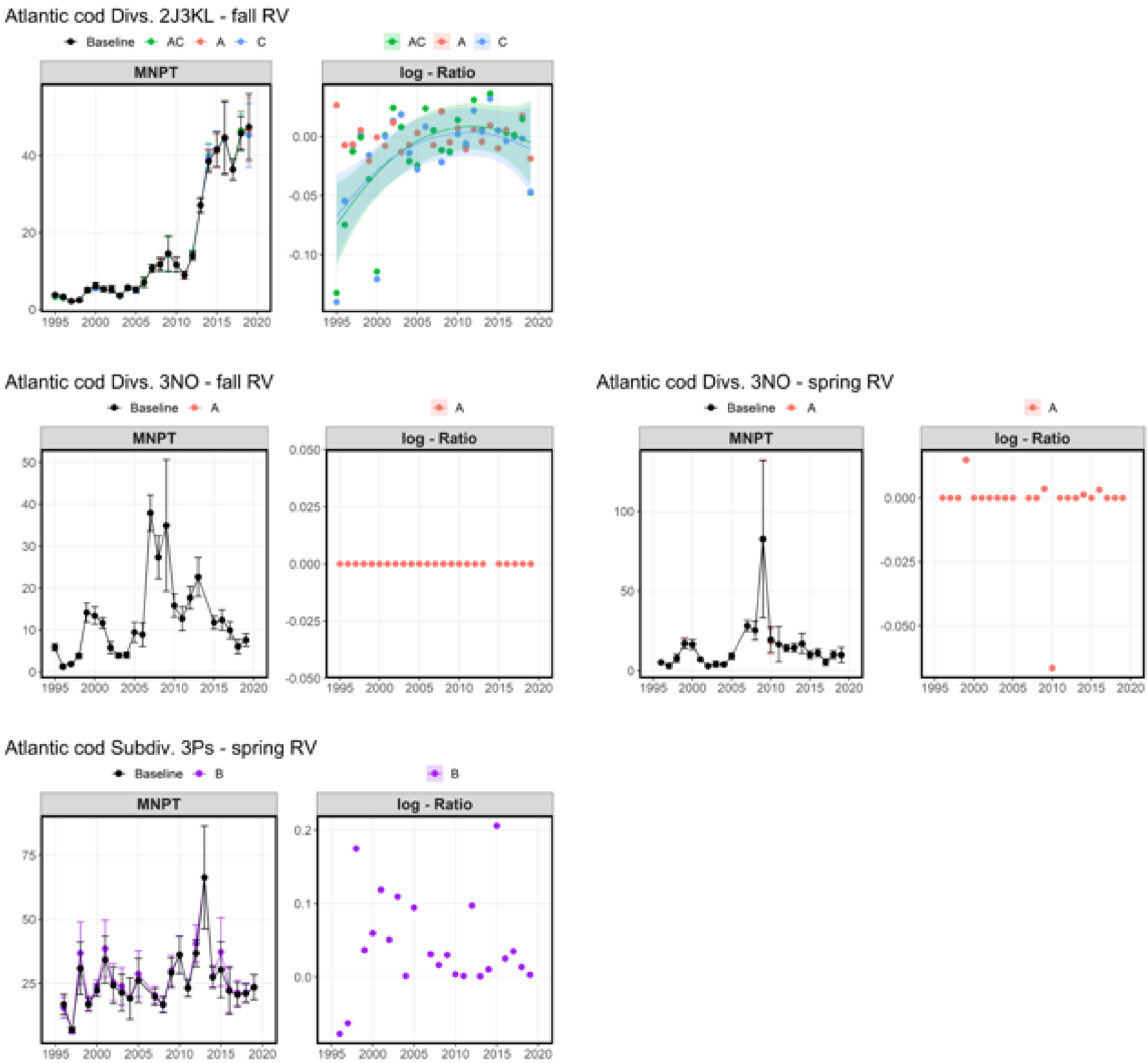


Figure C2. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Atlantic cod (Divs. 2J3KL, Divs. 3NO, Subdiv. 3Ps). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

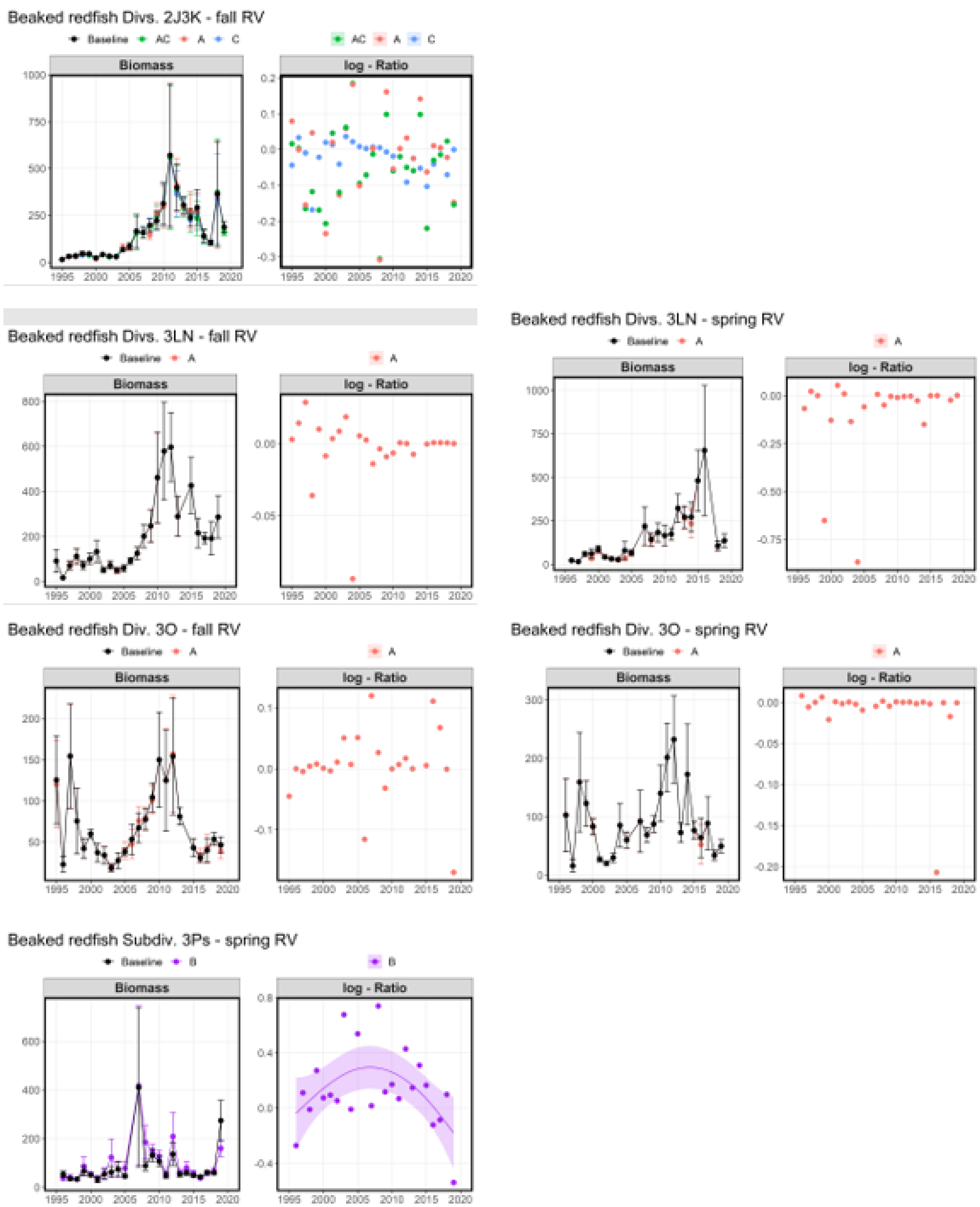


Figure C3. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Redfish (Divs. 2J3K, Divs. 3LN, Div. 3O, Subdiv. 3Ps). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

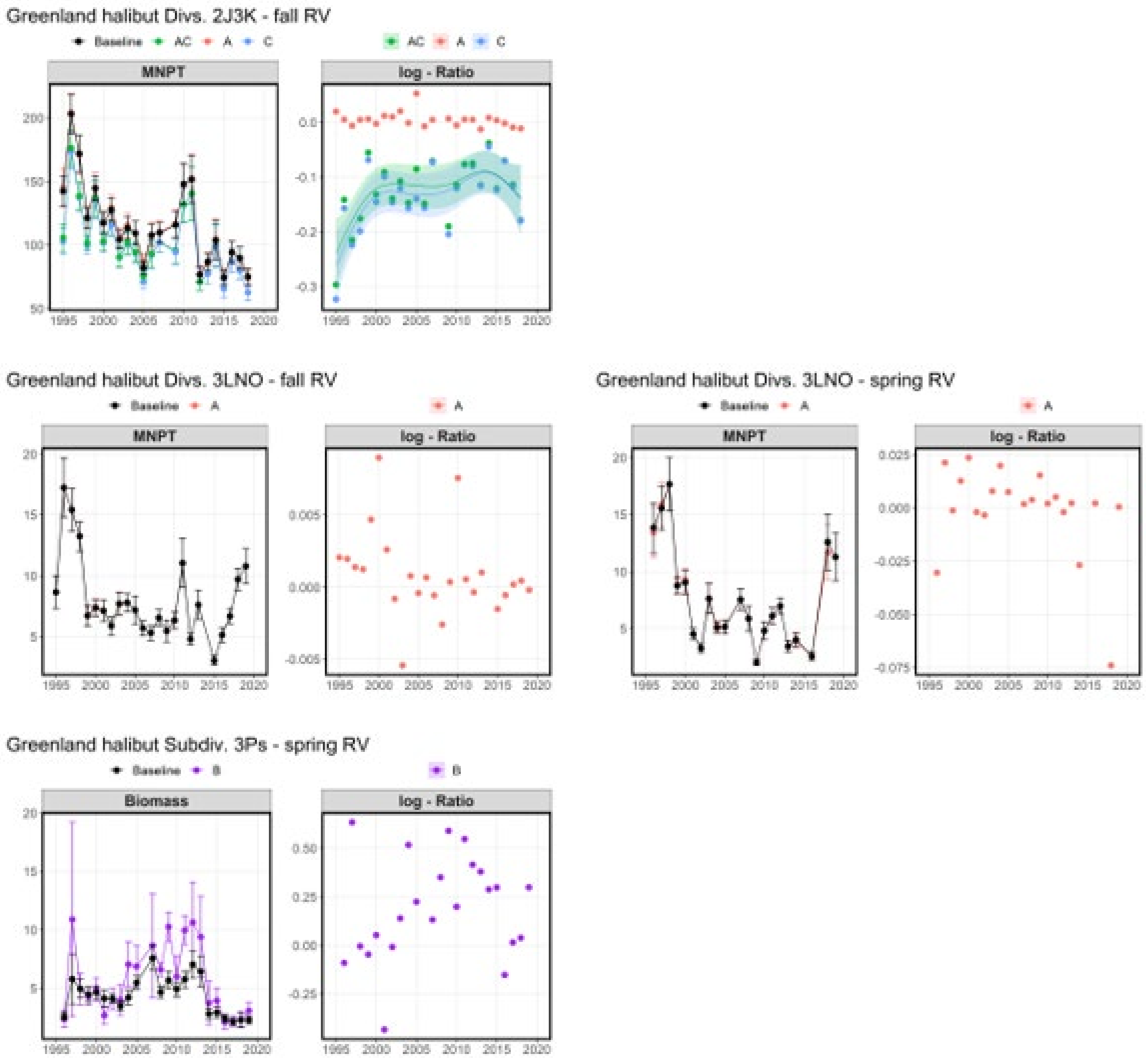


Figure C4. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Greenland Halibut (Divs. 2J3K, Divs. 3LNO, Subdiv. 3Ps). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

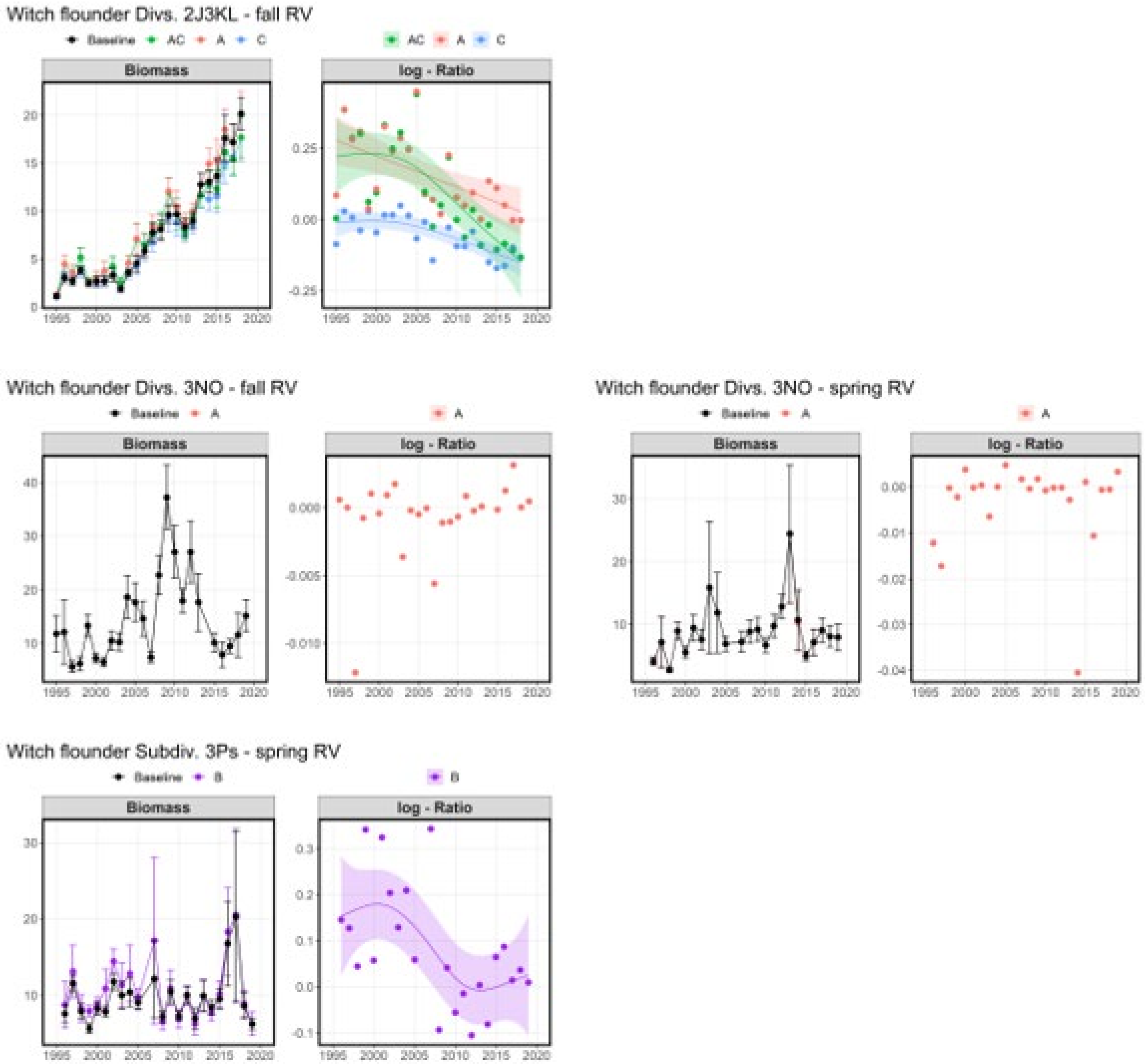


Figure C5. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Witch Flounder (Divs. 2J3KL, Divs. 3NO, Subdiv. 3Ps). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

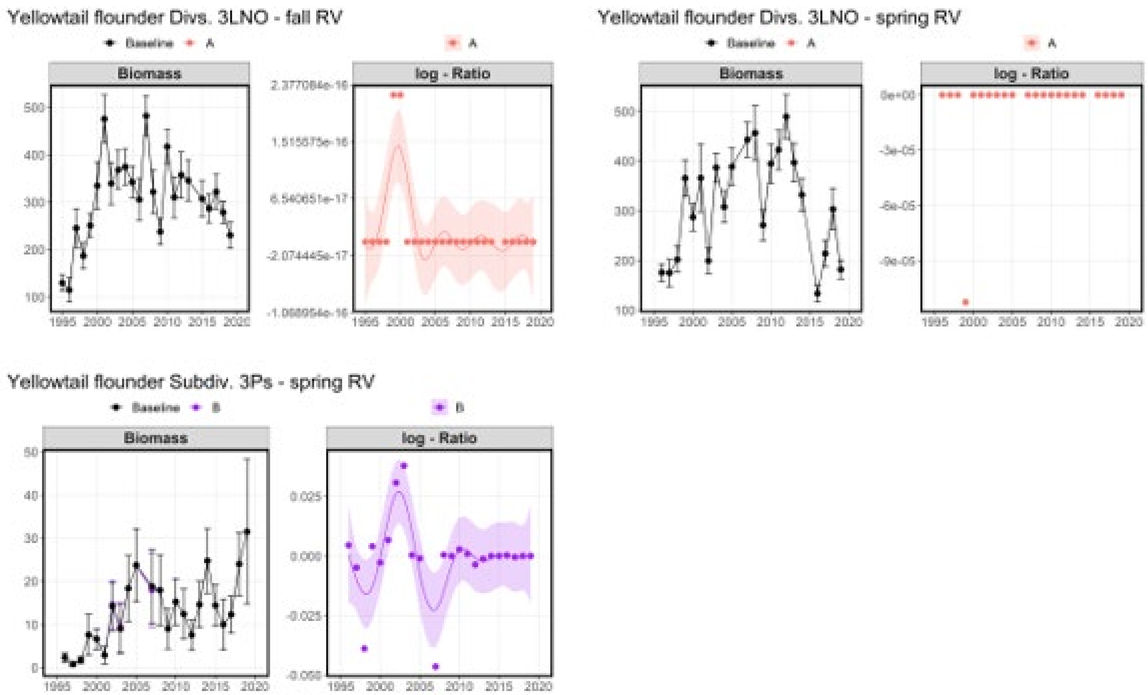


Figure C6. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Yellowtail Flounder (Divs. 3LNO, Subdiv. 3Ps). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

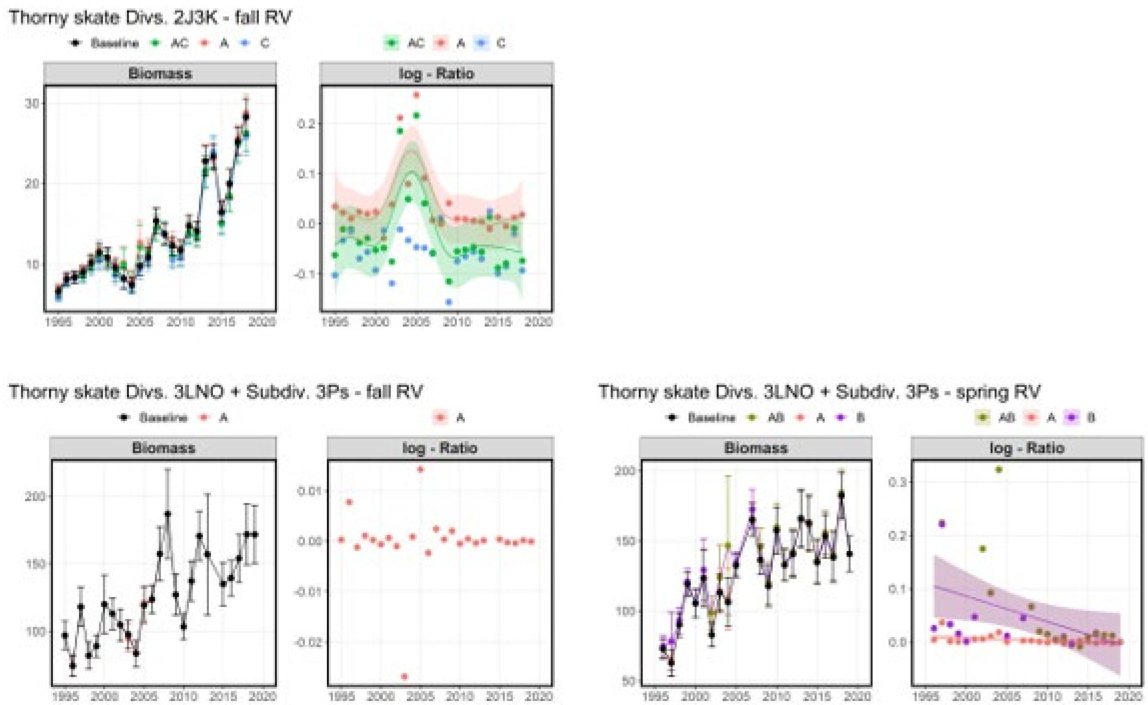


Figure C7. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Thorny Skate (Divs. 2J3K, Divs. 3LNOPs). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

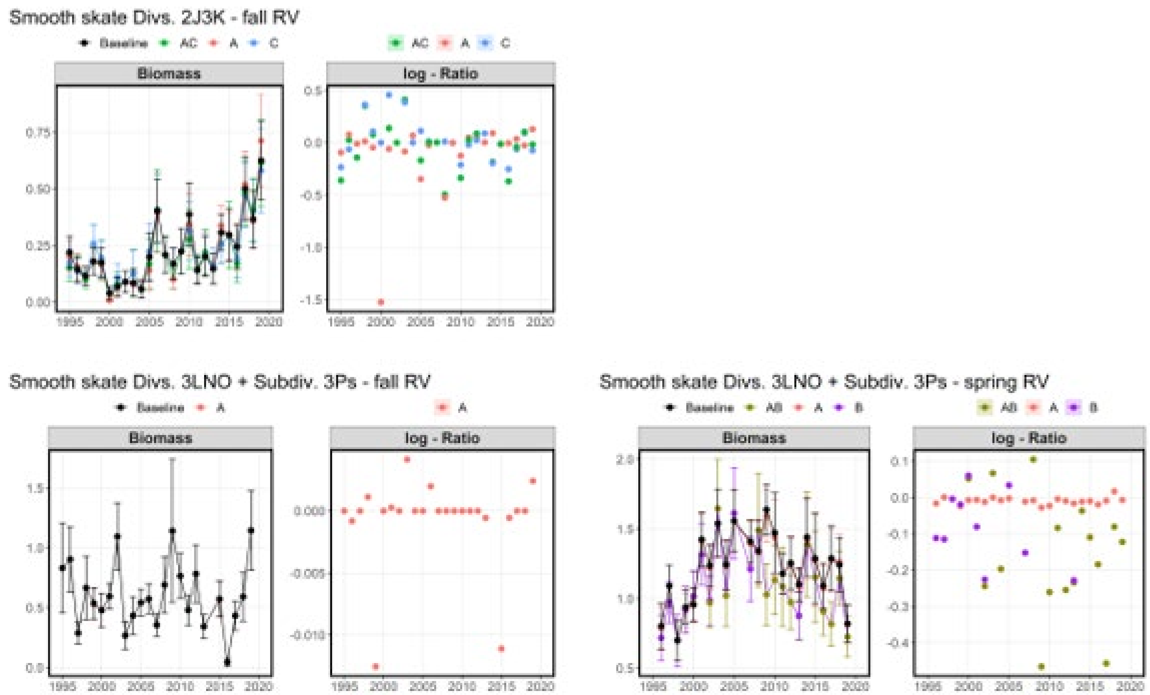


Figure C8. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Smooth Skate (Divs. 2J3K, Divs. 3LNOPs). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

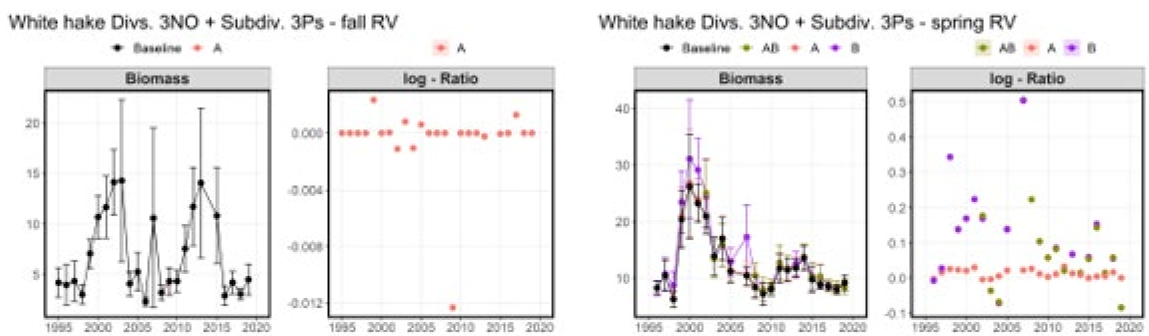


Figure C9. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: White Hake (Divs. 3NOPs). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

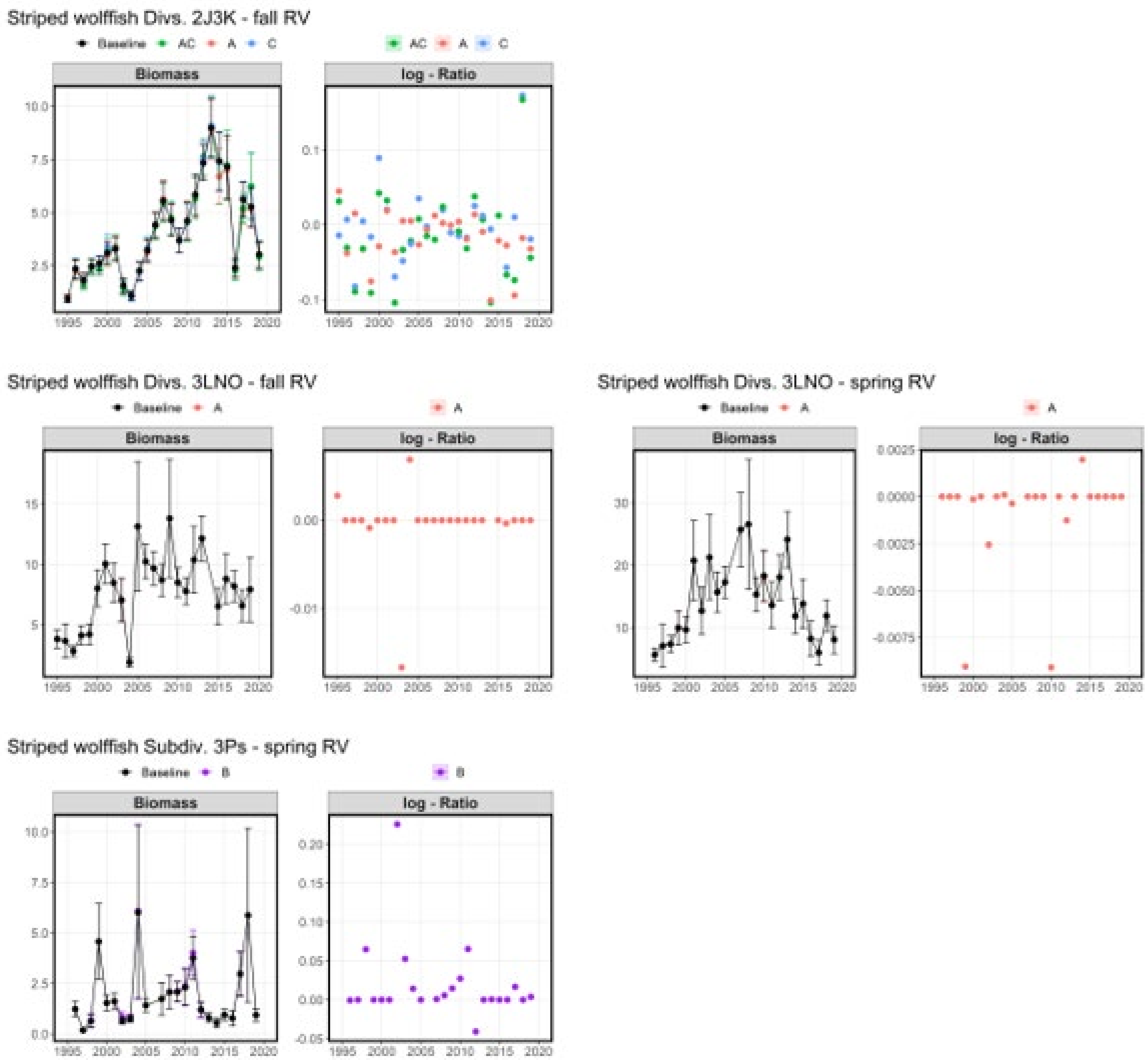


Figure C10. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Striped Wolffish (Divs. 2J3K, Divs. 3LNO, Subdiv. 3Ps). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

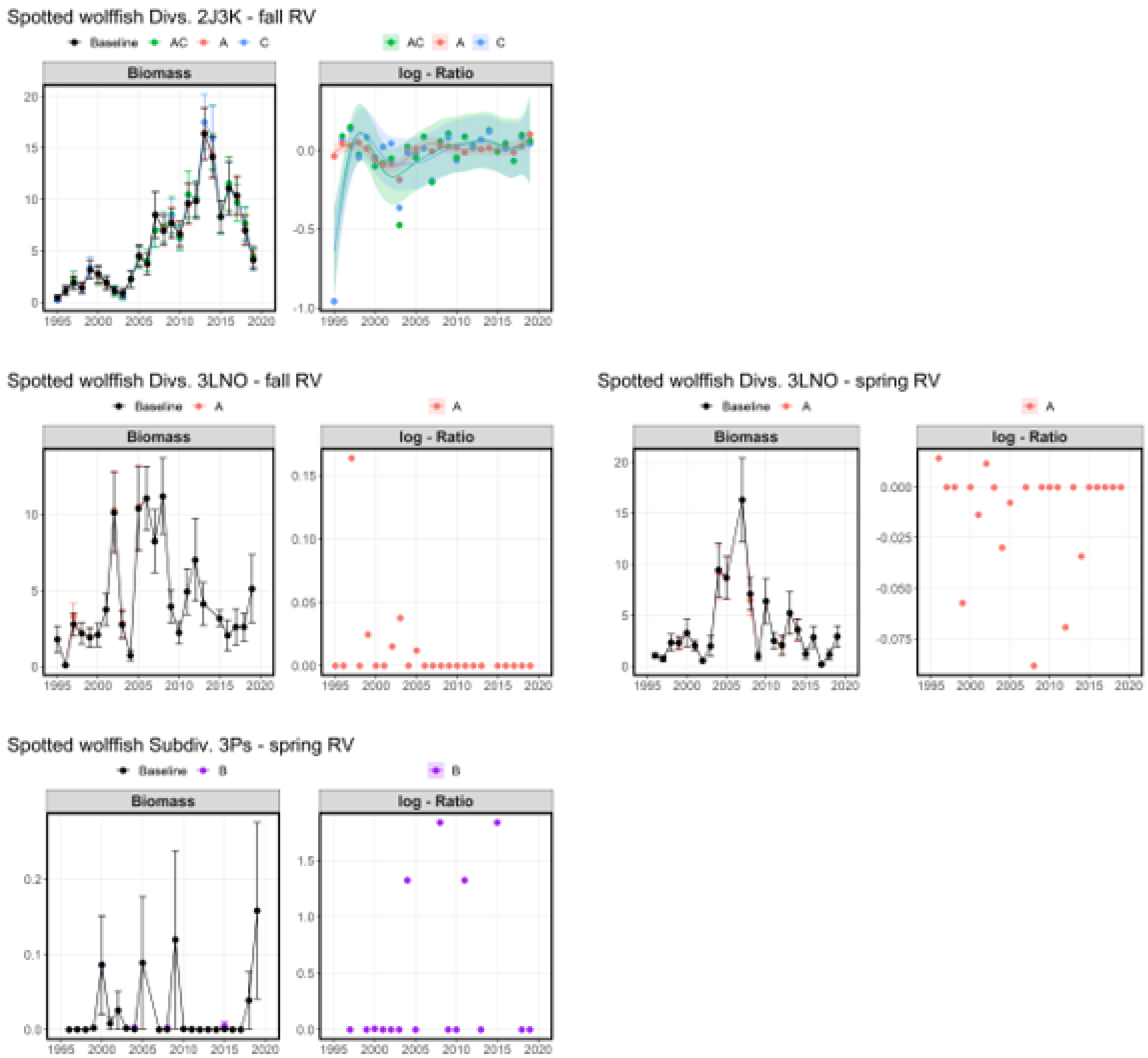


Figure C11. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Spotted Wolffish (Divs. 2J3K, Divs. 3LNO, Subdiv. 3Ps). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

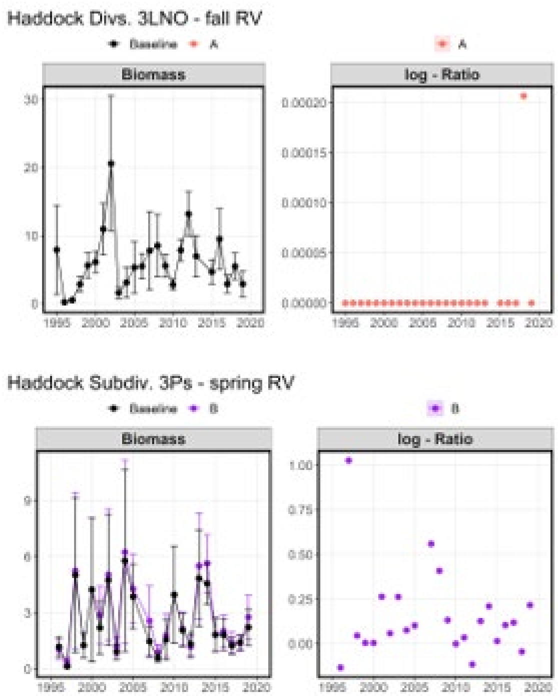


Figure C12. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Haddock (Divs. 3LNO, Subdiv. 3Ps). The survey indices presented are those currently used in the respective assessments. The 'Baseline' scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

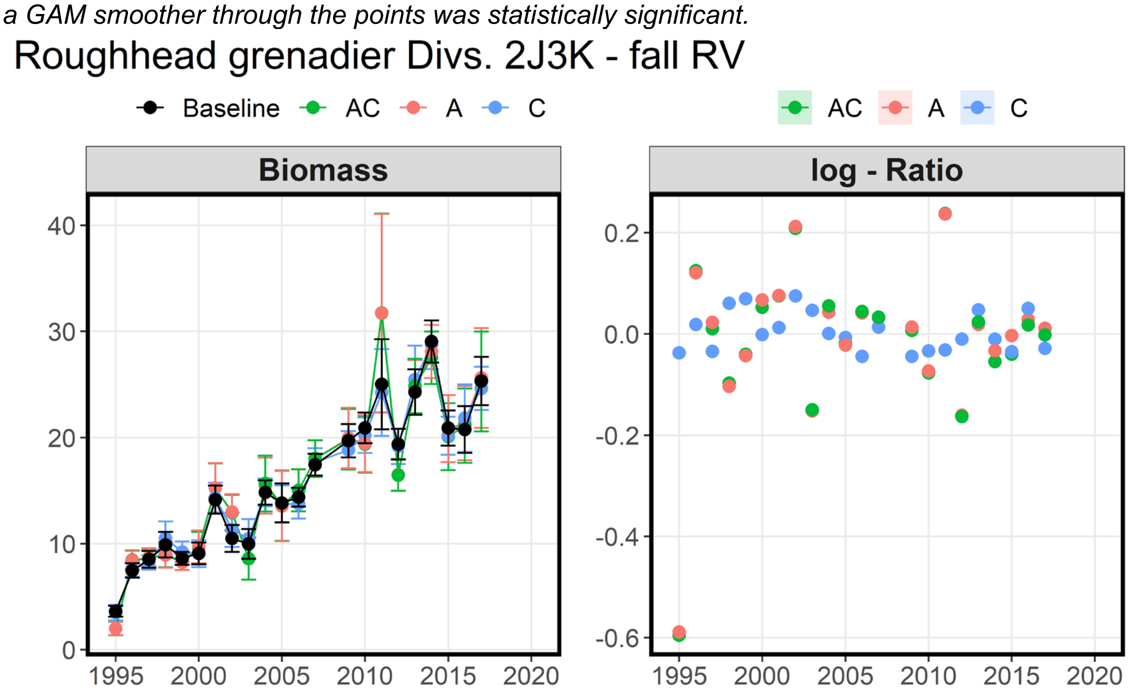


Figure C13. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Roughhead Grenadier (Divs. 2J3K). The survey indices presented are those currently used in the respective assessments. The ‘Baseline’ scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.

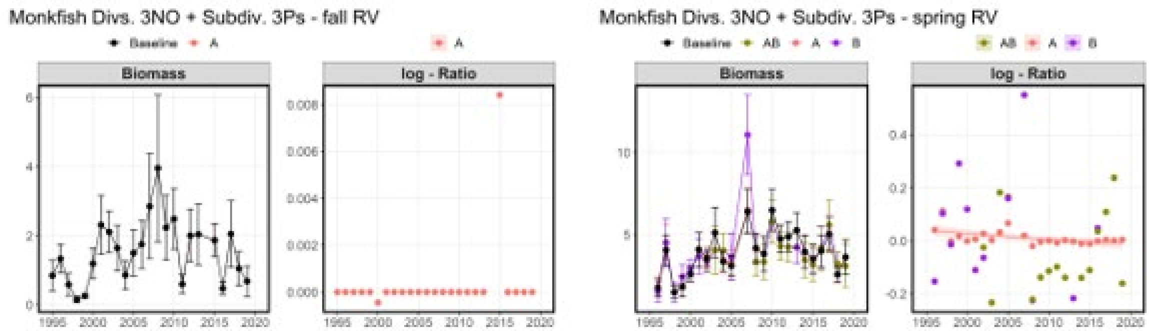


Figure C14. Potential impacts of excluding NL RV multi-species bottom trawl surveys from protected areas: Monkfish (Divs. 3LNOPs). The survey indices presented are those currently used in the respective assessments. The ‘Baseline’ scenario represents the status quo approach (i.e., no exclusion of surveys from closed areas) and the other scenarios represent the removal of data from within the closed areas (where A = sponge and gorgonian coral protection areas, B = sea pen protection areas, C = fish habitat protection areas). Error bars in the index plots are ±1 SD. The log-ratio plots indicate the relative bias caused by removing data from the protected areas and the trend line and 95% CIs are shown when a GAM smoother through the points was statistically significant.