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Pacific Region

Reassessment of the Ecologically and Biologically Significant Areas (EBSAs) in the Pacific Northern Shelf Bioregion

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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 committed to maintaining biological diversity and productivity in the marine environment under the *Oceans Act* (1997). Identifying Ecologically and Biologically Significant Areas (EBSAs) is a key component of this commitment and Fisheries and Oceans (DFO) and the Convention on Biological Diversity (CBD) have developed guidelines and criteria to identify these areas. EBSAs were identified in the Northern Shelf Bioregion (NSB) in 2006 using a two-phase expert-driven approach. In response to a science advice request from Oceans Sector, and following DFO Science's recommendation that EBSAs should be re-evaluated and updated with new information every five years, we re-assess the original EBSAs with available empirical data to increase understanding of the underlying ecological support for the existing EBSAs. In addition, we present an approach for identifying productivity and diversity hotspots, two EBSA criteria not evaluated in the first process. In general, we found empirical evidence for at least one important species listed in the original EBSA justification for all EBSAs except for the Hecate Strait Front. Although the results of our empirical analysis showed that existing EBSAs do an adequate job of capturing at least a portion of areas important to the ecology of multiple species, the shape and configuration of the EBSA boundaries could likely be improved to better match the ecological features within. In addition to the EBSA reassessment, we present hotspot maps of 1) nearshore habitat diversity, 2) diversity (fish and invertebrates), and 3) biomass (using catch per unit effort of fish and invertebrates). We also provide updated maps for 1) important areas for primary productivity, and 2) Sponge Reef EBSAs. These new data layers can be used to update the EBSAs and be used to inform the MPA network planning process ongoing in the NSB.

ACRONYMS

BB	Bella Bella Nearshore
BCMCA	British Columbia Marine Conservation Analysis
BP	Brooks Peninsula
CBD	Convention on Biological Diversity
CM	Central Mainland
CPUE	Catch per unit effort
CS	Chatham Sound
CSAS RPR	Canadian Science Advisory Secretariat Regional Peer Review
CSJ	Cape St James
CWS	Canadian Wildlife Service
DB	Dogfish Bank
DFO	Fisheries and Oceans Canada
EBSA	Ecologically and Biologically Significant Area
FNK	First Nations Knowledge
HG	Haida Gwaii Nearshore
HSF	Hecate Strait Front
IA	Important Area
KDE	Kernel Density Estimate
LB	Learmonth Bank
LEK	Local Ecological Knowledge
MB	McIntyre Bay
MDNN	Maximum distance to the nearest neighbour
MPA	Marine Protected Area
MPATT	Marine Protected Area Technical Team
NIS	North Islands Straits
NPPSD	North Pacific Pelagic Seabird Database
NSB	Northern Shelf Bioregion
PHMA	Pacific Halibut Management Association
PNCIMA	Pacific North Coast Integrated Management Area
SB	Shelf Break
SBA	Sensitive Benthic Area
SHI	Spawn Habitat Index
SI	Scott Islands
SR	Sponge Reefs

1 INTRODUCTION

1.1 CONTEXT

Canada's Oceans Act (Government of Canada 1997) provides the legislative basis for an integrated ecosystem approach to management in Canada's oceans, particularly in areas considered ecologically or biologically significant. DFO has developed guidance for the identification of Ecologically and Biologically Significant Areas (EBSAs; DFO 2004, 2011), and has endorsed the scientific criteria used by the Convention on Biological Diversity (CBD) for identifying marine EBSAs (CBD 2008)[1]. DFO's science advice recommends identifying EBSAs as a first step to planning networks of marine protected areas (DFO 2010) in accordance with the CBD. This approach was re-emphasized in Canada's National Framework for Canada's Network of Marine Protected Areas (MPAs; Government of Canada 2011). In addition, the incorporation of EBSAs into MPA networks is a design principle agreed upon in the Canada-BC MPA Network Strategy (2014), and by the Marine Protected Area Network Technical Team (MPATT)[2] for the MPA network planning process underway in the Northern Shelf Bioregion (NSB). Any updates or refinement to existing EBSA boundaries will help to inform marine conservation planning and management in the bioregion, including the Pacific North Coast Integrated Management Area (PNCIMA) Plan.

1.1.1 Definitions

An EBSA is defined as an area of relatively higher ecological or biological significance than surrounding areas, where greater risk aversion is required in the management of activities (DFO 2004). Within the EBSA boundary, perturbations are also expected to cause greater ecological consequences than in surrounding areas exposed to comparable perturbations. Similar to the DFO definition, CBD (2008) defines an EBSA as an area that is important for the healthy functioning of our oceans and the services they provide.

Scientific criteria to identify EBSAs have been established at the national (DFO 2004) and international (CBD 2008) levels (Box 1 & 2 respectively). The DFO and CBD criteria overlap (Table 1), and it is generally accepted that similar areas will be identified by following either set of criteria (DFO 2012, Gregr et al. 2012, Westhead et al. 2013). Similar to the methods used by Ban et al. (2016) to identify EBSAs in the Pacific Offshore Bioregion, we amalgamated the DFO/CBD criteria into seven criteria based on conceptual overlap to identify EBSAs in the NSB. These amalgamated criteria are: Uniqueness, Special importance for life history stages of species, Importance for threatened, endangered or declining species, Vulnerability, Productivity (Aggregation), Biodiversity, and Naturalness (see Box 1 & 2 for definitions and a summary of the overlap).

EBSAs can be identified based on single features or species (e.g., spawning areas for a single species, or aggregations of single species), or multiple species or features (e.g., areas of high diversity, productivity, or overlap of many single-feature EBSAs). In the Pacific Region single-feature or taxon-specific EBSAs are referred to as "Important Areas" (IAs) (Clarke and Jamieson 2006a, Levesque and Jamieson 2015).

[1] The Convention on Biological Diversity defines EBSAs as Ecologically *or* Biologically Significant Marine Areas but we will refer to them as Ecologically *and* Biologically Significant Areas to keep consistent with DFO language

[2] MPATT is the technical team responsible for the design and implementation of the MPA network planning process in NSB, with representatives from the federal government, the province of British Columbia and 17 First Nations

Box 1. Summary of the DFO (2004) EBSA criteria, reproduced from Hastings et al. (2014)

1. Uniqueness

- The area contains unique, rare, or distinct features.

2. Aggregation

- Significant numbers of a species are found in the area during some period of the year.
- Significant numbers of a species use the area for a life history function.
- A structural feature or ecological process is observed in high density in the area.

3. Fitness Consequences

- The life history activities of a species or population in the area strongly affect its fitness.

4. Resilience

- The habitat structures or species present in the area are highly sensitive, easily perturbed, and/or slow to recover.

5. Naturalness

- The area is relatively pristine, with little to no evidence of human influence.

Box 2. Summary of the CBD (2008) criteria, reproduced from Hastings et al. (2014)

1. Uniqueness or rarity

- A unique, rare, or endemic species, population, or community is present.
- A unique, rare, or distinct habitat or ecosystem is present.
- A unique or unusual geomorphological or oceanographic feature is present.

2. Special importance for life-history stages of species

- The area is required for a population to survive and thrive (e.g., breeding or nursery grounds, spawning areas, migratory species habitat).

3. Importance for threatened, endangered or declining species and/or habitats

- The area contains habitat that is critical for the survival and recovery of endangered, threatened, or declining species.
- Significant assemblages of endangered, threatened, or declining species are found in the area.

4. Vulnerability, fragility, sensitivity, or slow recovery

- The area contains a high proportion of sensitive habitats, biotopes, or species that are especially susceptible to degradation or depletion, and/or are slow to recover.

5. Biological productivity

- The area contains species, populations, or communities with comparatively higher natural biological productivity.

6. Biological diversity

- The area contains comparatively higher diversity of ecosystems, habitats, communities, or species.
- Comparatively higher genetic diversity is observed in the area.

7. Naturalness

- Exhibits a comparatively higher degree of naturalness resulting from little to no anthropogenic pressure.

Table 1. Overlap between DFO and CBD criteria as indicated in Westhead et al. (2013), Hastings et al. (2014), and Ban et al. (2016). X indicates overlap between two criteria.

CBD (2008)	DFO (2004)				
	Uniqueness	Aggregation	Fitness Consequences	Resilience	Naturalness
Uniqueness or Rarity	X	-	-	-	-
Special Importance for life history stages of species	-	X	X	-	-
Importance for threatened, endangered or declining species and/or habitats	-	X	X	-	-
Vulnerability, fragility, sensitivity, or slow recovery	-	-	-	X	-
Biological productivity	-	X	-	-	-
Biological diversity	-	-	-	-	-
Naturalness	-	-	-	-	X

1.2 EBSAS AND RELATED SPATIAL MANAGEMENT MEASURES

Areas identified as EBSAs do not automatically trigger new management measures. However, EBSAs are considered special natural areas and are afforded an increased measure of risk aversion in marine spatial management of human activities (DFO 2004, 2007). The need for management, and the type of management action required to conserve or protect an EBSA, is determined by the ecological characteristics of the EBSA, including the reason it was designated as an EBSA, the type and extent of human activities occurring in or adjacent to it, and how the ecological components and the stressors associated with the human activity interact.

The criteria used to identify EBSAs are related to, or overlap with, some of the other criteria used in other marine spatial management programs and policies in Canada (Figure 1). For example, Sensitive Benthic Areas (SBAs) are benthic areas that are vulnerable to the impacts of fishing (DFO 2009). Vulnerability is also an EBSA criterion; therefore, EBSAs identified for benthic species that are vulnerable, specifically to stressors associated with fishing, also may qualify as SBAs (e.g., sponge reef, coral aggregations). Although different policies or programs each have their own specific criteria, EBSAs broadly defined by the DFO and CBD criteria can act as a good starting point for other programs within the department, particularly if the EBSA identification process is clear and the resulting spatial layers are well annotated. Figure 1 shows an example of how the EBSAs may feed into other ongoing processes in the Pacific Region.

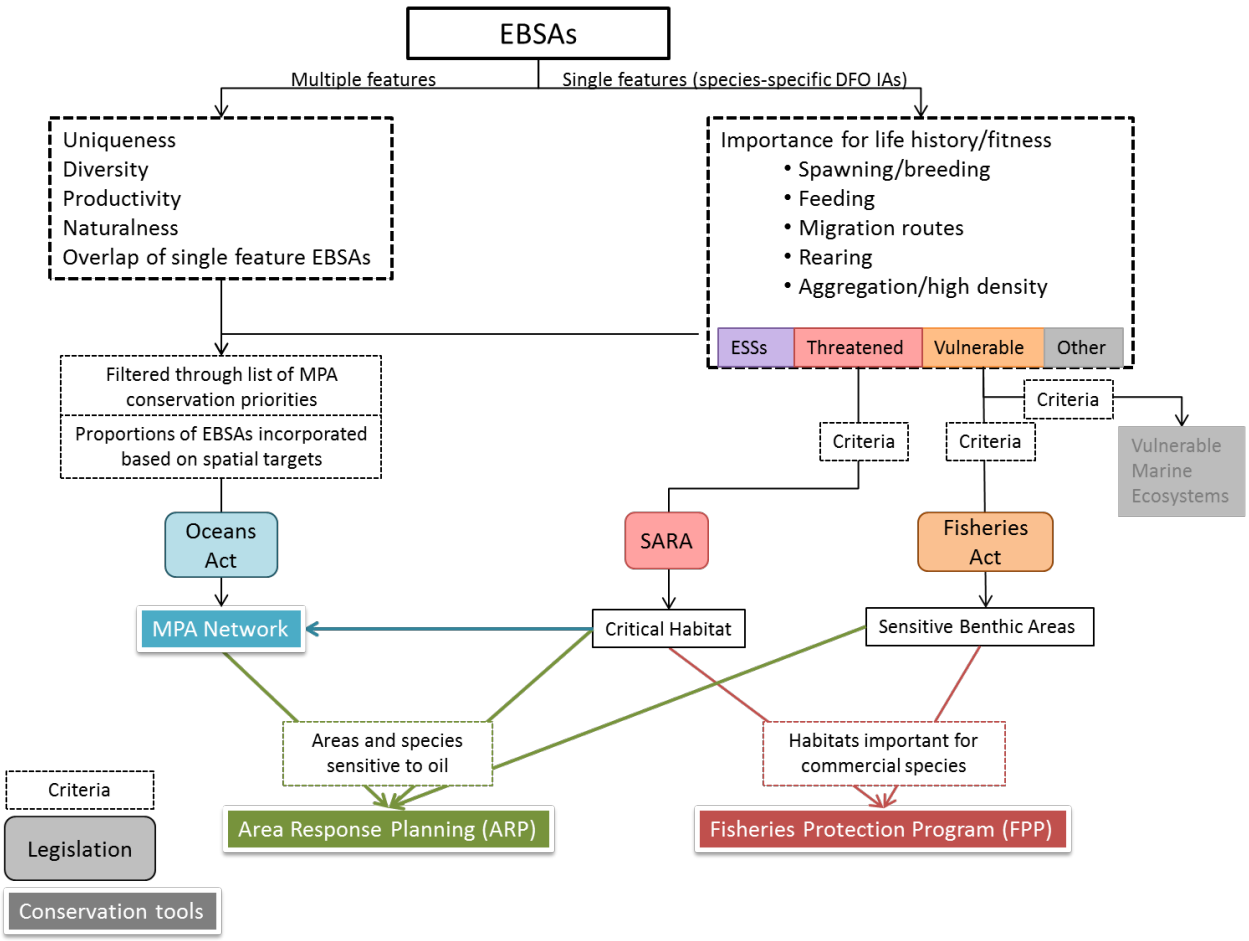

Figure 1. Example of how EBSAs may relate to other programs within DFO to inform integrated ocean management. EBSA criteria are shown within the dashed-line boxes. "Important Areas" (IAs) are identified using the criteria listed within the dashed line and are applied to: Ecologically Significant Species (ESSs), Threatened or declining species (Threatened), Vulnerable and/or Unique species. A subset of IAs for specific species may feed into other programs within DFO. For example the breeding area for a SARA listed species is an EBSA (DFO IA), but it also may feed into the Critical Habitat process. Boxes with the word "criteria" written within, highlight that each legislative framework includes specific criteria that must be met prior to policy implementation.

In addition to EBSAs being related to, or incorporated into other processes in DFO (e.g., SBAs, MPAs, etc.), EBSAs can be identified at multiple spatial scales. For example, the CBD has identified EBSAs at an ocean basin scale in a series of workshops with related reports, and within Canada EBSAs have been identified at the bioregion scale (e.g., Doherty and Horsman 2007, Hartwig 2009, Cobb 2012, Kenchington 2014, Fuentos-Yaco and Li 2015, Levesque and Jamieson 2015, Ban et al. 2016). Given that by definition, EBSAs are identified *relative* to the surrounding area, the scale or planning area of the EBSA identification process is critically important. In this paper, we are re-evaluating EBSAs that were identified at the scale of the NSB (Figure 2).

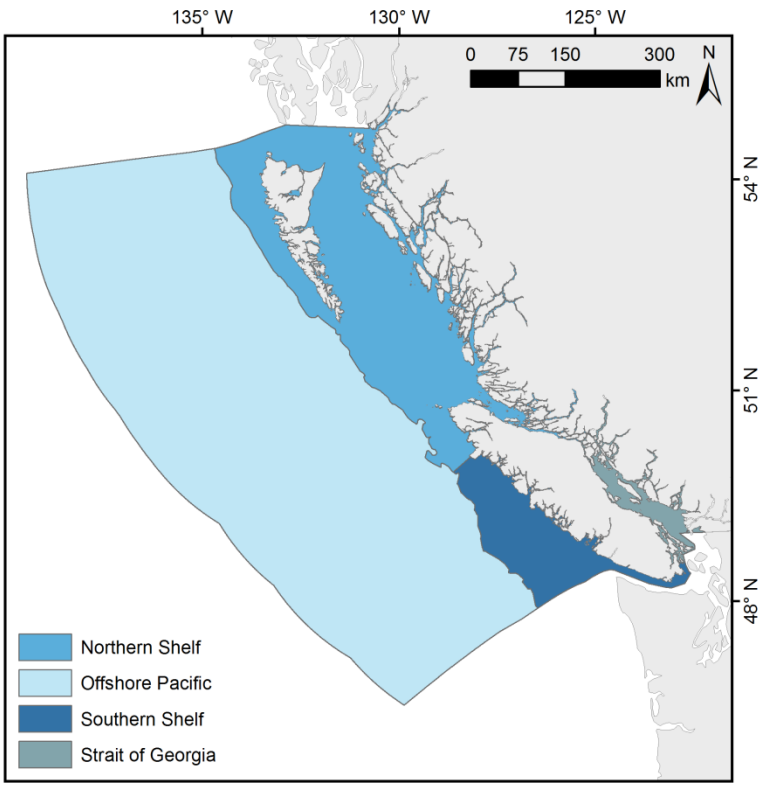

Figure 2. Bioregions in the Pacific Region of Canada. The study area, the Northern Shelf Bioregion (NSB) includes the waters north of Brooks Peninsula on the west coast of Vancouver Island and Campbell River on the east side Vancouver Island, to the border with the USA. It is the same footprint as the Pacific North Coast Integrated Management Area (PNCIMA) and is also referred to as the "Great Bear Sea" as part of DFO's Ocean Protection Plan.

1.3 SUMMARY OF PREVIOUS EBSA PROCESS

EBSAs in the NSB were identified in two DFO Technical Reports in 2006 (Clarke and Jamieson 2006a,b) and reviewed in a Canadian Science Advice Secretariat Regional Peer Review Process (CSAS RPR) in 2012 (DFO 2013). The approach by Clarke and Jamieson to identify EBSAs used a two-phase approach that was driven by expert knowledge of biological information (2006a,b, DFO 2013). DFO Science Advice recommends EBSAs in any bioregion should be re-evaluated and updated with new information approximately every five years (DFO 2004, 2013). Here, we assess the original EBSAs with available empirical data to better understand the level of ecological support for EBSA boundaries and provide new and updated EBSAs where possible.

The approach by Clarke and Jamieson (2006a,b, DFO 2013) to identify EBSAs in the NSB focused on the continental shelf region, excluding deep offshore areas (<500m) and most nearshore areas (DFO 2013). The approach followed a two-phase process. In Phase I (Clarke and Jamieson 2006a), species experts recommended areas worthy of enhanced protection for individual species, species groups, or habitat features. These recommendations were based on the five DFO EBSA criteria (Box 1) because this EBSA process pre-dated the release of the CBD criteria. Phase I resulted in >140 Important Areas (IAs) for 36 species, as well as four additional thematic layers (Figure 3, Clarke and Jamieson 2006a). When mapped together, this showed that nearly all marine waters in the NSB were identified as important for at least one species or group of species.

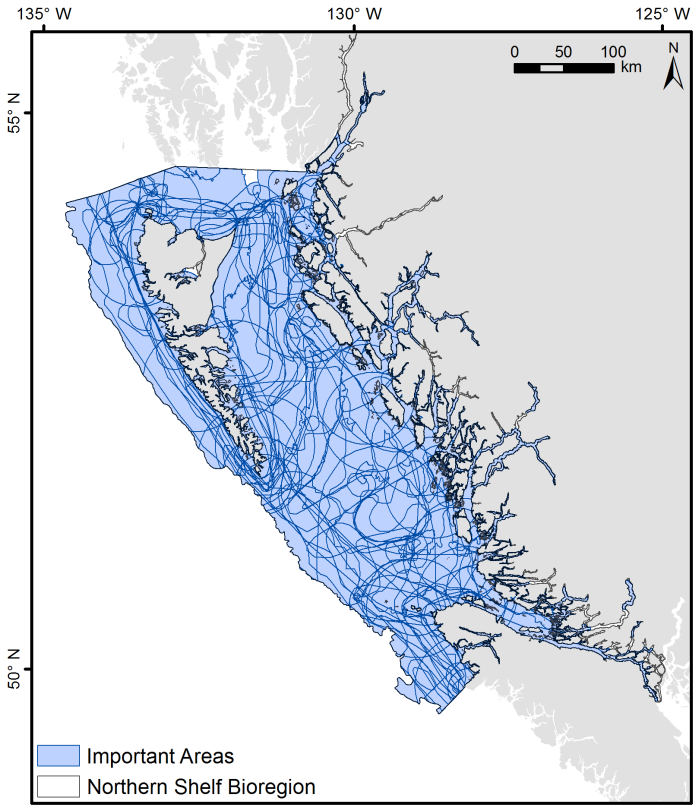

Figure 3. Northern Shelf Bioregion Important Areas (IAs) for 36 species, as well as IAs for oceanography and areas identified by Parks Canada (recreated from Clarke and Jamieson 2006a). Benthic and pelagic ecounits not shown.

In order to synthesize these species-specific IAs into a smaller number of spatially distinct EBSAs, the authors developed Phase II of the EBSA identification process (Clarke and Jamieson 2006b). In 2006, when the original EBSA identification process occurred, there were no clear management objectives for the study area, making it difficult to reduce the IAs into a well-connected network of EBSAs in the absence of this direction from science and management (Clarke and Jamieson 2006a). Clarke and Jamieson (2006a) made some suggestions for Phase II, including the use of the optimization software, Marxan (Ball et al. 2009) to identify EBSAs; however, without clear objectives for the study region, they could only provide example outputs of Marxan using indiscriminate spatial targets (Clarke and Jamieson 2006a). Therefore, Clarke and Jamieson (2006b) developed an overlay approach to reduce the spatial coverage of the IA EBSAs for Phase II of the EBSA identification process. In Phase II, three categories of unique physical features were used to identify the EBSAs where they overlapped with the species IAs. These three features were: 1) physical oceanographic features (such as gyres and eddies, fronts, upwelling regions, etc.), 2) geographic bottlenecks (troughs, narrow passages), and 3) and glass sponge bioherms (also referred to as glass sponge reefs). Therefore, the species IAs were identified on the basis of species experts' knowledge on the biology of individual species, or groups of species, and the resulting EBSAs were primarily identified on the basis of expert knowledge about physiographic features which *also* overlap with IAs for at least one species or species group (Clarke and Jamieson 2006b).

Phase II of the original EBSA process resulted in 15 areas being identified (Clarke and Jamieson 2006b). However, after the EBSA Phase I & II technical reports were reviewed

through the CSAS process in February of 2012, two more nearshore EBSAs were added, and one nearshore EBSA was expanded as part of the Science Advice Report (DFO 2013). Therefore there are currently 17 mapped existing EBSAs in the NSB (Figure 4).

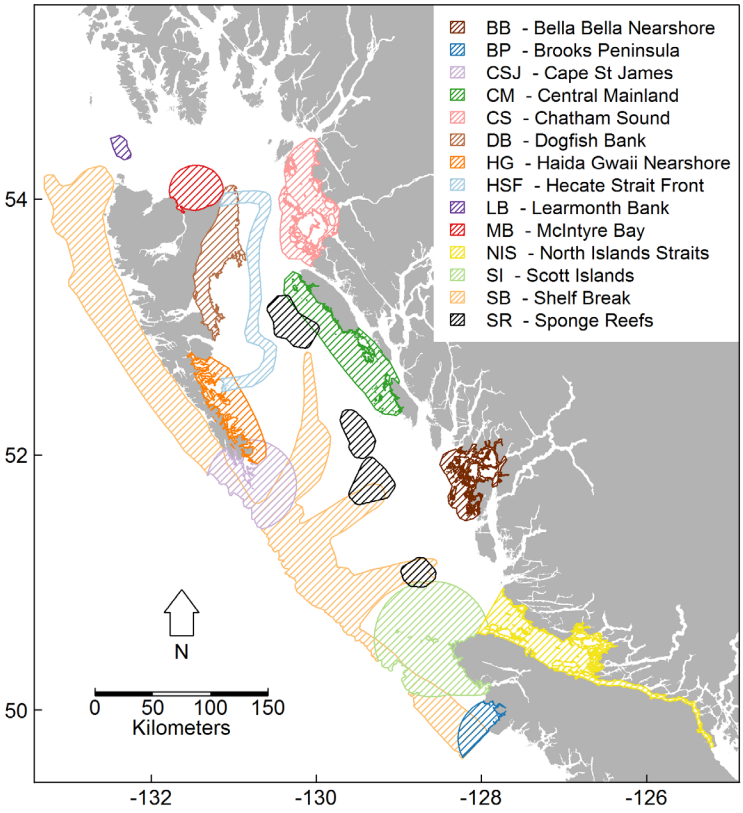

Figure 4. EBSAs in the NSB (Clarke and Jamieson 2006b, DFO 2013). Bella Bella Nearshore (BB), and Haida Gwaii Nearshore (HG) were added and Central Mainland (CM) was expanded (referred to as Caamaño Sound in Clarke and Jamieson 2006b) after the CSAS RPR in 2012.

River mouths and estuaries were also identified as an EBSA, bringing the total number of EBSA in the NSB to 18 (Clarke and Jamieson 2006a,b, DFO 2013); however, the River mouths and Estuary EBSA was not mapped in the previous process. A recent CSAS Science Response[3] that focused on nearshore features and habitats that fit the EBSA criteria provided a map of estuaries in NSB as an update to the EBSA process, but that EBSA was not considered in this analysis given that the development of a spatial layer of estuaries was not part of the original process that is being re-evaluated here.

1.3.1 Limitations and knowledge gaps in the previous EBSA process

The last EBSA process in the NSB focused on the continental slope and did not complete a comprehensive analysis of the nearshore. To help fill this gap, a recent CSAS Science Response process[3] (June 2017) assessed nearshore habitat and features against the EBSA criteria. Another necessary update to the previous process is an assessment of the two CBD

[3] Rubidge, E., Jeffery, S., Gregr, E., Gale, K.S.P., and Frid, A. in revision. Assessment of nearshore features in the Northern Shelf Bioregion against criteria for determining Ecologically and Biologically Significant Areas (EBSAs). DFO Can. Sci. Advis. Sec. Sci. Response

criteria that were not yet published during the previous EBSA process in the NSB. Areas of high productivity and high biodiversity (Box 2) were not specifically included in the previous analysis and can be assessed here using available biological survey data.

1.4 OBJECTIVES

This project stems from a request for science advice from DFO Oceans Sector of the Ecosystems Management Branch to DFO Science to evaluate existing EBSAs using available empirical data.

The objectives of this paper are to:

1. Evaluate previously identified EBSAs in the NSB using available empirical biological data. Based on the outcome of this analysis summarize support for existing EBSA boundaries.
2. Identify areas of high biodiversity and high productivity in the Northern Shelf Bioregion, two EBSA criteria not directly addressed in the last process.

This paper is broken into two parts. Part 1 addresses Objective 1, and focuses on reassessing the existing EBSA boundaries with available biological data. The purpose of the analysis is to examine empirical support for existing EBSAs. Part 2 presents an approach for identifying EBSAs based on the CBD criteria of high biodiversity and high productivity. The purpose of Part 2 is to fill the gap in the first process that did not directly identify areas of high species diversity or productivity. We also provide new information that can be used to update the existing Sponge Reef EBSAs.

2 PART 1: REASSESSMENT OF EXISTING EBSAS

2.1 REASSESSMENT APPROACH

To assess empirical support for the existing EBSA boundaries, we first summarized species listed as important for each existing EBSA (Table 2). Species used to evaluate each EBSA, hereinafter referred to as “important species”, were selected based on the original EBSA reports. To be included in the reassessment, the species or faunal group had to be listed as a justification of the EBSA in at least one of the following publications: Clarke and Jamieson (2006a,b), DFO (2013), or Jamieson and Levesque (2014). In addition to be listed as a justification for the EBSA, we also pulled from the reports the EBSA criteria that the area fulfilled for each important species or species group. For example, the McIntyre Bay EBSA was in part justified as an EBSA because the area is important to the Fitness (specifically, feeding) of Humpback Whale and Pacific Herring (Table 2).

Once we had collected the species information for the existing EBSAs from the EBSA reports, we collated available data sources to test empirical support for the EBSA boundaries. It is important to note that this analysis is evaluating the EBSAs using existing and available data sources. We were limited in our analysis and interpretation by the types of data that were available. To explicitly test EBSA boundaries and justify refinement, one must have adequate sampling inside and outside those boundaries. Ideally, one would develop and implement a survey designed to specifically test the validity of the boundary prior to refining it. Given this caveat, using existing research surveys and commercial data sources, our analysis can provide a cursory assessment of empirical support for EBSAs where we have adequate sampling.

2.2 DATA

Based on the species listed as important to the 17 EBSAs (Table 2), we collated research and commercial data that 1) was readily available, 2) included metadata, and 3) spatially covered the majority of the NSB. This analysis evaluated the EBSAs relative to their surrounding area, which was the entire NSB. For this reason, data that had limited coverage of the NSB was not suitable to evaluate the existing EBSAs. Decisions on data suitability were also made at the level of each EBSA. Some data that covered nearly all the NSB still had gaps for several EBSAs. For example, the English Sole data used covers the majority of the NSB but has limited overlap with the Dogfish Bank EBSA (Figure 7d). A threshold of 20% overlap between the data and an EBSA was chosen as a cut-off. If the data covered less than 20% of the EBSA it was not used to evaluate the EBSA and classified as insufficient data for that particular EBSA (see Table 2).

For some species, a single dataset that covered the extent of the NSB was not available so multiple data sources were used. Combining data from multiple sources has challenges as sources can vary by gear type, units of measure, detectability of species, sampling resolution and spatial extent. We use several different approaches to incorporate data from multiple sources. The most appropriate method depended on the degree of variation between the datasets. The most conservative approach taken for disparate datasets was to keep the datasets separate and analyse them independently. This approach was adopted for trawl and longline data that had different units and detectability as well as very little spatial overlap. The other approach was to combine data from multiple sources into one dataset. Combing data was accomplished two ways: 1) normalizing each dataset (rescaling the values by dividing the maximum value in each dataset) before combing the datasets or 2) reclassifying values as presence or absence then combining all presence records into one dataset. The presence only approach was adopted for selected invertebrate species where data sources varied by gear, detectability and units. The normalizing approach was adopted for cetacean species where data sources varied by survey methods.

A summary of the all species data is shown in Table 3 and a description of the sources of that data can be found in Appendix A.

2.2.1 Fishes

Fish species included in the EBSA assessment (Table 3) include: Yellowtail Rockfish (*Sebastes flavidus*), Pacific Ocean Perch (*Sebastes alutus*), Yellowmouth Rockfish (*Sebastes reedi*), Widow Rockfish (*Sebastes saxicola*), Pacific Hake (*Merluccius productus*), Pacific Halibut (*Hippoglossus stenolepis*), Pacific Herring (*Clupea pallasii*), Pacific Cod (*Gadus macrocephalus*), Lingcod (*Ophiodon elongatus*), Sablefish (*Anoplopoma fimbria*), Arrowtooth Flounder (*Atheresthes stomias*), Dover Sole (*Microstomus pacificus*), Butter Sole (*Isopsetta isolepis*), English Sole (*Parophrys vetulus*), Rock Sole (*Lepidopsetta bilineata*) and Petrale Sole (*Eopsetta jordani*).

Data from the DFO synoptic trawl survey and Pacific Halibut Management Association (PHMA) longline survey were used (see Appendix A for description). Catch per unit effort (CPUE) was calculated for each species for each tow or set. For longline surveys, total count of each species per set was divided by the number of hooks or traps used, divided by the duration of bottom time (time between the end of deployment and the beginning of retrieval) (CPUE = count/hook/hr). For trawl surveys, total weight of each species per set was divided by the duration of bottom time (CPUE = kg/hr). Because large catches with small durations lead to higher CPUE values, tows with durations of less than 3 minutes were excluded. Ninety percent of the tows were between 17 and 23 minutes long. To reduce the effects of uneven sampling

across the study area, each survey dataset was subsampled to randomly select one fishing event (tow or longline) from a surface of 1-km grid cells.

PHMA data were only used to supplement the trawl data for Sablefish, Lingcod and Pacific Halibut, which the PHMA survey adequately samples. PMHA was considered as a data source for rockfish species as well, however it did not meet the 20% coverage threshold for the Shelf Break EBSA for which rockfish were designated as important. Other data sources such as International Pacific Halibut Commission (IPHC) Longline Survey and DFO Sablefish Research and Assessment Survey were also considered but were similarly excluded because of the 20% coverage rule.

EBSAs listed as important for Pacific Herring spawning, as opposed to Pacific Herring aggregation, were assessed using a cumulative Spawn Habitat Index (SHI). The index, developed by DFO, is a long term measure of the cumulative use by km of coastline of Pacific Herring while spawning (Hay and McCarter 2013). The index is the median of the product of spawn width and egg layer density multiplied by spawn length per km of coastline and summed across years since 1928 (Hay and McCarter 2013).

Table 2. Summary table of "important species" by EBSA. Rows include the number and name of the EBSA and columns indicate EBSA criteria. The species listed in the cells are the species identified as important for that criterion for each EBSA. Information was summarized from Clarke and Jamieson (2006a,b), DFO (2013), and Jamieson and Levesque (2014). Species or species groups not assessed for a particular EBSA in this reassessment shown in grey italicized font.

Original EBSA Number	EBSA Name	Uniqueness or rarity	Threatened, endangered, or species of special concern	Fitness - Spawning, Breeding or Rearing	Fitness - Feeding	Fitness - Migration routes	Aggregation
1	Hecate Strait Front (HSF)	-	-	-	-	-	*Zooplankton*
2	McIntrye Bay (MB)	-	Killer Whale	Pacific Halibut	Pacific Herring, Humpback Whale	*Scoters*	Dungeness Crab, *zooplankton, seabirds, geese, ducks, Eulachon, Razor Clam, Weathervane Scallop*
3	Dogfish Bank (DB)	-	-	*Pacific Cod, Arrowtooth Flounder, Petrale Sole, Butter Sole, Rock Sole, Dover Sole, English Sole*	-	*Scoters*	Dungeness Crab, *shearwaters, phalaropes, Herring Gull, Ancient Murrelet*
4	Learmonth Bank (LB)	-	-	-	*Alcids*	Grey Whale	Fin Whale, coral
5	Brooks Peninsula (BP)	-	-	Lingcod, Common Murre, Tufted Puffin, Glaucous-winged Gull, Rhinoceros Auklet, *Black-legged Kittiwake*	-	*Shearwaters, phalaropes*	Sea Otter, *Green Sturgeon, Olympia Oyster*
6	Cape St. James (CSJ)	-	-	Pacific Halibut, Steller Sea Lion	-	-	Humpback Whale, Blue Whale, Fin Whale, coral, sponge, *shearwaters*

Original EBSA Number	EBSA Name	Uniqueness or rarity	Threatened, endangered, or species of special concern	Fitness - Spawning, Breeding or Rearing	Fitness - Feeding	Fitness - Migration routes	Aggregation
7	Shelf Break (SB)	-	Sperm Whale, Blue Whale, Fin Whale	Sablefish, Dover Sole, Pacific Ocean Perch, Yellowtail Rockfish, Yellowmouth Rockfish, Cassin's Auklet, *Ancient Murrelet,* Rhinoceros Auklet, Tufted Puffin, storm petrels	Humpback Whale, *Eulachon, Northern Fur Seal*	Pacific Hake, Grey Whale	Tanner Crab, coral, sponge
8	Scott Islands (SI)	-	-	Pacific Cod, Lingcod, Sablefish, Steller Sea Lion, Cassin's Auklet, Rhinoceros Auklet, Tufted Puffin, Common Murre, cormorants, Pigeon Guillemot, storm petrels, Glaucous-winged Gull, Arrowtooth Flounder, Petrale Sole, Butter Sole, Rock Sole, Dover Sole, English Sole, *Pacific Sand Lance,* Widow Rockfish	Pacific Hake, Pacific Herring, Grey Whale, *Black-footed Albatross, Northern Fulmar, shearwaters, Herring and Thayer's Gulls, Northern Fur Seal*	-	Humpback Whale, Sea Otter
9	North Island Straits (NIS)	-	Killer Whale	Rhinoceros Auklet, storm petrels	Grey Whale	*Sockeye and Coho Salmon, Steelhead, Pacific Herring*	Humpback Whale, shrimp, Spot Prawn, Green Sea Urchin, Sea Otter
10, 11, 12, 13	Sponge Reefs (SR)	Sponge reefs	-	-	-	-	-

Original EBSA Number	EBSA Name	Uniqueness or rarity	Threatened, endangered, or species of special concern	Fitness - Spawning, Breeding or Rearing	Fitness - Feeding	Fitness - Migration routes	Aggregation
14	Chatham Sound (CS)	-	-	Pacific Herring, *Walleye Pollock*	Killer Whale, Humpback Whale	*Scoters*	Green Sea Urchin, Dungeness Crab, shrimp
15	Haida Gwaii Nearshore (HG)	-	-	Pacific Herring, Pacific Cod, Arrowtooth Flounder, Petrale Sole, Butter Sole, Rock Sole, Dover Sole, English Sole, Steller Sea Lion	-	Grey Whale	Fin Whale, Humpback Whale, Red Sea Urchin, Red Sea Cucumber, Northern Abalone, *shearwaters*
16	Central Mainland (CM)	-	-	Steller Sea Lion, Sablefish, *Walleye Pollock*	Killer Whale, Humpback Whale, Fin Whale	Grey Whale	*Shearwaters*, Sea Otter, Red Sea Cucumber
17	Bella Bella Nearshore (BB)	-	-	Pacific Herring	*Steller Sea Lion*	Killer Whale	Sea Otter, Geoduck, Red Sea Urchin, Red Sea Cucumber, *Manila Clam,* shrimp

2.2.2 Invertebrates

Invertebrate species included in the EBSA boundary assessment (Table 3) include: Northern Abalone (*Haliotis kamtschatkana*), shrimp (*Pandalus jordani, Pandalus borealis, Pandalopsis dispar, Pandalus danae, Pandalus hypsinotus*), Spot Prawn (*Pandalus platyceros*), Tanner Crab (*Chionoecetes tanneri)*, Dungeness Crab (*Metacarcinus magister*), Red Sea Urchin (*Mesocentrotus franciscanus*), Green Sea Urchin (*Strongylocentrotus droebachiensis*), Red Sea Cucumber (*Apostichopus californicus*), Geoduck (*Panopea generosa*), corals (Alcyonacea, Antipatharia, Scleractinia, and Anthoathecata spp.), sponges (Porifera spp.), and glass (hexactinellid) sponge reef complexes.

For all invertebrate species excluding corals and sponges, records were extracted from a number of DFO research surveys and commercial shellfish logs (see Appendix A for description). The data was pulled from a number of different sources, which varied by species (see Table 3), to maximize the number of records and the spatial coverage of the species data. Species experts within DFO were consulted to ensure use of all possible data sources and determine which were appropriate for each species. To combine records from multiple sources, values were standardized to presence and absence. Information on which species were consistently recorded as absent was not available for all sources therefore we limited these datasets to presence only. Once the species dataset was converted to presence only, no distinction could be made between 'no data' and 'absence' thus the true spatial coverage of the data is unknown. Consequently, we could not apply the 20% coverage rule to these presence-only datasets.

Sponge and coral (excluding sea pens) data was sourced from DFO synoptic trawl surveys and commercial trawl harvest logs between 2007 and 2017. CPUE (kg/hr) for each sponge and coral species was summed within tows. CPUE was normalized within each dataset for each species group by rescaling the values by dividing the maximum value. The range of values for each dataset therefore ranged from 0 to 1. After normalization, the fishing event tracklines from each dataset were combined. Sea pens were separated from the rest of the coral group because their distribution and habitat differs from that of the other corals. The resulting sponge and coral data is similar to that presented by Ardron and Jamieson (2006) and represents an update to the data originally used to delineate the sponge and coral IAs in the NSB (Clarke and Jamieson 2006a).

Glass sponge reefs were assessed using a polygon layer that was created from multibeam bathymetry and backscatter data and provided by Geological Survey of Canada (Shaw et al. 2018). The layer identifies the geological signature of the "bioherm" or sponge reef and it does not distinguish between live and dead reef (Conway et al. 2001, Conway et al. 2005). Biological surveys to date have indicated the ratio of live to dead sponge coverage varies among reefs in (Chu and Leys 2010). Efforts to map live sponge areas are underway (A. Dunham, pers. comm.).

2.2.3 Marine birds

Bird species included in the EBSA boundary assessment (Table 3) include: Cassin's Auklet (*Ptychoramphus aleuticus*), Glaucous-winged Gull (*Larus glaucescens*), Rhinoceros Auklet (*Cerorhinca monocerata*), storm petrels (*Oceanodroma furcata* and *O. leucorhoa*), Tufted Puffin (*Fratercula cirrhata*), Common Murre (*Uria aalge*), Pigeon Guillemot (*Cepphus columba*) and cormorants (*Phalacrocorax penicillatus* and *P. pelagicus*).

Seabird data was sourced from the BCMCA (see Appendix A for description). Colony data was deemed the most appropriate to evaluate the existing EBSAs as the majority of EBSAs

identified as important for seabirds were listed for spawning, breeding or rearing (Table 2). The BCMCA dataset represents all known seabird colonies along the coast of BC, along with the most recent population estimates for each known colony. Breeding population estimates were available as either number of nest pairs or individual counts. The unit of abundance (nest pair or individual counts) could vary between surveys. For species that did not have a consistent unit across surveys, the individual count unit was used. To convert nest pair counts to individual counts, nest pair counts were multiplied by two. Some colonies had zero counts which represent historical colony locations that are no longer occupied. We removed all records with zero counts from our dataset to exclude empty colonies from our analysis. The field survey techniques varied depending on the species and year of survey. Data from all three techniques (total, transect and partial count) were included here. As this data represents an inventory of all known seabird colonies on the coast, it was not appropriate to apply the 20% coverage rule.

BCMCA buffered the point locations of the colonies by the area of interest extracted from the CWS Marine Birds Areas of Interest database. Cassin's Auklet (5 km), Glaucous-winged Gull (2 km), Rhinoceros Auklet (5 km), storm petrels (5 km), Tufted Puffin (5 km), Common Murre (5 km), Pigeon Guillemot (2 km), and cormorants (2 km).

Data sources that represented at-sea densities of marine birds were also available, such as the Raincoast Conservation Foundation surveys (Fox et al. 2017) and the North Pacific Pelagic Seabird Database (NPPSD; Drew et al. 2015). These were not utilized here, but could be employed for future assessments of EBSAs which were designated as important for seabirds aggregations such as Shearwaters in Haida Gwaii nearshore.

2.2.4 Marine mammals

Mammal species included in the EBSA boundary assessment (Table 3) include: Humpback Whale (*Megaptera novaeangliae*), Grey Whale (*Eschrichtius robustus*), Killer Whale (*Orcinus orca*), Fin Whale (*Balaenoptera physalus*), Blue Whale (*Balaenoptera musculus*), Sperm Whale (*Physeter macrocephalus*), Steller Sea Lion (*Eumetopias jubatus*) and Sea Otter (*Enhydra lutris*).

Cetacean species data originated from several sources: Raincoast Conservation Foundation, North Pacific Pelagic Seabird Database (NPPSD), and DFO marine mammal program (see Appendix A for description). Cetacean sighting data from Raincoast and NPPSD was available as density (number of individuals per km^2) while DFO data required processing in order to convert cetacean observations into effort corrected density data. DFO marine mammal surveys recorded abundance at the location of each sighting. Species counts were converted to density by dividing the number of individuals by the area sampled within a 25 km^2 area. The large grid size (25 km^2) was recommended by DFO marine mammal experts to account for errors associated with estimating the position of sightings from the vessel and the highly mobile nature of marine mammals (R. Abernethy and L. Nichol, pers. comm.).The sampled area was estimated by buffering the transect line by the sampling width (the estimated detection distance from the vessel), which varied by vessel and weather condition. The total sampled area was calculated by summing the sample area within each 25 km^2 grid cell.

Density estimates (individuals/km^2 at every nautical mile along transect) of marine mammals sourced from Raincoast surveys were calculated using a Multiple Covariate Distance Sampling method (Best et al. 2015).This method differs from the conventional method used to process DFO and NPPSD data (dividing sighting counts by surveyed area) in that it uses a detection function to correct for sightings that may have been missed by the observer as individuals are less likely to be seen at greater distance from a survey vessel.

The three cetacean density datasets were normalized by dividing by the maximum value in each dataset before they were combined into one dataset. The resulting density index ranged from 0 to 1. Normalizing the data removes differences in the absolute magnitude of density values between the dataset that are caused by different survey and data processing methods. We retained no detection ("absence") values from the Raincoast and DFO dataset but not from the NPPSD dataset which was only opportunistically recording cetacean observations.

Sea Otters and Steller Sea Lions were assessed using BCMCA areal extent polygons based on recommendations at the BCMCA Marine Mammals Experts Workshop (BCMCA 2008, 2011). These datasets are derived from expert knowledge and therefore not considered "empirical"; however, our analysis can assess how well the existing EBSAs capture important areas to these species. The Sea Otter layer represents their range in 2008 and the Steller Sea Lion layer represents a 15 km buffer around known rookery sites. Future assessments should consider using DFO Sea Lion colony data which was not available in time for use here.

2.2.5 Diversity and productivity

To evaluate diversity within the EBSAs, richness (number of species) and Shannon Diversity (also known as the Shannon-Weiner index; $H' = -\sum_{i=1}^{n} p_i \ln p_i$, where *p* is the proportional abundance of species *i;* Shannon 1948) were calculated using catch records from the DFO synoptic trawl surveys. Trawl data was processed following the method described in section 2.2.1. For a description of the survey methods see Appendix A. Species or higher-level taxa are recorded in GFBio database using 3-character Hart Codes, which were attached to the current taxonomic name and level using the World Register of Marine Species (WoRMS) database (WoRMS Editorial Board 2017). For species richness and diversity calculations only species-level taxa were used. CPUE (kg/hr) was calculated for each tow and used as input to the *diversity* function in the R package 'vegan' (Oksanen 2014). Richness and diversity were calculated separately for fishes and invertebrates. Prior to using CPUE based diversity metrics to evaluate EBSAs, a test for the effect of tow length on species richness was completed and no correlation was found.

To evaluate productivity within the EBSAs, surface chlorophyll a concentration (ChlA), a proxy of primary productivity, was used. The ChlA data was sourced from the MODIS satellite (NASA Ocean Color). NASA derived ChlA values from reflectances using the OC4 and CI algorithm (for more details see Hu et al. 2012). The MODIS ChlA (mg m^{-3}) band has a resolution of 1 by 1 km. Daily swath data was between March and October from 2012 to 2015 and mosaicked by month. Months from November to February were excluded as cloud cover is persistent during that period. The monthly ChlA data was interpolated spatially using Spline with Barriers (ArcGIS 10.4) to fill in any gaps that remained after mosaicking. These gaps were typically located nearshore and in coastal inlets. To limit highly uncertain values, mainly in those areas, the interpolated ChlA surface was constrained by re-classifying locations which had data gaps in all 32 months to 'no data'.

Two indices of productivity were created from the monthly ChlA data: mean ChlA concentration and bloom frequency. Mean ChlA concentration was calculated by averaging the monthly surface ChlA concentration (mg m^{-3}) across the time-period. Bloom frequency was calculated following Gregr et al. (2016), by classifying ChlA concentration greater than 3.0 mg m^{-3} as blooming. The 3.0 mg m^{-3} chlorophyll bloom threshold was reported for the study area (Mackas et al. 2007). For each month, each 1 by 1 km raster cell was classified as either blooming (1) or not blooming (0). Monthly bloom rasters were summed to calculate bloom frequency which ranged from 0 to 32. Values of 32 represent areas where monthly ChlA concentrations exceeded the bloom threshold for all months from March to October over a 4 year period from 2012 to 2015.

Table 3. Summary of species data used for EBSA reassessment analysis. The data presented here is post-processed data (e.g., after combining records from multiple sources) but prior to aggregating to the 5 by 5 km grid. The units, number of records and temporal range outlined here do not necessarily reflect the entirety of the available source data. For a description of the sources from which these data originate see Appendix D. Data sources numbers are listed below in the table footer and in Table D1. Months are represented by numbers (e.g., 5–10 represents May to October). CPUE: Catch Per Unit Effort.

Species or faunal group	Sources	Units	Number of presence records	Number of no detection records	Years	Months
Yellowtail Rockfish	1	CPUE (kg/hr)	578	2,701	2003–2016	5–10
Pacific Ocean Perch	1	CPUE (kg/hr)	1,736	1,543	2003–2016	5–10
Yellowmouth Rockfish	1	CPUE (kg/hr)	524	2,755	2003–2016	5–10
Widow Rockfish	1	CPUE (kg/hr)	12	3,267	2003–2016	5–10
Pacific Hake	1	CPUE (kg/hr)	1,111	2,168	2003–2016	5–10
Pacific Halibut	1	CPUE (kg/hr)	1,281	1,998	2003–2016	5–10
	2	CPUE (count/hook/hr)	1,418	81	2006–2016	8–9
Pacific Herring	1	CPUE (kg/hr)	409	2,870	2003–2016	5–10
	3	Spawn Habitat Index	5,348	0	1928–2016	–
Pacific Cod	1	CPUE (kg/hr)	1,652	1,627	2003–2016	5–10
Lingcod	1	CPUE (kg/hr)	862	2,417	2003–2016	5–10
	2	CPUE (count/hook/hr)	965	534	2006–2016	8–9
Sablefish	1	CPUE (kg/hr)	1,610	1,669	2003–2016	5–10
	2	CPUE (count/hook/hr)	427	1,072	2006–2016	8–9
Arrowtooth Flounder	1	CPUE (kg/hr)	2,816	463	2003–2016	5–10
Dover Sole	1	CPUE (kg/hr)	2,282	997	2003–2016	5–10
Butter Sole	1	CPUE (kg/hr)	154	3,125	2003–2016	5–10
English Sole	1	CPUE (kg/hr)	1,210	2,069	2003–2016	5–10
Rock Sole	1	CPUE (kg/hr)	752	2,527	2003–2016	5–10
Petrale Sole	1	CPUE (kg/hr)	1,104	2,175	2003–2016	5–10
Northern Abalone	12, 13, 15, 16, 17, 19, 21	presence	2,557	0	1995–2016	2–11

Species or faunal group	Sources	Units	Number of presence records	Number of no detection records	Years	Months
Shrimp	1, 10, 11, 19, 20, 21, 22, 23, 24	presence	122,431	0	1963–2016	1–12
Spot Prawn	1, 10, 11, 18, 19, 21, 22, 23, 24	presence	300,534	0	1963–2016	1–12
Tanner Crab	1, 10, 14, 20, 23, 24	presence	5,510	0	1996–2014	1–5, 8–11
Dungeness Crab	1, 10, 14, 19, 23, 24	presence	207,046	0	1967–2017	1–12
Red Sea Urchin	1, 10, 12, 15, 16, 17, 18, 19, 21, 22, 23, 24	presence	34,434	0	1967–2016	1–12
Green Sea Urchin	1, 10, 15, 16, 17, 18, 19, 21, 22, 23, 24	presence	5,007	0	1967–2016	1–12
Red Sea Cucumber	1, 10, 12, 15, 16, 17, 19, 21, 22, 23, 24	presence	18,649	0	1998–2016	2–11
Geoduck	12, 15, 16, 17, 19, 21, 23	presence	59,729	0	1993–2016	1–12
Coral	1, 9	normalized CPUE (0 to 1)	580	63,546	2003–2017	1–12
Sponges	1, 9	normalized CPUE (0 to 1)	1,822	62,304	2003–2017	1–12
Glass sponge reef	25	Areal extent of reefs	–	–	2000–2016	_
Humpback Whale	4, 5, 6	normalized observer sightings (0 to 1)	1,348	9,366	1995–2017	1–11
Grey Whale	4, 5, 6	normalized observer sightings (0 to 1)	47	4,788	1995–2017	1–7
Killer Whale	4, 5, 6	normalized observer sightings (0 to 1)	140	10,512	1994–2017	1–11
Fin Whale	4, 5, 6	normalized observer sightings (0 to 1)	425	10,224	1995–2017	1–11
Blue Whale	4, 5, 6	normalized observer sightings (0 to 1)	4	4,829	2002–2017	1–7
Sperm Whale	4, 5, 6	normalized observer sightings (0 to 1)	35	4,803	1995–2017	1–9
Steller Sea Lion	7	Areal extent of rookeries	–	–	2009	–
Sea Otter	7	Areal extent of range	–	–	2008	–
Cassin's Auklet	8	Nest pair counts	62	0	1971–2003	–
Glaucous-winged Gull	8	Nest pair counts	184	0	1971–2005	–
Rhinoceros Auklet	8	Nest pair counts	32	0	1977–1993	–
Storm Petrels	8	Nest pair counts	54	0	1977–1997	–
Tufted Puffin	8	Individual counts	35	0	1977–1989	–

Species or faunal group	Sources	Units	Number of presence records	Number of no detection records	Years	Months
Common Murre	8	Individual counts	4	0	1977–2004	–
Pigeon Guillemot	8	Individual counts	249	0	1937–1991	–
Cormorants	8	Nest pair counts	24	0	1977–1989	–

Data sources: 1) DFO groundfish synoptic trawl surveys; 2) Pacific Halibut Management Association longline surveys; 3) DFO Pacific Herring Spawn Habitat Index; 4) DFO Cetacean program; 5) Raincoast Conservation Foundation; 6) North Pacific Pelagic Seabird Database 2.0; 7) BCMCA Marine Mammal Workshop; 8) BCMCA Seabird Workshop; 9) Commercial trawl harvest logs; DFO Shellfish Research Surveys including 10) Shrimp; 11) Prawn; 12) Geoduck; 13) Abalone; 14) Crab; 15) Sea Cucumber; 16) Red Sea Urchin; 17) Green Sea Urchin; 18) Scallop; 19) Clam; 20) Tanner Crab; 21) World Class Tanker Safety System Dive; and 22) World Class Tanker Safety System ROV; 23) Shellfish Fishery Logs; 24) other DFO trawl or longline surveys including Sablefish Research and Assessment, Hecate Multispecies Trawl, IPHC Longline, Inshore Rockfish Longline, Joint Can–US Hake, Hake Stock Delineation, Hecate Strait Pacific Cod Monitoring; and 25) Geological Survey of Canada.

2.3 ANALYSIS

To create an even spatial resolution, species data and the diversity and productivity metrics were aggregated to a 5 by 5 km grid that covered the NSB. Gridding the data ensured equal weights were given to each equal area spatial unit in subsequent calculations. This size was chosen because it was appropriate for the scale of the study area, the resolution of the empirical data (which varied by taxonomic group) and the size of the EBSAs. Density, diversity and productivity values were aggregated by grid cell using the mean. Once the CPUE values had been aggregated and averaged to the 5 by 5 km grid cells, we assume that the mean CPUE/25 km^2 represents a density index for each species. The density index (referred to as density hereafter) can then be used to assess the aggregation and/or the productivity EBSA criteria, given it is an index of biomass per unit area. Species density or diversity data were only used to evaluate an EBSA if the gridded data covered at least 20% of the EBSA area. If this condition was not met, the species fell under the "insufficient data" category.

For presence-only data, a grid cell was classified as presence if at least one presence record occurred within the cell. The presence analysis was based on comparing the spatial coverage of species within and outside EBSA boundaries. If an EBSA was deemed important for a particular species, our expectation is that the % presence (similar to % cover) is higher inside the EBSA than outside. The presence analysis is limited given there is no information about the abundance or density of the important species; however, it does provide an initial assessment of empirical support for the EBSA in terms of the species' distribution in the NSB, and allows us to assess many more species than if we only included species where an index of relative abundance is available.

The gridded data were summarized by computing the mean density or % presence by species for each EBSA. Depending upon the type of data available for each species (refer to Table 3) we calculated either the mean or % presence inside and outside of EBSA boundaries to evaluate the empirical support for each EBSA. The area classified as "outside" varied by species. The outside areas were defined as the total NSB area excluding any EBSAs where the species was identified as important for that particular EBSA. For diversity and productivity metrics, which have not been assessed previously, summary statistics were calculated for each EBSA and the area outside of all NSB EBSAs.

The grid cells with data within the EBSA boundaries were considered the "inside EBSA sites", and therefore the number of grid cells with data inside the EBSA is the "inside EBSA sample". Similarly, the grid cells with data outside the EBSA boundaries were considered the "outside EBSA sites" and the number of grid cells with data is the "outside EBSA sample". To compare the inside and outside EBSAs we calculated summary statistics (mean species density, species %presence, mean diversity and mean productivity) for the inside and outside EBSA samples. We then calculated confidence intervals using a bootstrapping approach. We created a bootstrap distribution (10,000 bootstraps/sample) by calculating the summary statistic (e.g., mean or % presence) of each bootstrap sample drawn from the original "inside EBSA" and "outside EBSA" samples. The 95% confidence intervals were estimated as the interval from the 2.5% to 97.5% of the bootstrap distribution following the percentile method for estimating confidence intervals (Efron and Tibshirani 1993). Issues of unequal sample sizes exist in our inside/outside comparison; however, the area within EBSAs is smaller than outside so sample sizes are expected to be lower within EBSAs. In addition, for areas to be identified as EBSAs, they must meet the EBSA criteria relative to the surrounding area. In other words, if an area is designated as an EBSA for coral aggregations, it is expected that the percent cover or density of corals is significantly higher within the EBSA boundary than outside the EBSA boundary in

the planning area, despite the size of the EBSA. In this case, the planning area was the entirety of the NSB.

Each EBSA was evaluated by comparing the value of each summary statistic within the EBSA to the area outside of the EBSA. In addition to the value of the summary statistic, the degree of overlap of 95% confidence intervals around the statistic was used to evaluate the level of support the species had for being listed as important within the EBSA. Using the 95% confidence intervals, species were semi-quantitatively categorized as having strong, moderate or no support. EBSAs were categorized as have “strong support” for a particular species when a summary statistic was greater within an EBSA than outside EBSA areas with no overlap in confidence intervals. “Moderate support” occurred when a summary statistic was greater within an EBSA than outside EBSA areas with limited overlap in confidence intervals (inside EBSA upper bound greater than outside upper bound and within EBSA lower bound greater than outside EBSA lower bound). EBSAs with no empirical support for a particular species occurred when a summary statistic was lower within an EBSA than outside EBSA or when complete overlap occurred between inside and outside EBSA confidence intervals (no inside/outside difference detected).

2.4 REASSESSMENT RESULTS

We found adequate data to test empirical support for at least a subset of important species for 16/17 EBSAs. Overall, our results show that the available empirical data generally corroborate the expert derived EBSAs. However, the maps of the empirical data show that although the EBSA boundaries in many cases do encompass areas important for species, the shape and configuration of the EBSA boundary has low precision and could be improved and refined to reduce the overall EBSA footprint. Results are presented by EBSA below, with maps for fishes (Figure 5–10), invertebrates (Figure 10–12), marine mammals (Figure 13–14), marine birds (Figure 15–16), fish and invertebrate diversity and richness (Figure 17), and primary productivity (Figure 18).

2.4.1 Hecate Strait Front EBSA

The Hecate Strait Front (HSF) was originally identified as an EBSA by experts due to its oceanographic importance. The narrow band represented by the EBSA boundaries is a tidal front, effective from spring through fall, that accumulates zooplankton (Perry and Waddell 1997) (Table 2). We did not have an appropriate zooplankton dataset to test the boundaries of the HSF. However, our assessment indicates that the HSF EBSA and surrounding area is important for Dungeness Crab (Figure 10b), Pacific Halibut (Figure 5b), Pacific Herring (Figure 5d), Pacific Cod (Figure 8a), English Sole (Figure 7d), and Rock Sole (Figure 9a). Inside/outside comparisons for invertebrate species richness and diversity (Figure 17c,d) show moderate support for higher diversity within the HSF boundary than outside, but no support for fish species richness or diversity (Figure 17ab). There was no support for productivity measured by ChlA mean concentration but moderate support for higher ChlA bloom frequency inside the HSF EBSA than outside (Figure 18). Overall, our results suggest that the general area has biological importance for six species with available data. However, the current boundary of the HSF EBSA does not adequately capture the spatial extent of the area of importance.

2.4.2 McIntyre Bay EBSA

McIntyre Bay (MB) was designated an EBSA given its importance for the fitness of multiple species (Table 2). Oceanographically, it is important due to eddies that occur in the area that have been shown to concentrate decapod larvae and support high zooplankton diversity (Clarke and Jamieson 2006a). With available datasets, we were able to complete inside/outside

comparisons for five species: Killer Whale, Humpback Whale, Pacific Herring, Pacific Halibut and Dungeness Crab. Although we do have data for Pacific Halibut density from the DFO survey data, the MB EBSA was listed as an important area for Pacific Halibut spawning, and the surveys are restricted mainly to the spring and summer months and so cannot adequately test this criterion. Our assessment indicates that the MB EBSA has strong support for ecological importance to Dungeness Crab (Figure 10b), but there was no difference between inside/outside for Pacific Herring (Figure 5d), Humpback Whale (Figure 13d) or Killer Whale (Figure 14a). In the nearshore area of the MB EBSA, small but dense aggregations of Pacific Herring and Pacific Halibut are observed (Figure 5b,d) but the scale mismatch between the size of the EBSA and the size of these aggregations results in low support in an inside/outside comparison. Our analysis indicates the area appears to be important to Arrowtooth Flounder (Figure 7a), Pacific Cod (Figure 8a) and Petrale Sole (Figure 8d), species not listed in the original MB EBSA. Inside/outside comparisons found no evidence for higher species richness or diversity with the MB EBSA, however there is strong support that there is higher primary productivity within the MB EBSA than outside (both ChlA bloom frequency and mean ChlA concentration, Figure 18).

2.4.3 Dogfish Bank

Dogfish Bank (DB) is the largest shallow bank in the NSB and serves as a larval rearing area for a large diversity of invertebrate species (Clarke and Jamieson 2006a). The DB EBSA was designated based on its uniqueness (largest shallow bank) and its importance to multiple species (Table 2). However, because the DFO fish surveys we used in our analysis do not have good spatial coverage of the DB EBSA, our analysis was limited to a % presence analysis for Dungeness Crab. The inside/outside comparison for % presence for Dungeness Crab showed strong support for the DB EBSA (Figure 10b). We had insufficient spatial coverage for the inside/outside diversity comparison; however the DB EBSA has relatively higher primary productivity than the surrounding area (both bloom frequency and ChlA concentration, Figure 18).

2.4.4 Learmonth Bank EBSA

Experts identified the Learmonth Bank (LB) EBSA because it is an isolated bank that traps a diversity of plankton in the surrounding water (Clarke and Jamison 2006a). It is also an important feeding area for marine birds, a migration route for Grey Whale and an aggregation area for Fin Whales and corals (Table 2). We were limited in our analysis because fishing is actively limited in the area due to the presence of corals and high seafloor rugosity, and DFO bottom trawl surveys avoid the area (Sinclair et al. 2005). We found no differences in our inside/outside comparisons for this EBSA for the three species with available data: Fin Whale (Figure 13b), Grey Whale (Figure 13c) and coral (Figure 12d). Corals did show high density within the LM EBSA but our analysis was unlikely to detect significant difference between inside/outside for several reasons: 1) our data did not completely cover Learmonth Bank, 2) our sample size is very low given the scale of our analysis (5 x 5 km), and 3) the small size of the LB EBSA. We had insufficient data to complete the inside/outside diversity comparison. Thus the lack of empirical support for the LB EBSA does not reflect its ecological importance (see Ardron et al. 2007, Du Preez and Tunnicliffe 2011, Neves et al. 2014). Other data sources, including ROV surveys, are likely a more appropriate source for evaluating this EBSA at a smaller scale. There was no signal of higher primary production within the EBSA boundary when compared to outside (Figure 18).

2.4.5 Brooks Peninsula EBSA

The Brooks Peninsula (BP) EBSA has an offshore flow of nearshore waters and is a significant north/south boundary for many eastern Pacific species (Clarke and Jamieson 2006a). This area was designated as important for several species of sea bird, Green Sturgeon, Olympia Oyster, Tanner Crab, Lingcod and Sea Otter (Table 2). With the datasets we collated, we had sufficient data to examine empirical support for Lingcod, Sea Otter and several sea birds. Inside and outside comparisons showed strong support for the BP EBSA for both Sea Otter (Figure 14b), Lingcod (Figure 6a), Tanner Crab (Figure 12b) and Tufted Puffin (Figure 16d) and moderate support for Glaucous-winged Gull (Figure 15d). We did not have adequate spatial coverage to complete the diversity inside/outside comparison. There was strong support for higher productivity inside the BP EBSA measured by ChlA mean concentration and bloom frequency (Figure 18).

2.4.6 Cape St. James EBSA

The Cape St. James (CSJ) EBSA is an area where Haida eddies are formed. These eddies concentrate plankton and transport them from the NSB to the Gulf of Alaska (Clarke and Jamieson 2006a). Several species use the CSJ EBSA for spawning/rearing or breeding (Pacific Halibut, Steller Sea Lion), and other species aggregate in the area (Humpback Whale, Blue Whale, and Fin Whale – see Table 2). Our analysis showed strong support for this EBSA in terms of Steller Sea Lions (Figure 14d) and Fin Whale (Figure 13b) and moderate support for Humpback Whale (Figure 13d). We found no difference in the inside/outside comparison for Blue Whale (Figure 13a), coral (Figure 12d), or sponges (Figure 12c). Although we did present data for Pacific Halibut (Figure 5a,b), the CSJ EBSA was listed as an important area for Pacific Halibut spawning, and the surveys we are using are restricted mainly to the spring and summer months so cannot adequately test this criterion. The CSJ EBSA appears to be an important area for several species not listed in the original process. Strong support was identified for Lingcod (Figure 6a), Pacific Hake (Figure 8b), Pacific Ocean Perch (Figure 8c), Tanner Crab (Figure 12b), Cassin's Auklet (Figure 15a), Common Murre (Figure 15b), Tufted Puffin (Figure 15d) and moderate support for Northern Abalone, Sablefish (Figure 6d), Sperm Whale (Figure 14c) and storm petrels (Figure 16c). There was low support for diversity and productivity indices. The CSJ EBSA had overall very strong support; however, the boundaries of the CSJ EBSA appear to encompass a larger than necessary area when considering the extent of the areas shown as important with the survey data.

2.4.7 Shelf Break EBSA

The Shelf Break (SB) EBSA is the largest EBSA, covering the upper continental shelf and troughs of Queen Charlotte Sound. It is an area of high aggregation of macrozooplankton (Clarke and Jamieson 2006a) and listed as important for multiple species (Table 2). We were able to do inside/outside comparisons for 18 species. Our results show that multiple species use the SB habitat. The inside/outside comparison showed higher densities within the SB EBSA for Blue Whale (Figure 13a), Sperm Whale (Figure 14c), Fin Whale (Figure 13b), Pacific Hake (Figure 8b), Pacific Ocean Perch (Figure 8c), Sablefish (Figure 6d), Yellowmouth Rockfish (Figure 9c), Tufted Puffin (Figure 15d) and Cassin's Auklet (Figure 15a), and a higher % presence for Tanner Crab (Figure 12b) than outside EBSA boundaries. There was no empirical support for importance to Dover Sole (Figure 7c), Yellowtail Rockfish (Figure 9d), coral (Figure 12d), Grey Whale (Figure 13c), and Rhinoceros Auklet (Figure 16b) with the datasets we used for the analysis. In addition to the species listed in the original EBSA paper, the SB EBSA seems to be important for Lingcod (Figure 6b) on the eastern boundary of the EBSA, cormorants (Figure 15c) near Brooks Peninsula, and Steller Sea Lions (Figure 14d) near Cape

St. James. There was also moderate support for Pacific Halibut (Figure 5a) along the eastern boundary of Haida Gwaii. The spatial distribution of the areas important to the various species varied within the EBSA given its large size. Some species had higher densities in the troughs (e.g., Fin Whale [Figure 13b] and Yellowmouth Rockfish [Figure 9c]) whereas others seemed to have higher densities on the both the slope and the troughs (e.g., Sablefish [Figure 6d], Pacific Ocean Perch [Figure 8c]). There was moderate support for higher fish species richness within the SB EBSA, but no support when examining fish diversity (Figure 17a,b). There was also no support for higher invertebrate diversity or richness (Figure 17c,d) or primary production (Figure 18).

2.4.8 Scott Islands EBSA

The area around the Scott Islands (SI) was designated an EBSA because it is an area of significant tidal mixing, which drives high productivity (Clarke and Jamieson 2006a). Several species were designated as additional justification for the SI EBSA (Table 2). The SI EBSA is important to the fitness of multiple bird species (breeding area) and several fish species (feeding and spawning/rearing) and an area of aggregation for Humpback Whales and Sea Otters (Table 2). Although sampling was limited within the EBSA, we had adequate data for inside outside comparisons for 24/30 species or species groups listed as justifications for the SI EBSA. Of these comparisons, ten species showed strong support including all birds (Cassin's Auklet, Glaucous-winged Gull, Rhinoceros Auklet, storm petrels, Tufted Puffin, Common Murre, Pigeon Guillemot, and cormorants; shown in Figure 15 and Figure 16) as well as Sea Otter (Figure 14b) and Steller Sea Lion (Figure 14d). Six species showed moderate support: Arrowtooth Flounder (Figure 7a), Humpback Whale (Figure 13d), Lingcod (Figure 6), Sablefish, Pacific Cod (Figure 8b), and Widow Rockfish (Figure 9c). The remainder of the species either showed low support with our limited datasets or we did not have adequate data to test them. In addition to the species listed in the original EBSA paper, the SI EBSA also has strong support for Tanner Crab (Figure 12b) and moderate support for Sperm Whale (Figure 14c), both in the region of the SI EBSA that overlaps with the SB EBSA. Inside/outside comparisons for diversity and primary productivity showed no differences. Overall, the inside/outside comparison for the SI EBSA corroborates the expert knowledge used to devise this EBSA.

2.4.9 North Island Straits EBSA

The North Island Straits (NIS) EBSA is an important migration corridor and bottleneck for multiple species (Clarke and Jamieson 2006a, DFO 2013). It was designated as an EBSA based on its importance to Killer Whales, marine birds, Grey Whales, Humpback Whales, Sea Otters, Pacific Herring, salmon and several invertebrate species (Table 2). The two key datasets (synoptic trawl and PHMA longline surveys) used in this analysis had little to no spatial coverage in this EBSA (Figure A 1) reducing our ability to test for empirical support for fish species and species diversity. However, using the marine mammal datasets we found strong support for Sea Otter (Figure 15b), moderate support for Killer Whale (Figure 14a), and no support for inside versus outside for Grey and Humpback Whale (Figure 13c,d). We also found strong support for the NIS EBSA based on % presence for Green Sea Urchin and Spot Prawn (Figure 10d, Figure 11a). We found evidence of ecological importance of the NIS EBSA to several additional species including: Northern Abalone, Geoduck (Figure 10c), Red Sea Cucumber (Figure 11b), Red Sea Urchin (Figure 11c) and Dungeness Crab (Figure 10b). There were no readily available datasets that allowed us to test the NIS EBSA's importance as a migration corridor for Sockeye, Steelhead and Coho Salmon and Pacific Herring. This EBSA had higher relative primary production than the surrounding area (both bloom frequency and ChlA concentration, Figure 18).

2.4.10 Sponge Reef EBSAs

Since the designation of the four Sponge Reef (SR) EBSAs, new sponge reef structures have been discovered throughout the NSB with the use of multibeam and high resolution seismic imagery (Figure 33). To be consistent with the inside/outside comparison we gridded presence of sponge reef into 5 x 5 km grids for this analysis, but also provide an updated SR EBSA map in section 4. The existing SR EBSA boundaries adequately captured the sponge reefs in Hecate Strait and Queen Charlotte Sound (Figure 12a), however the results of the new geological analysis shows that several other existing EBSAs also have sponge reefs within their boundaries: Bella Bella Nearshore, Chatham Sound, Central Mainland and North Island Straits. There are also newly discovered sponge reefs in Portland Canal and Pearse Canal that currently fall outside any of the EBSA boundaries. The original SR EBSAs were also appear to be important to Fin Whale (Figure 13b), Pacific Ocean Perch (Figure 8c), Spot Prawn (Figure 11a), shrimp (Figure 11d) and Steller Sea Lion (Figure 14d). Inside/outside comparison also show moderate support for fish richness (Figure 17b) and invertebrate richness and diversity (Figure 17c,d) despite the limited sampling within the SR EBSA boundaries (Figure A 1).

2.4.11 Chatham Sound EBSA

Chatham Sound (CS) EBSA is an area with a major river outflow with strong tidal mixing and high phytoplankton biomass and productivity (Clarke and Jamieson 2006a, DFO 2013). It was identified as important for the fitness of Pacific Herring, Walleye Pollock, Killer Whale and Humpback Whales, and an area of aggregation for Green Sea Urchins, shrimp, scoters, and Dungeness Crab (Table 2). We were able to do inside/outside comparisons for six of these species or species groups. The CS EBSA had strong empirical support for Pacific Herring spawn (Figure 5c), Dungeness Crab (Figure 10b), Green Sea Urchin (Figure 10d), and shrimp (Figure 11d). There was moderate support for Killer Whale (Figure 14a) and we did not have a dataset with appropriate spatial coverage to do the inside/outside comparisons for Walleye Pollock or the diversity metrics. We found strong support for several additional species including: Northern Abalone, Geoduck (Figure 10c), Spot Prawn (Figure 11a), Red Sea Cucumber (Figure 11b), Red Sea Urchin (Figure 11c) and sponge reef (Figure 12a) and moderate support for Rhinoceros Auklets (Figure 16b). Additionally, the CS EBSA has significantly higher primary productivity relative to surrounding areas (both bloom frequency and ChlA concentration, Figure 18). Overall, there is substantial empirical support for the Chatham Sound EBSA.

2.4.12 Haida Gwaii Nearshore EBSA

The Haida Gwaii (HG) nearshore EBSA has high tidal mixing and productivity (DFO 2013) and was designated on the basis of its ecological importance to 16 species including several species of groundfish, nearshore invertebrates, marine mammals and seabirds (Table 2). Of these important species, we completed inside/outside comparisons for 15. We found the HG EBSA had strong empirical support for Pacific Herring spawn (Figure 5c), Northern Abalone, English Sole (Figure 7d), Petrale Sole (Figure 8d), Red Sea Cucumber (Figure 11b), Red Sea Urchin (Figure 11c) and Humpback Whale (Figure 13d). We did not see empirical support for the HG EBSA for Fin and Grey Whales (Figure 13b,c) or Steller Sea Lions (Figure 14d) using available datasets. We did not have appropriate data for Arrowtooth Flounder, Butter Sole, Dover Sole, Pacific Cod or Rock Sole due to a seasonal mismatch between spawning season and the season of our surveys. New species identified as important for the HG EBSA include: Green Sea Urchin (Figure 10d), Tufted Puffin (Figure 16d), Geoduck (Figure 10c) and Spot Prawn (Figure 11a). We found moderate support for higher fish diversity, but not fish richness, within the HG EBSA boundary (Figure 17a,b) and no evidence of higher invertebrate richness or

diversity inside than outside (Figure 17d). Primary production was not significantly higher within HG EBSA than the surrounding area (Figure 18).

2.4.13 Central Mainland EBSA

The Central Mainland (CM) EBSA is an area of strong tidal mixing, tidal fronts and freshwater plumes (DFO 2013) and an area important to many marine mammals (Steller Sea Lion, Killer Whale, Humpback Whale, Fin Whale, Grey Whale and Sea Otter). It was also identified as an area important for spawning for Walleye Pollock, and aggregations of shearwaters and Red Sea Cucumber (Table 2). We were able to carry out inside/outside comparisons for all of these species except for Walleye Pollock as trawl data did not overlap this EBSA and shearwaters as at-sea bird data was not used. Our analysis showed strong support for higher % presence inside the CM EBSA that outside for Red Sea Cucumber (Figure 11b), Sea Otter and Steller Sea Lion (Figure 14b,d), and no support for higher densities of Fin Whale, Humpback Whale, Grey Whale or Killer Whale (Figure 13b,c,d, Figure 14a). Species not listed as important in the original EBSA process but that appear to be important in the CM EBSA include Northern Abalone, Geoduck (Figure 10c), Pacific Halibut (Figure 5a), Red Sea Urchin (Figure 11c), Green Sea Urchin (Figure 10d), Rhinoceros Auklet (Figure 16b) and Pigeon Guillemot (Figure 16a). There was insufficient data for inside/outside comparisons of diversity, but primary productivity was significantly higher with the CM boundary than outside (Figure 18). Similar to the assessment of other EBSAs, although the CM EBSA boundary encompassed areas ecologically important to many species, the shape and configuration of the boundary itself could potentially be improved to better capture the important ecological components within the EBSA.

2.4.14 Bella Bella Nearshore EBSA

The Bella Bella (BB) nearshore EBSA is an area of tidal mixing and tidal fronts, and plankton concentrations (Clarke and Jamison 2006a, DFO 2013). It was identified as an EBSA due to its importance as a Pacific Herring spawning area, a feeding area for Sea Otters, a migration route for Killer Whale and aggregations of multiple invertebrate species (Table 2). Inside/outside comparisons of % presence showed strong support for the BB EBSA for Geoduck (Figure 10c), Red Sea Cucumber (Figure 11b), Red Sea Urchin (Figure 11c), shrimp (Figure 11d) and Sea Otter (Figure 14b). Our analysis did not indicate this area as particularly important to Pacific Herring spawn (Figure 5c) or Killer Whale (Figure 14a). The BB EBSA appears to be an important area for species not identified in the previous process. There was strong support for Northern Abalone, Green Sea Urchin (Figure 10d), Dungeness Crab (Figure 10b) and Prawn (Figure 11a) and moderate support for Sablefish (Figure 6a) and sponge reef (Figure 12a). Geological signatures for sponge reefs have been identified within the BB EBSA boundary, further supporting its EBSA designation. We did not have appropriate data for the inside/outside comparison of diversity but the BB EBSA is an area of high productivity. Both bloom frequency and ChlA concentrations were significantly higher inside the EBSA than in the surrounding area (Figure 18).

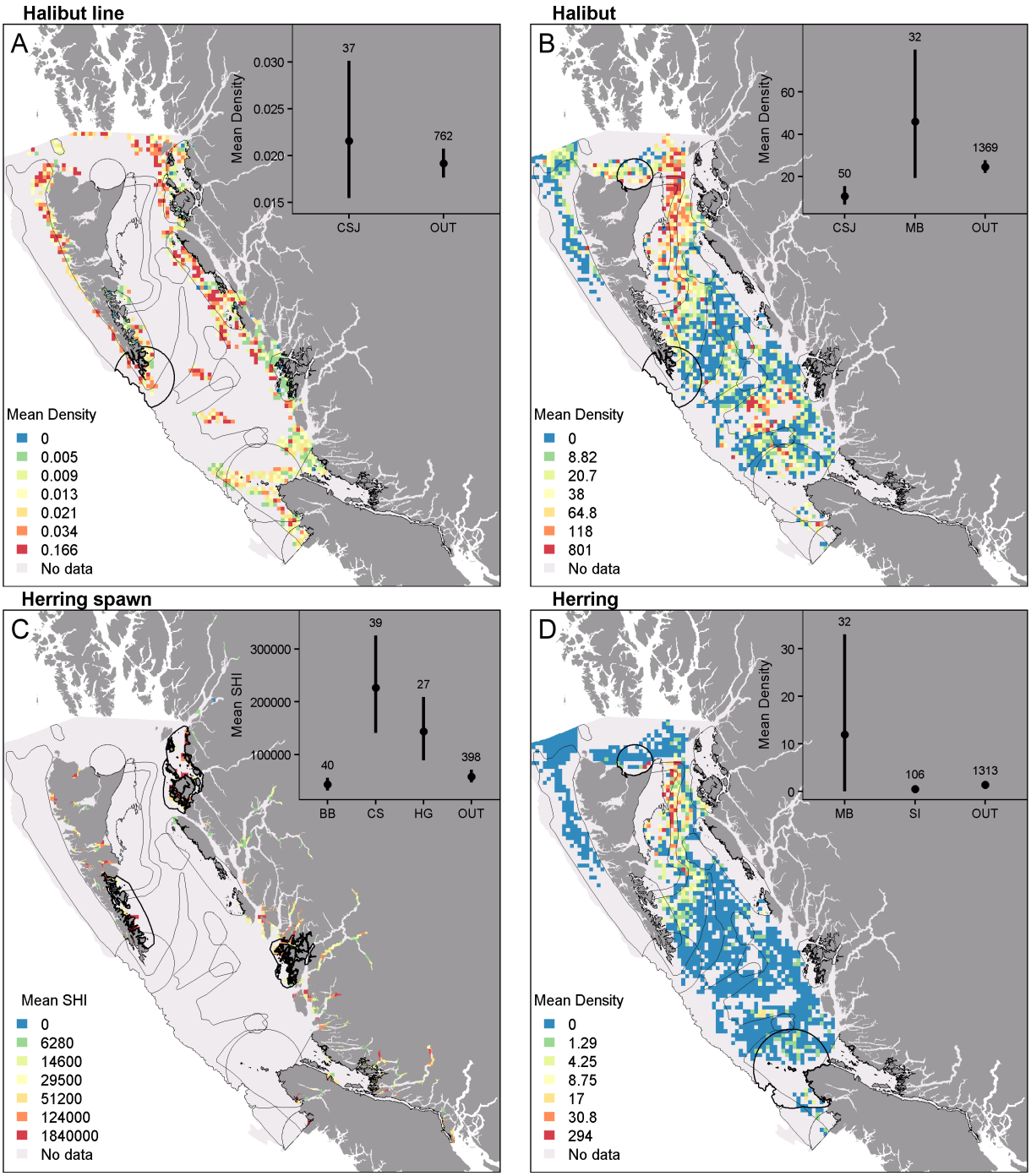

Figure 5. Mean density within 5 by 5 km planning units, showing A) Pacific Halibut (count/hook/hr) from longline sets, B) Pacific Halibut (kg/hr) from trawl sets, C) Pacific Herring spawn as the cumulative Spawn Habitat Index (SHI), and D) Pacific Herring (kg/hr) from trawl sets. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing the mean values inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units).

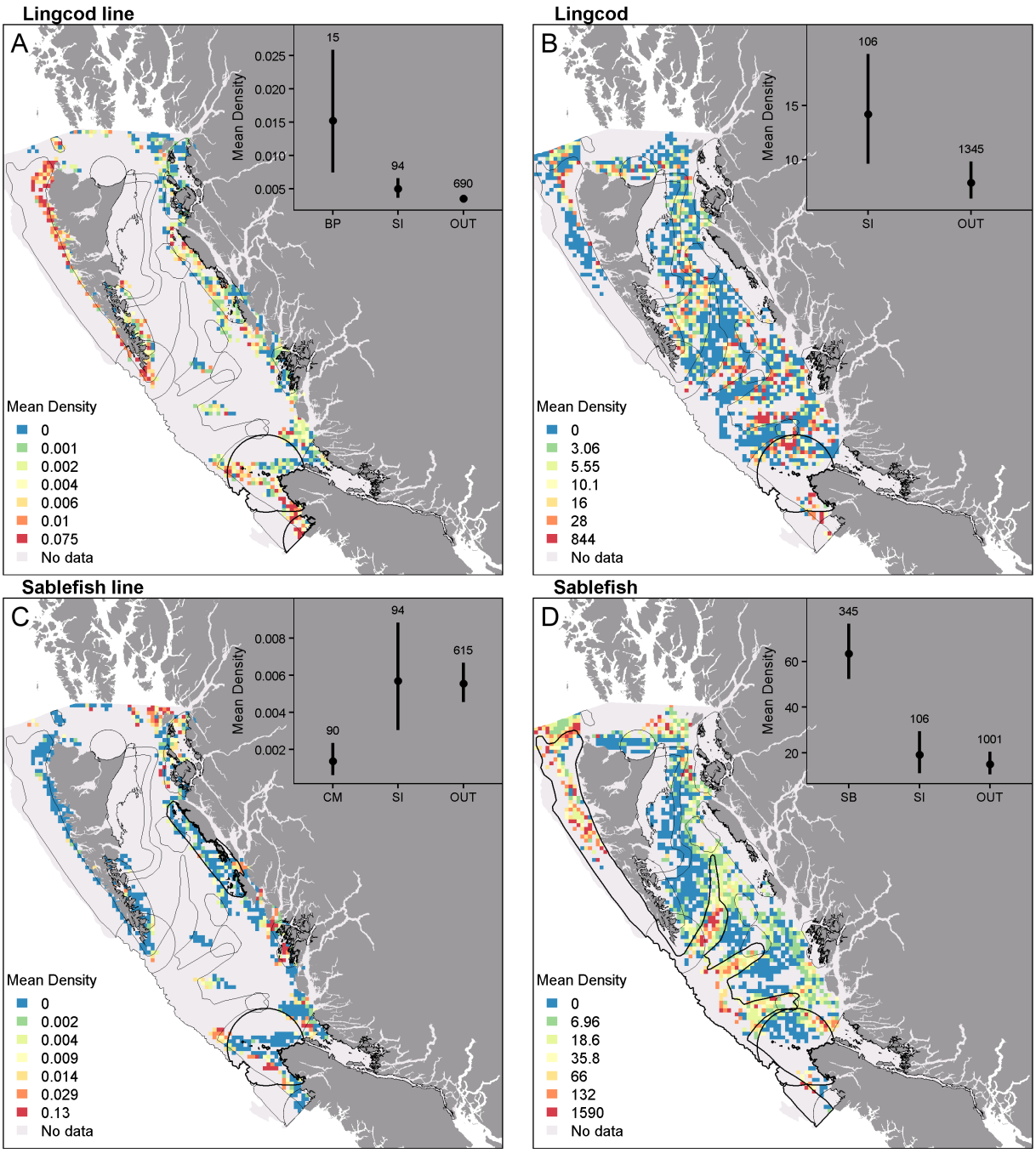

Figure 6. Mean density within 5 by 5 km planning units, showing A) Lingcod (count/hook/hr) from longline sets, B) Lingcod (kg/hr) from trawl sets, C) Sablefish (count/hook/hr) from longline sets, and D) Sablefish (kg/hr) from trawl sets. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing the mean values inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units).

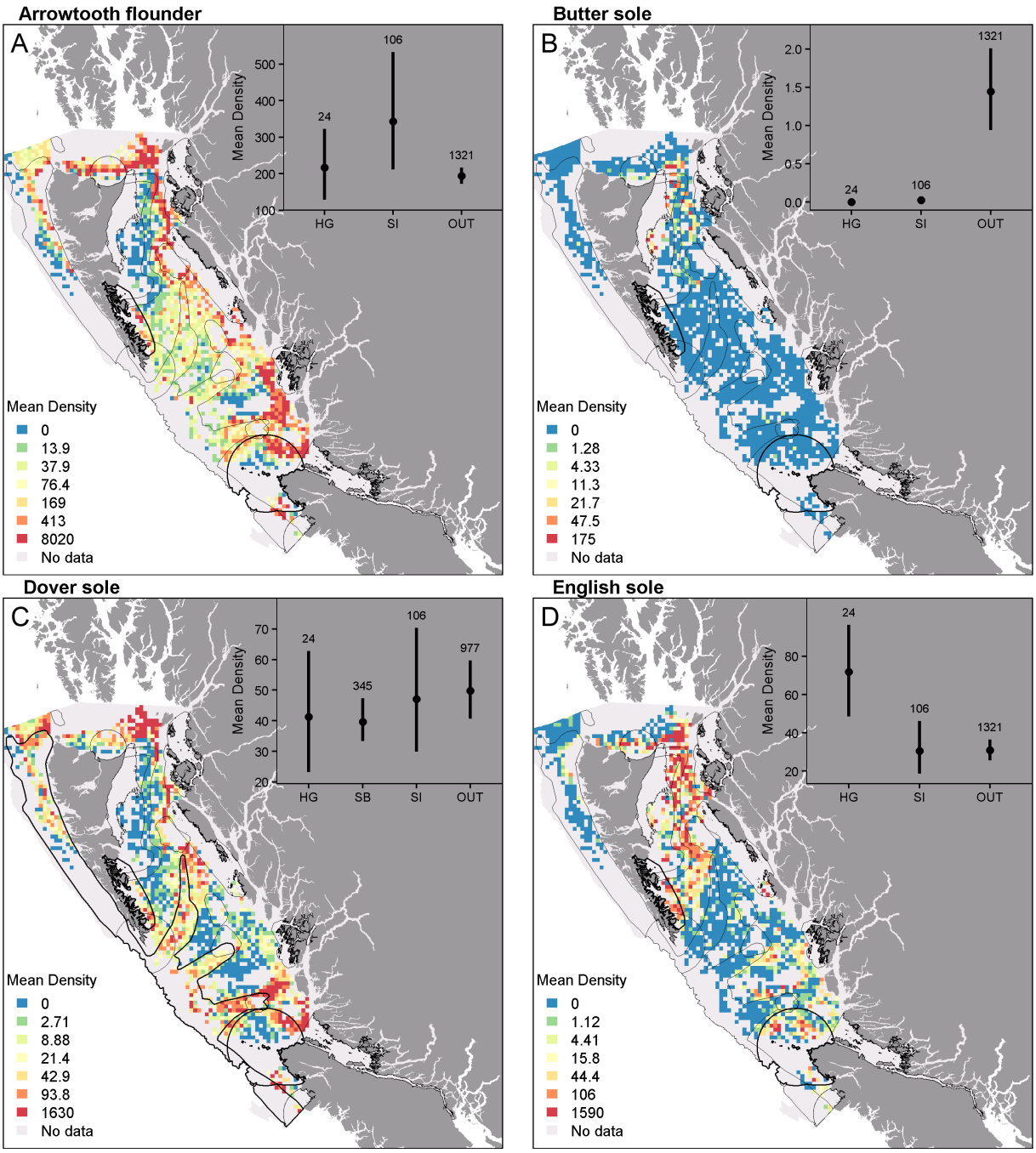

Figure 7. Mean density within 5 by 5 km planning units, showing A) Arrowtooth Flounder, B) Butter Sole, C) Dover Sole, and D) English Sole as CPUE (kg/hr) from trawl sets. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing the mean values inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units).

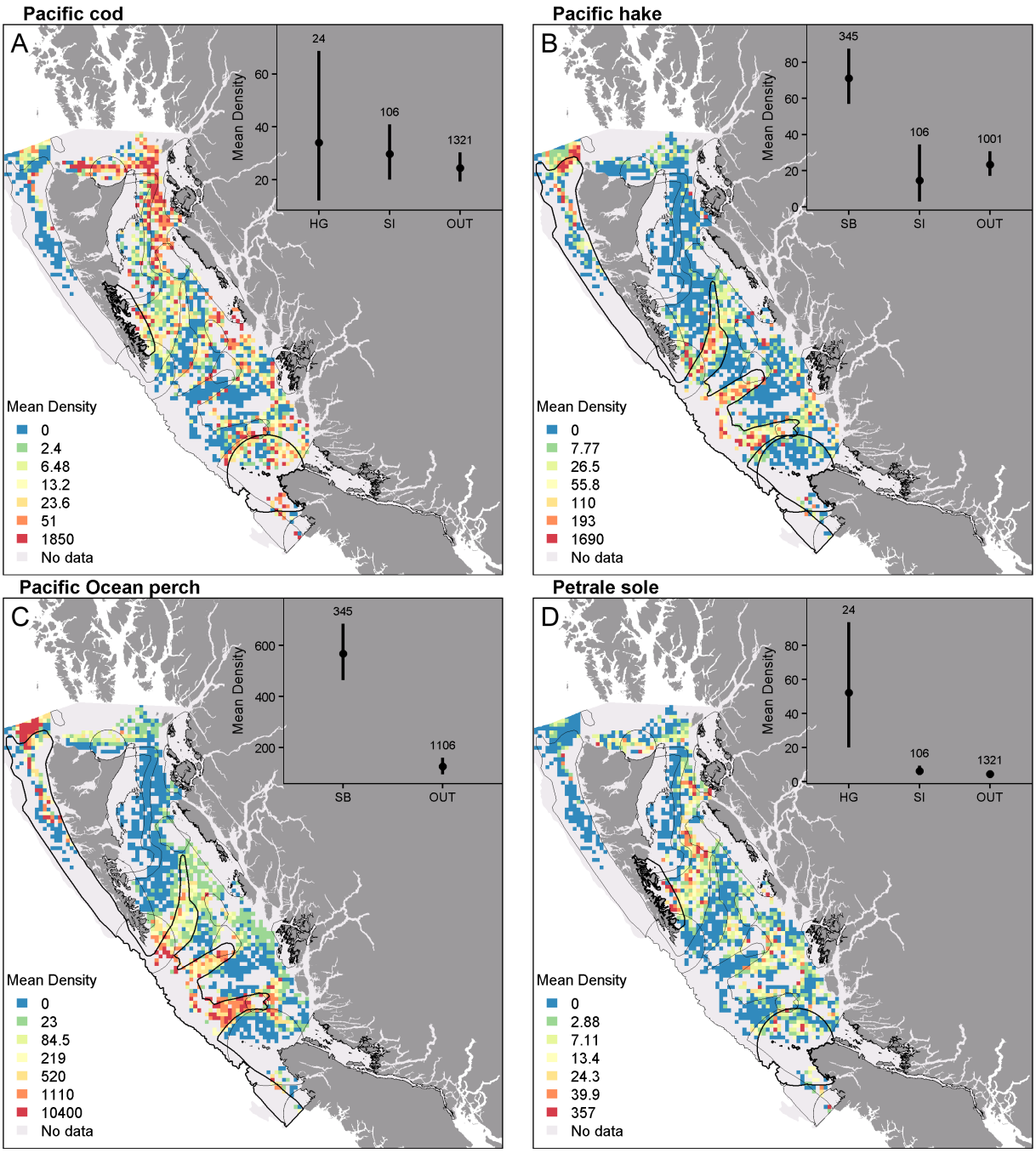

Figure 8. Mean density within 5 by 5 km planning units, showing A) Pacific Cod, B) Pacific Hake, C) Pacific Ocean Perch and D) Petrale Sole as CPUE (kg/hr) from trawl sets. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing the mean values inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units).

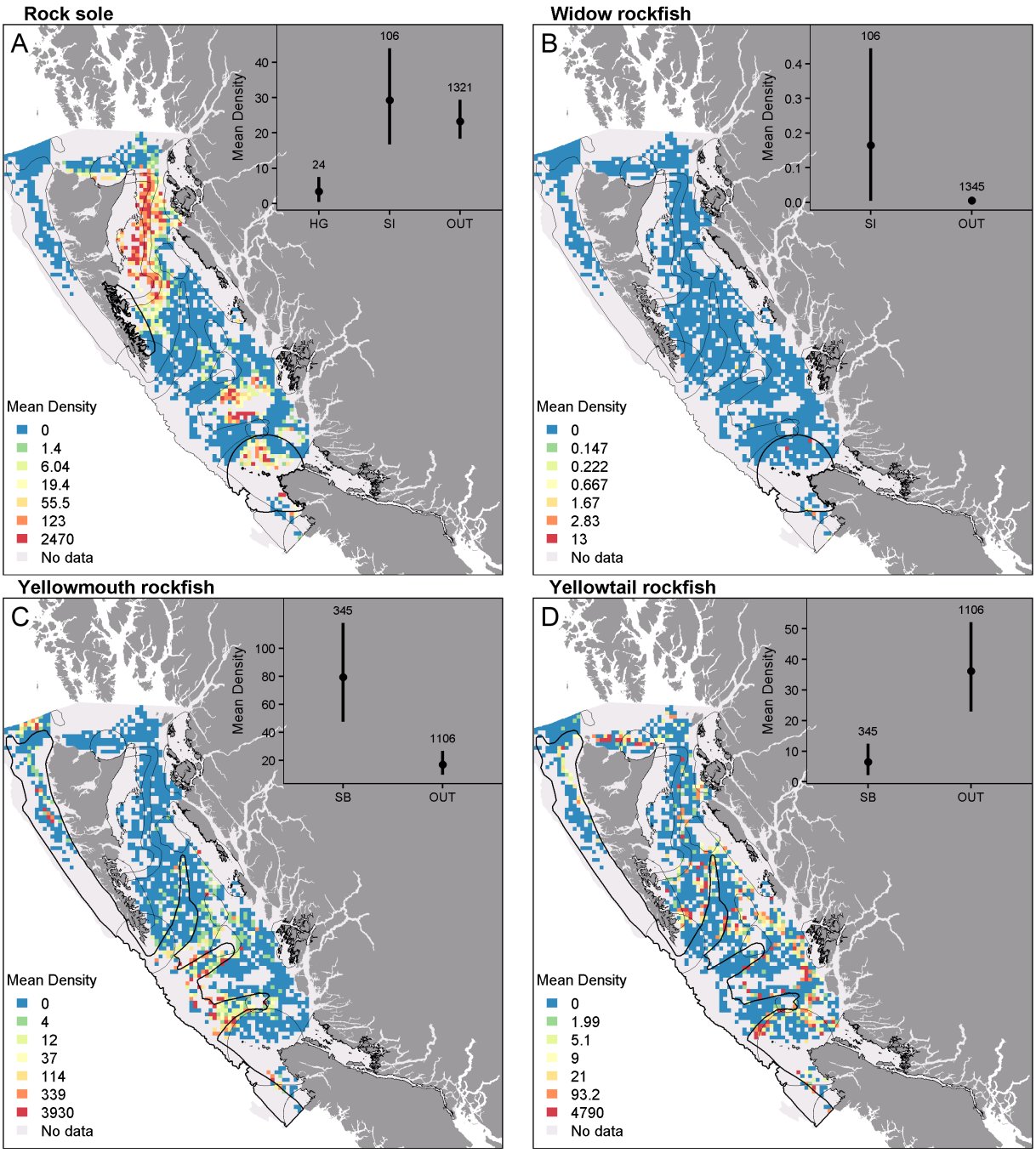

Figure 9. Mean density within 5 by 5 km planning units, showing A) Rock Sole, B) Widow Rockfish, C) Yellowmouth Rockfish, and D) Yellowtail Rockfish as CPUE (kg/hr) from trawl sets. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing the mean values inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units).

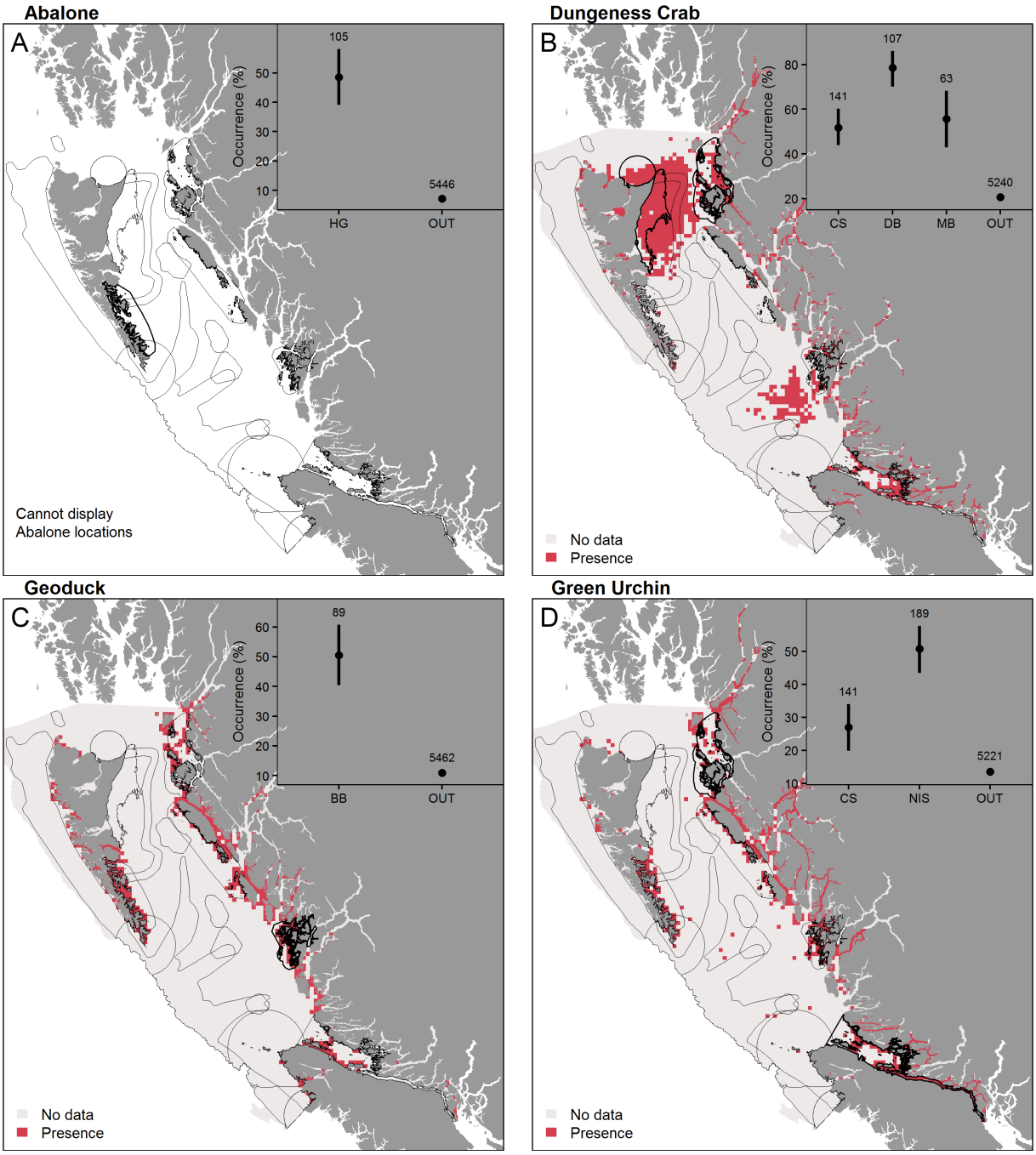

Figure 10. Presence (occurrence) within 5 by 5 km planning units, showing A) Northern Abalone, B) Dungeness Crab, C) Geoduck, and D) Green Sea Urchin. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing the % occurrence inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units). Northern Abalone locations cannot be shown for confidentiality reasons.

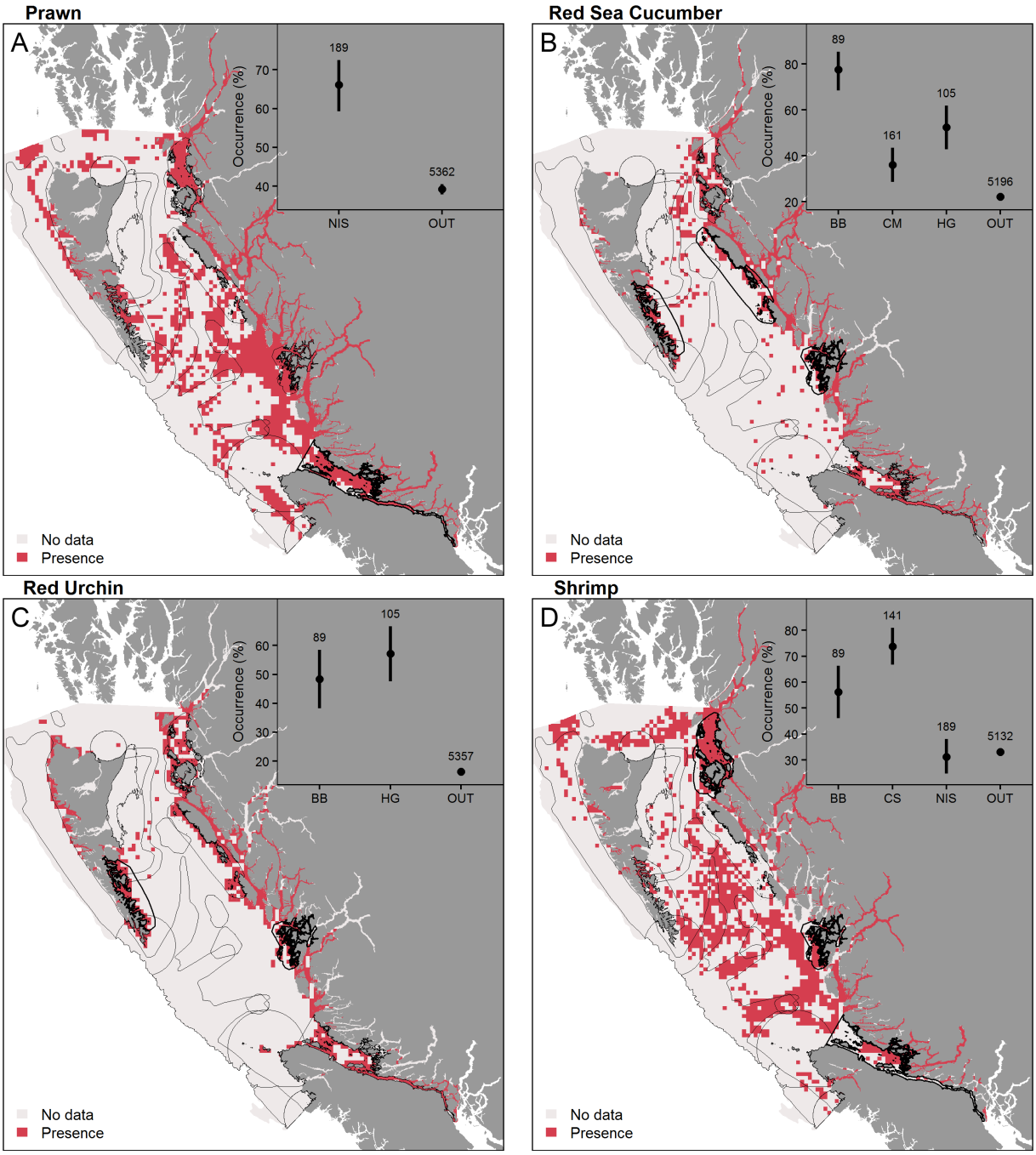

Figure 11. Presence (occurrence) within 5 by 5 km planning units, showing A) Spot Prawn, B) Red Sea Cucumber, C) Red Sea Urchin and D) Shrimp. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing the % occurrence inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units).

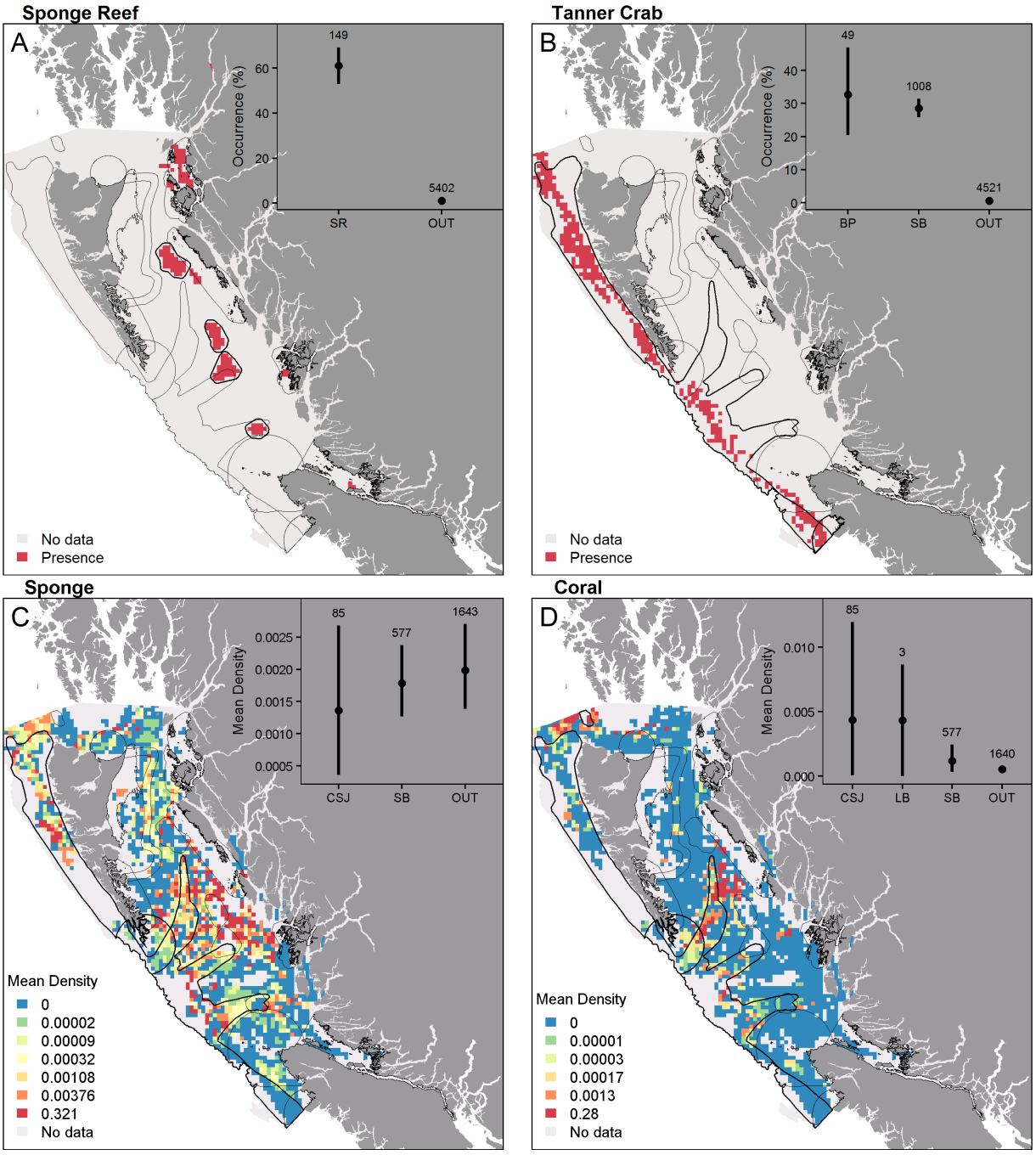

Figure 12. Mean density or presence within 5 by 5 km planning units, showing A) sponge reef and B) Tanner Crab as presence, and C) sponges and D) corals as normalized mean density ranging from 0 from 1. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing mean values or % occurrence inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units with data including zeros).

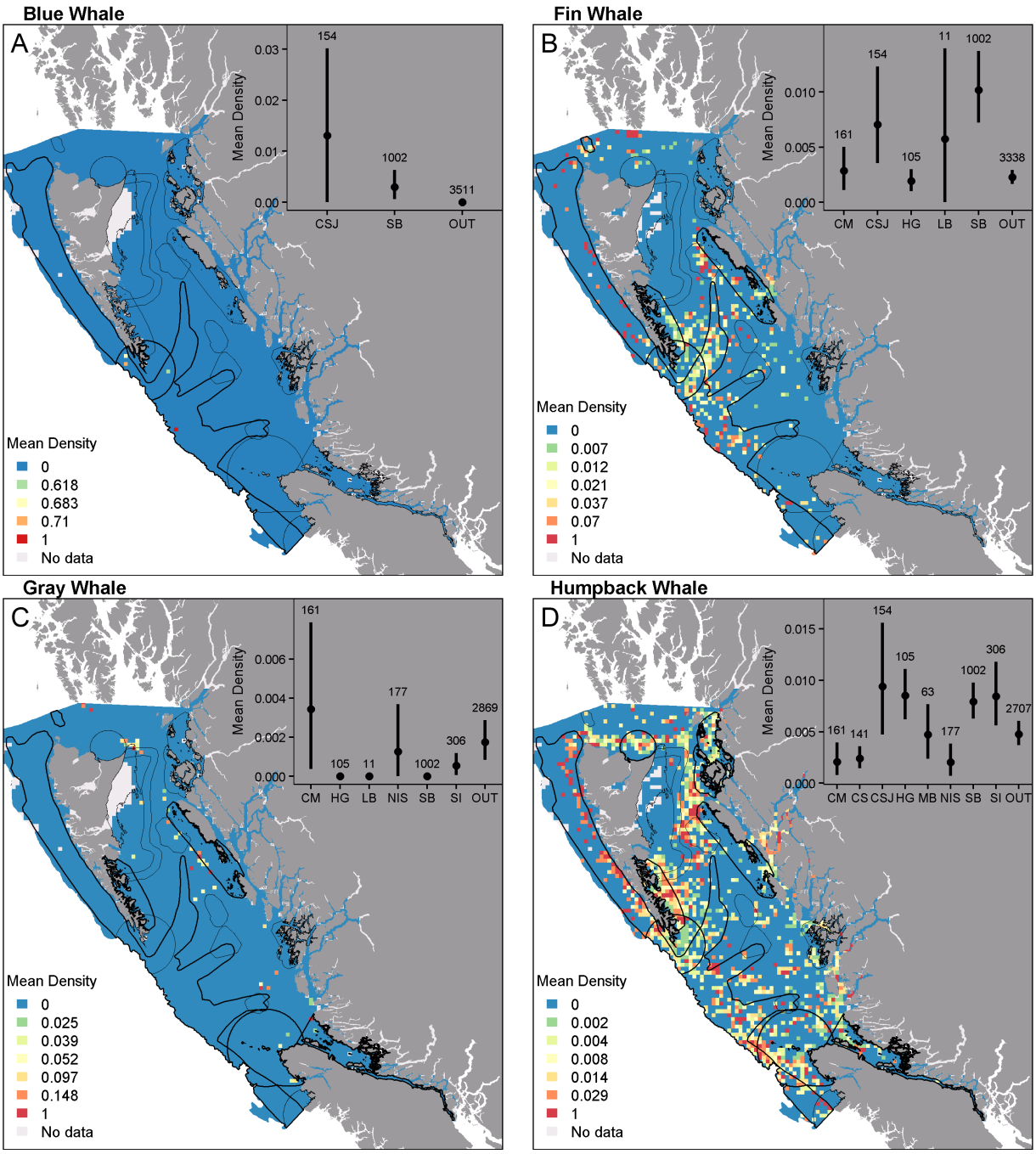

Figure 13. Mean density within 5 by 5 km planning units, showing A) Blue Whale, B) Fin Whale, C) Grey Whale and D) Humpback Whale as normalized density from 0 to 1 from multiple sources of observer sightings. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing the mean values inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units with data including zeros).

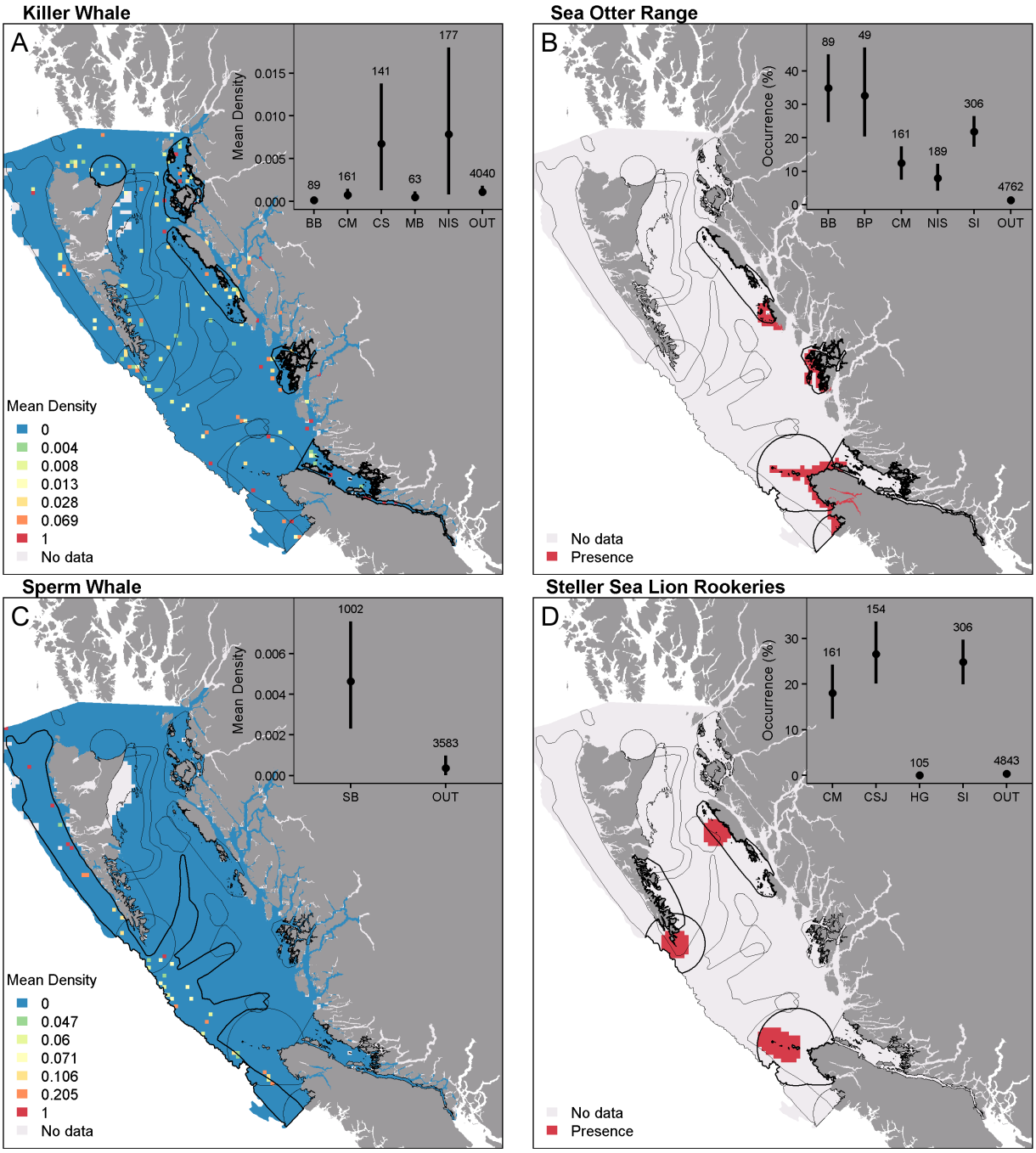

Figure 14. Mean density or presence within 5 by 5 km planning units, showing A) Killer Whale (normalized density from 0 to 1) from multiple sources of observer sightings, B) Sea Otter 2008 modelled range from BCMCA, C) Sperm Whale (normalized density from 0 to 1) from multiple sources of observer sightings, and D) Steller Sea Lion rookery locations from BCMCA. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing the mean values or % occurrence inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units with data including zeros).

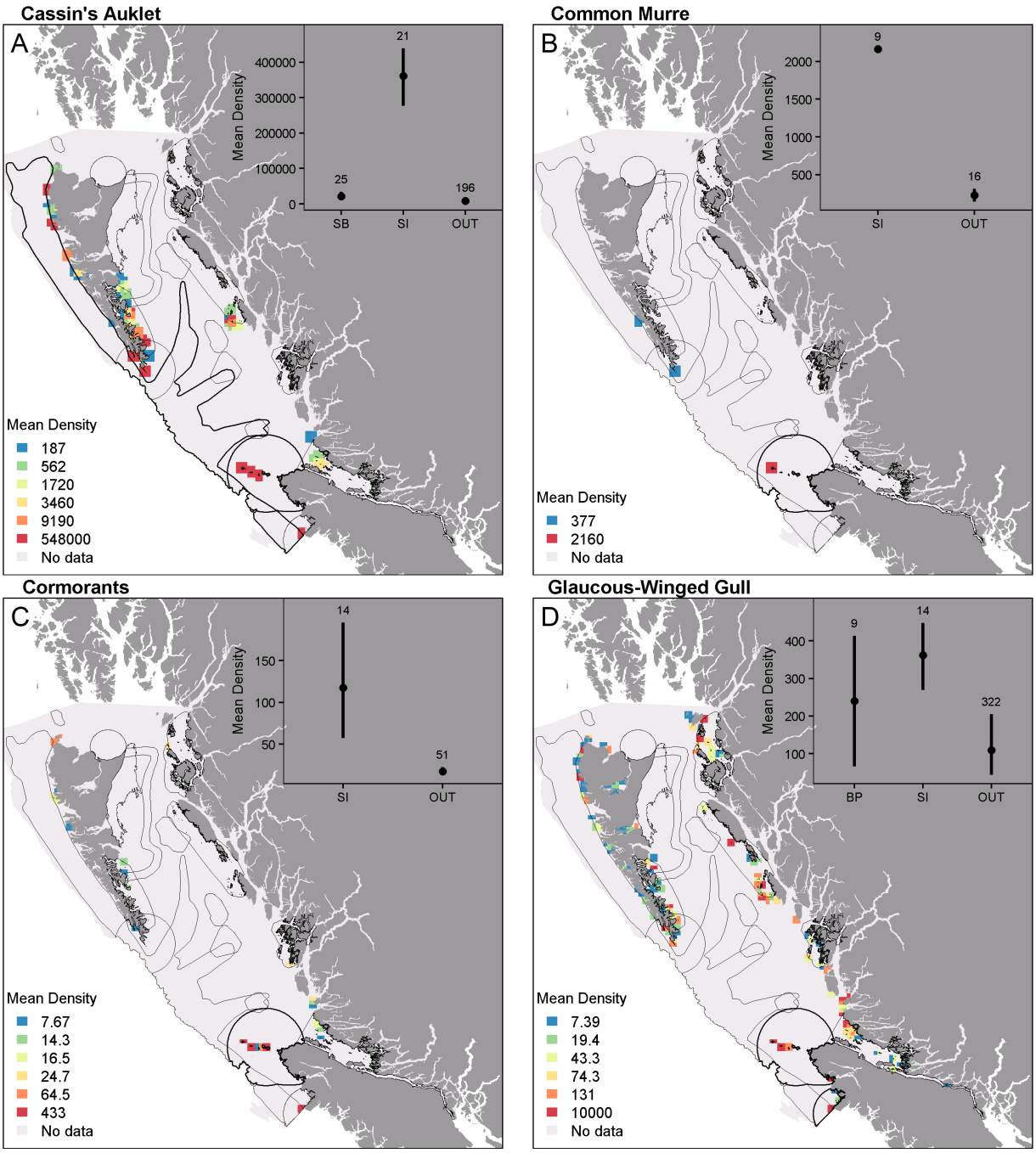

Figure 15. Mean density of nest pairs or individual seabirds in colonies within 5 by 5 km planning units, showing A) Cassin's Auklet, B) Common Murre, C) cormorants and D) Glaucous-winged Gull. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing the mean values inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units with data not including zeros).

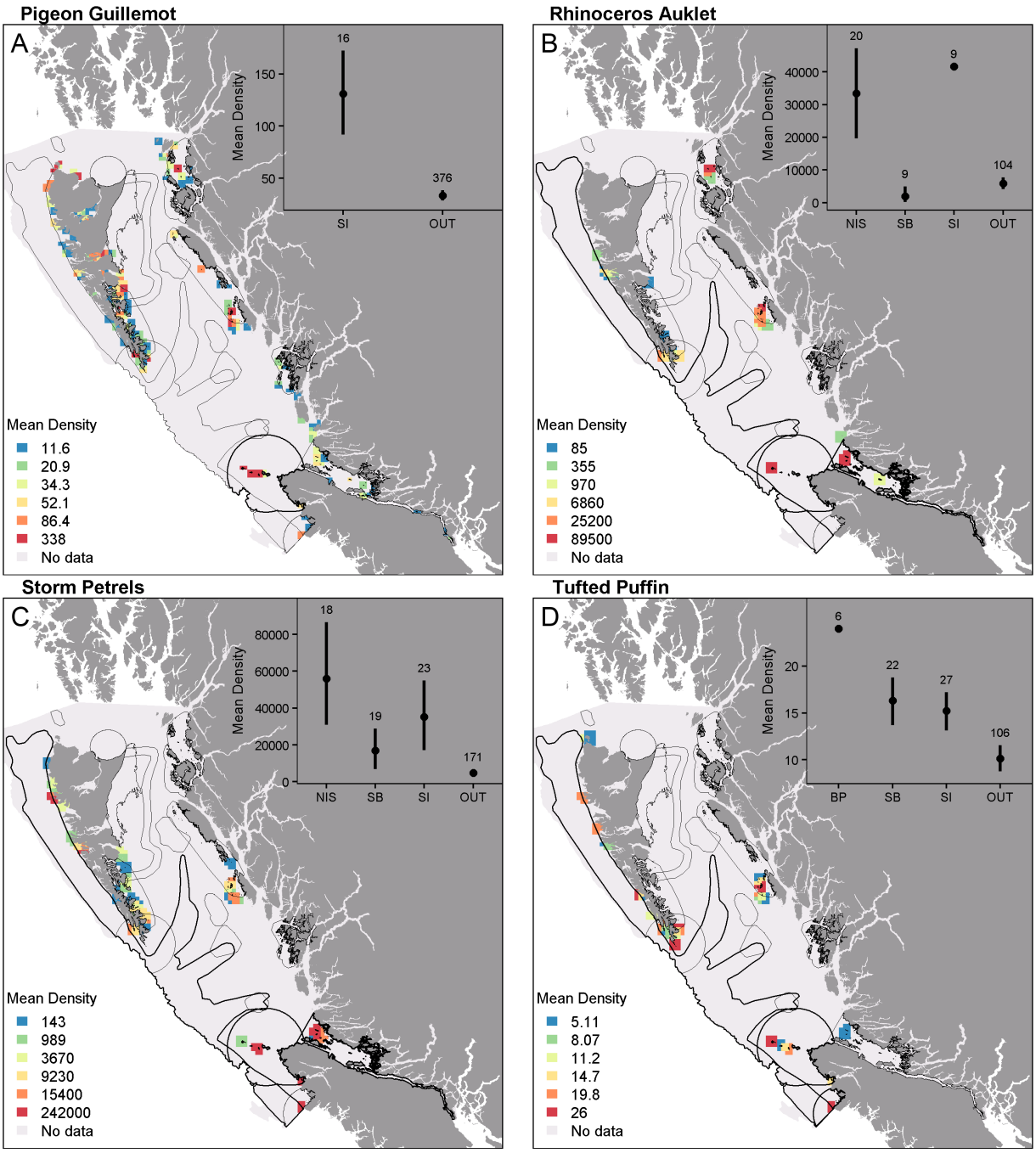

Figure 16. Mean density of nest pairs or individual seabirds in colonies within 5 by 5 km planning units, showing A) Pigeon Guillemot, B) Rhinoceros Auklet, C) storm petrels and D) Tufted Puffin. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those where the species was identified as important for that particular EBSA. Inset figure showing the mean values inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units with data not including zeros).

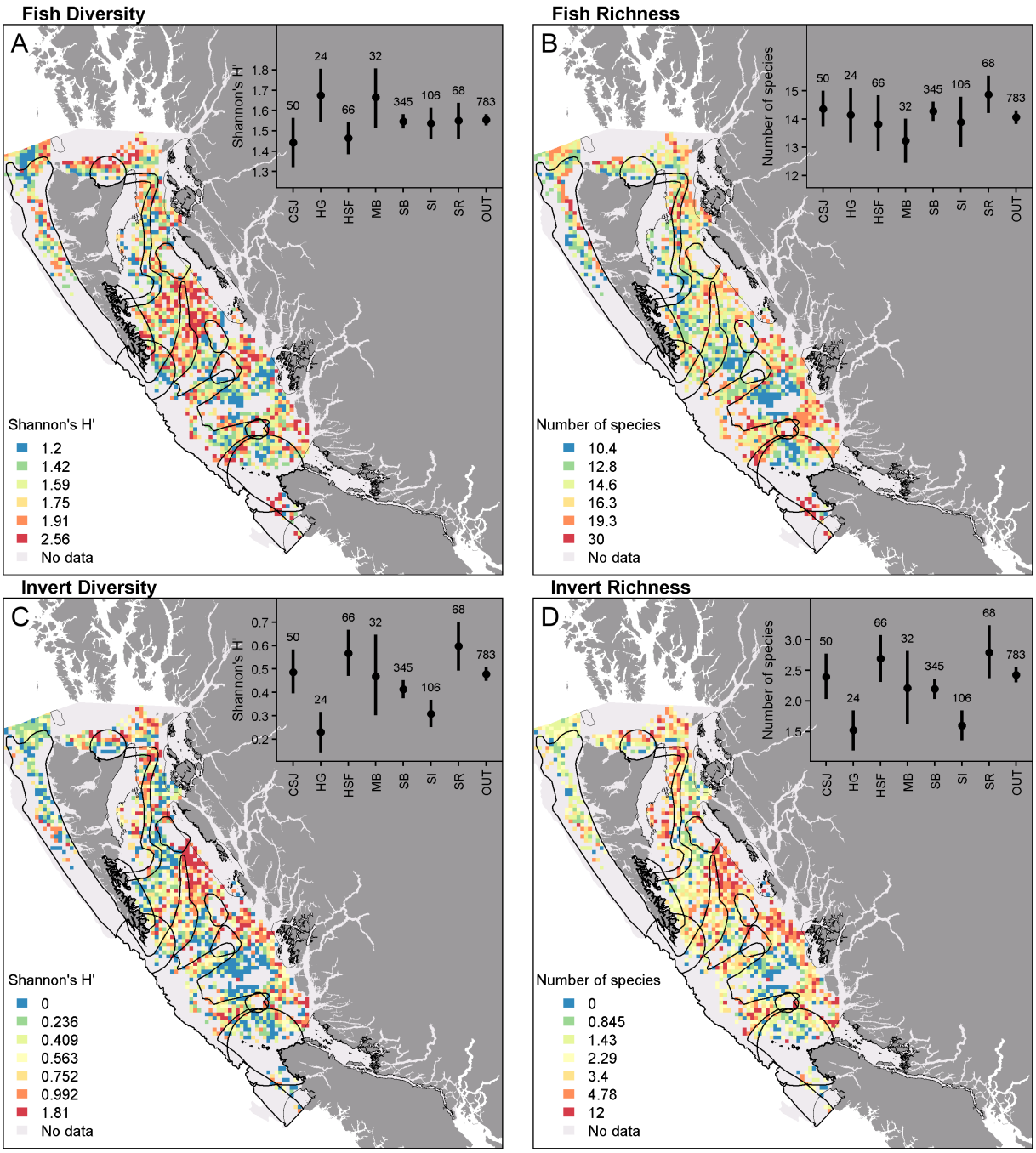

Figure 17. Mean species diversity or richness within 5 by 5 km planning units, showing A) fish diversity (Shannon H'), B) fish richness (number of species), C) invertebrate diversity (Shannon H'), and D) invertebrate richness (number of species) from DFO synoptic survey trawl sets. Boundaries are shown for all EBSAs. EBSAs with bold boundaries are those which had adequate data coverage for the analysis. Inset figure showing the mean values inside and outside of EBSA boundaries for the bold EBSAs. Outside area ('OUT') is the total NSB area excluding the bold EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units with data including zeros).

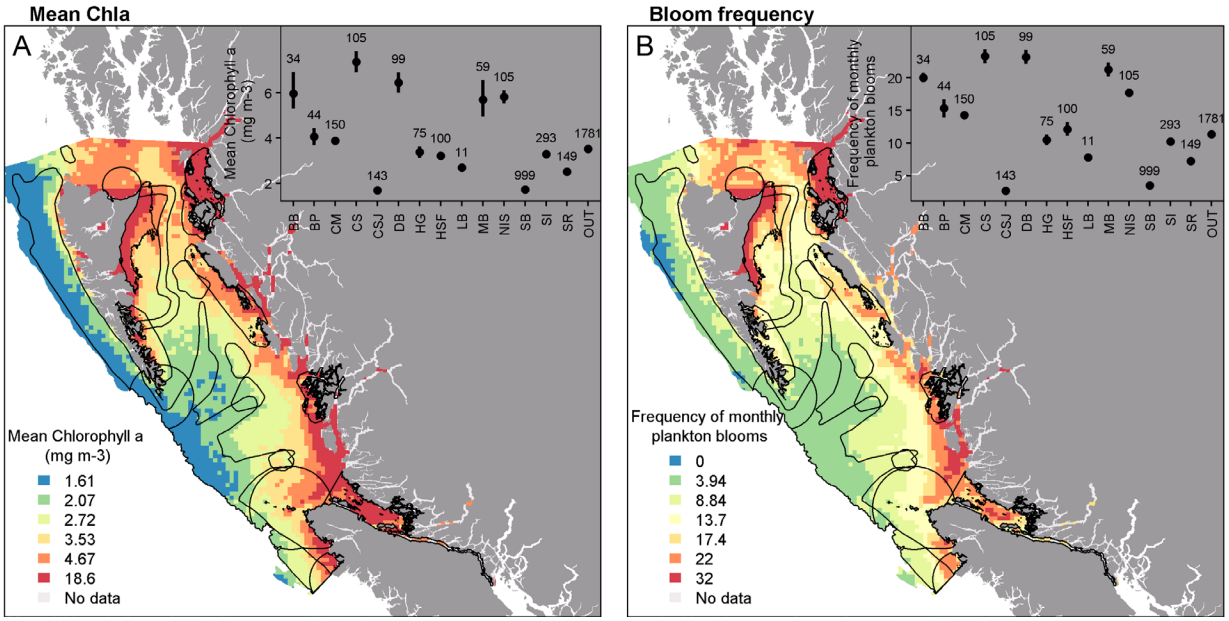

Figure 18. Mean A) chlorophyll A concentration and B) chlorophyll bloom frequency within 5 by 5 km planning units. Boundaries are shown for all EBSAs. Inset figure showing the mean values inside and outside of EBSA boundaries for all EBSAs. Outside area ('OUT') is the total NSB area excluding all EBSAs. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units with data including zeros

Table 4. Summary table of empirical support by species for each EBSA. Empirical support (strong, moderate, or no) was assessed for species originally used to justify identification of each EBSA (Table 2), based on presence or density of each species inside and outside of the EBSA boundaries (see Figure 5–18). New species are species not previously identified for a particular EBSA. Diversity and productivity indices are listed as high ("strong empirical support"), moderate, or low ("no empirical support") for a particular EBSA. Criteria for strong, moderate or no support are defined in Section 2.3. Note that several datasets used in these analyses were not collected in all seasons. The average seasonal range across datasets was from March to October. Species that migrate or exhibit seasonal movements may not be fully represented.

EBSA Name	Strong empirical support inside	Moderate empirical support inside	No evidence for empirical support inside	New species – Strong support inside	New species – Moderate support inside	Fish and Invertebrate Diversity	Primary Productivity
Hecate Strait Front (HSF)	–	–	–	Dungeness Crab, English Sole, Pacific Halibut, Pacific Herring, Pacific Cod, Rock Sole	–	Moderate	Moderate
McIntrye Bay (MB)	Dungeness Crab	–	Pacific Halibut, Pacific Herring, Humpback Whale, Killer Whale	Arrowtooth Flounder	Pacific Cod, Petrale Sole	Low	High
Dogfish Bank (DB)	Dungeness Crab	–	–	–	–	–	High
Learmonth Bank (LB)	–	–	Coral, Fin Whale, Grey Whale	–	–	–	Low
Brooks Peninsula (BP)	Lingcod, Sea Otter, Tanner Crab, Tufted Puffin	Glaucous-Winged Gull	–	Cassin's Auklet, cormorants, storm petrels	–	–	High
Cape St. James (CSJ)	Steller Sea Lion, Fin Whale	Humpback Whale	Pacific Halibut, Blue Whale, coral, sponges	Cassin's Auklet, Common Murre, Lingcod, Pacific Hake, Pacific Ocean Perch, Tanner Crab, Tufted Puffin	Northern Abalone, Sablefish, Sperm Whale, storm petrels	Low	Low

EBSA Name	Strong empirical support inside	Moderate empirical support inside	No evidence for empirical support inside	New species – Strong support inside	New species – Moderate support inside	Fish and Invertebrate Diversity	Primary Productivity
Shelf Break (SB)	Blue Whale, Fin Whale, Humpback Whale, Pacific Hake, Pacific Ocean Perch, Sablefish, Sperm Whale, storm petrels, Tanner Crab, Tufted Puffin, Yellowmouth Rockfish	Cassin's Auklet	Coral, Dover Sole, Grey Whale, Rhinoceros Auklet, sponges, Yellowtail Rockfish	Cormorants, Lingcod, Steller Sea Lion	Pacific Halibut	Moderate	Low
Scott Islands (SI)	Cassin's Auklet, Common Murre, cormorants, Glaucous-Winged Gull, Pigeon Guillemot, Rhinoceros Auklet, storm petrels, Tufted Puffin, Sea Otter, Steller Sea Lion	Arrowtooth Flounder, Humpback Whale, Lingcod, Pacific Cod, Sablefish, Widow Rockfish	Butter Sole, Dover Sole, English Sole, Grey Whale, Pacific Herring, Pacific Hake, Petrale Sole, Rock Sole	Tanner Crab	Sperm Whale	Low	Low
North Island Straits (NIS)	Green Sea Urchin, Spot Prawn, Rhinoceros Auklet, Sea Otter, storm petrels	Killer Whale	Grey Whale, Humpback Whale, shrimp	Northern Abalone, Dungeness Crab, Geoduck, Red Sea Cucumber, Red Sea Urchin	–	–	High
Sponge Reefs (SR)	Sponge reef	–	–	Fin Whale, Pacific Ocean Perch, Spot Prawn, shrimp, Steller Sea Lion	–	Moderate	Low
Chatham Sound (CS)	Dungeness Crab, Green Sea Urchin, Pacific Herring spawn	Killer Whale	Humpback Whale	Northern Abalone, Geoduck, Spot Prawn, Red Sea Cucumber, Red Sea Urchin, sponge reef	Rhinoceros Auklet	–	High

EBSA Name	Strong empirical support inside	Moderate empirical support inside	No evidence for empirical support inside	New species – Strong support inside	New species – Moderate support inside	Fish and Invertebrate Diversity	Primary Productivity
Haida Gwaii Nearshore (HG)	Northern Abalone, English Sole, Pacific Herring spawn, Humpback Whale, Petrale Sole, Red Sea Cucumber, Red Sea Urchin	–	Arrowtooth Flounder, Butter Sole, Dover Sole, Fin Whale, Grey Whale, Pacific Cod, Rock Sole, Steller Sea Lion	Geoduck, Green Sea Urchin, Tufted Puffin	Spot Prawn	Moderate	Low
Central Mainland (CM)	Red Sea Cucumber, Sea Otter, Steller Sea Lion	–	Fin Whale, Grey Whale, Humpback Whale, Killer Whale, Sablefish	Northern Abalone, Geoduck, Green Sea Urchin, Pacific Halibut, Red Sea Urchin, Rhinoceros Auklet	Pigeon Guillemot	–	High
Bella Bella Nearshore (BB)	Geoduck, Red Sea Cucumber, Red Sea Urchin, Sea Otter, shrimp	–	Pacific Herring spawn, Killer Whale	Northern Abalone, Dungeness Crab, Green Sea Urchin, Spot Prawn	Sablefish, sponge reef	–	High

2.5 PART 1 CONCLUSIONS AND DATA LIMITATIONS

Despite the data limitations detailed below, in general, we found empirical evidence for at least one important species listed in the original EBSA justification in all EBSAs except for the Hecate Strait Front. Furthermore, for all EBSAs with available data, we found additional important species or species groups that appear to be associated with the EBSAs. Although all existing EBSA boundaries do an adequate job of capturing at least a portion of areas important to the ecology and fitness of multiple species, the shape and configuration of the EBSA boundaries could likely be improved at a finer scale in future iterations to better delineate the ecological components within.

Our EBSA inside/outside comparison was limited by the data available to us. There were several species listed as justifications for existing EBSAs that lacked empirical datasets, or had existing empirical datasets but did not have sufficient spatial coverage of the NSB to be appropriate for this study (e.g., zooplankton, Olympia Oyster, Northern Fur Seal). For species with available and appropriate empirical datasets, there were several that had significant gaps that limited their utility for the inside/outside comparisons and resulted in limited interpretation of support. Many datasets did not have full spatial coverage of the NSB, leading to knowledge gaps in the assessments of several EBSAs (e.g., Walleye Pollock in Central Mainland EBSA). Additionally, the majority of the data were collected on surveys which occurred in spring and summer months (Table 3). Seasonal data gaps hinder the ability to detect aggregations, migration and spawning that occur seasonally, specifically in the winter months (e.g., Pacific Halibut). Finally, the nearshore species inside/outside comparisons are confounded by the restricted depth distribution and habitat of low mobility nearshore species. These species only occur in the nearshore, therefore comparing their presence to the entire area outside the specified EBSA, including depth ranges and habitat they do not occupy, biases the results towards support. However, given the cursory nature of the analysis the % presence data summaries and maps provide information about the distribution of the species relative to the EBSA boundaries.

This reassessment analysis provides a straightforward approach to quickly evaluate empirical support for the existing boundaries using datasets readily available. The original IAs for particular species and subsequent EBSAs were derived from expert opinion, and our results can indicate empirical support for those areas, but it is not adequate to refute original boundaries given the limitations of data used in the evaluation. Furthermore, a lack of empirical support for a particular EBSA for a specific species does not necessarily mean that the EBSA is not an important area for that species, it only means there was no empirical evidence of support that claim. To explicitly test EBSA boundaries, targeted surveys with adequate spatial coverage for important species inside and outside those boundaries are needed. Given that targeted surveys are a costly and time-consuming next step, we suggest using the empirical analysis presented here to highlight areas within the EBSA that have both empirical and expert knowledge support until more fine-scale mapping efforts are attainable.

3 PART 2: AREAS OF HIGH BIODIVERSITY AND PRODUCTIVITY

The previous EBSA process (Clarke and Jamieson 2006a,b) was completed prior to the development of the CBD (2008) EBSA criteria and relied on the DFO (2004) criteria to identify EBSAs. DFO endorsed the CBD EBSA criteria (DFO 2011), so identifying areas of high biodiversity and productivity is important to fulfil Canada's commitments as a signatory on the CBD. Although the previous process included high productivity as a justification in several existing EBSAs (e.g., Hecate Strait Front, Scott Islands, Chatham Sound, and Haida Gwaii nearshore; DFO 2013), quantitative measures of productivity were not explicitly mapped. Here, we present an approach for identifying areas of higher relative species diversity, higher relative habitat richness, and higher relative productivity with resulting maps that can be used to identify EBSAs in the NSB.

3.1 DESCRIPTION OF CBD CRITERIA

The term biodiversity is synonymous with biological diversity, and can be defined as: "the full range of variety and variability within and among living organisms and the ecological complexes in which they occur; the diversity they encompass at the ecosystem, community, species and genetic levels; and the interaction of these components" (Government of Canada 2011). Areas that contain comparatively higher diversity of ecosystems, habitats, communities, species, or genetic diversity than the surrounding area, are considered EBSAs under the criteria developed by the CBD (2008). Areas of high biodiversity are important for evolution and maintaining the resilience of ecosystems, and the services they provide (Royal Society 2003, Millennium Ecosystem Assessment 2005, Roff and Zacharias 2011).

A growing number of diversity measures have been developed and applied in biodiversity assessments (Southwood and Henderson 2000, Royal Society 2003, Magurran 2004). The more recently developed metrics expand from the classical measures of species richness, evenness, and abundance to evaluations of vulnerability, functional traits and phylogenetic diversity (Magurran and McGill 2011). Here, as an initial evaluation of areas of high biodiversity in the NSB, we focus on observed species diversity of fish and invertebrates similar to the approach for mapping biodiversity in the Scotian Shelf Bioregion (Ward-Paige and Bundy 2016). In addition to species diversity, we map nearshore habitat diversity. Research has shown environmental heterogeneity to have a positive influence on species diversity (e.g., Stein et al. 2014) and therefore habitat complexity, or specifically in this case, habitat richness is a suitable proxy for highlighting areas of high biodiversity in the absence of systematic species level surveys. In future iterations and as more data become available, the methodical approach for mapping species diversity described here can be adapted and applied to other biodiversity measures, such as functional and phylogenetic diversity.

High productivity is one of the criteria to identify EBSAs developed by the CBD (2008). Areas of high productivity are considered important for their role in fuelling ecosystems and increasing the growth rates of organisms and their capacity for reproduction. This criterion is specified to identify regions in the oceans which regularly exhibit high primary or secondary productivity (CBD 2012). Areas of high productivity in the ocean can be identified using remote sensing techniques (e.g., Gower 2004, Fuentos-Yaco and Li 2015) and by examining areas of high biomass or density of higher trophic level organisms as an indicator high secondary productivity (e.g., Kuletz et al. 2015). Here, we map areas of high primary productivity using remotely sensed data, and map areas of high fish and invertebrate biomass using available data sources from DFO surveys (Table 3, Appendix A).

3.2 HOTSPOT APPROACH

The term “hotspot” is used to describe an area or a region with a higher diversity at the ecosystem, species or genetic levels (Reid 1998, Hoekstra et al. 2005) and to refer to areas of high density of individual species or groups of species (e.g., Kenchington et al. 2014, Kuletz et al. 2015, Harvey et al. 2017). The term “biodiversity hotspot”, however, is very specific and was originally defined based on an estimate of endemic species and habitat loss or threat (Myers 1988, Myers et al. 2000). In the conservation literature, mapped hotspots are widespread and are a standard approach to identify important areas for marine conservation (e.g., Worm et al. 2003, Dunstan and Foster 2011, Nur et al. 2011, Schmiing et al. 2014). We use the term “hotspot” to refer to areas with relatively higher levels of the metric of interest, compared to surrounding areas. Therefore the “species diversity hotspots” described here, do not include a threat assessment so do not fit the strict “biodiversity hotspot” definition originally coined by Myers (1988).

In this paper we use two methods, threshold-based and spatial hotspot delineation, to identify areas of higher relative species diversity (fish and invertebrate diversity separately) and productivity (fish and invertebrate biomass). Threshold based hotspot delineations are a common approach, where a somewhat arbitrary threshold is applied to density, abundance or richness maps to identify areas where the top 2.5% (e.g., Ceballos and Ehrlich 2006), 5% (e.g., Harvey et al. 2017) 10% (e.g., Tolimieri et al. 2015) or 20% (Ward-Paige and Bundy 2016) of the feature of interest are located. In contrast, the spatial hotspot approach is a spatially explicit methodology acknowledging the spatial dependence in ecological datasets (Liebhold and Gurevitch 2002, Wagner and Fortin 2005). Thresholds for hotspot delineation in spatial methods are statistically determined and account for spatial patterns in the data (Nelson and Boots 2008). By accounting for spatial patterns in the data, these methods are able to identify where species are most abundant and where the spatial patterns of abundance are unlikely to have arisen from chance processes (Ord and Getis 2001). We use both methods here in order to compare the results and utility for EBSA identification.

3.2.1 Threshold-based hotspot delineation using Kernel Density Estimation

Kernel Density Estimation (KDE) is a non-parametric density estimator where kernel estimators smooth out the contribution of each observed data point over a local neighbourhood. KDEs are commonly used technique to identify areas of high use or high biomass of species or groups of species (Reiss et al. 2008, Horsman and Shackell 2009, Kenchington et al. 2011, O'Brien et al. 2012, Kenchington 2014, Levy et al. 2017). These areas are often called core-use areas, or hotspots. Often, core-use areas are areas of importance for life history stages (e.g., foraging, spawning, nesting, etc.) or areas of high diversity or biomass, making this approach suitable for identifying EBSAs. KDE is also a recognized approach for identifying EBSAs by the CBD (2012).

3.2.1.1 KDE analyses

KDEs (1 km resolution) were carried out to identify areas of high fish and invertebrate diversity (section 3.2.3.2) and productivity (section 3.2.4.2) following the algorithm in Figure 19. A neighbourhood size of 10 km was chosen by calculating the maximum distance to the nearest neighbour (MDNN) using the “Calculate distance band from neighbour count” tool in ArcMap with Euclidean distance and 1 neighbour (i.e., ensuring at least two sampling points are used for each estimate). The KDE rasters were then reclassified into deciles, excluding zero values, and the top decile (90^{th} percentile threshold) was extracted to obtain the hotspot. All analyses were run in ArcMap 10.4, using the ArcPy tools KernelDensity and Reclassify, which require the Spatial Analyst extension.

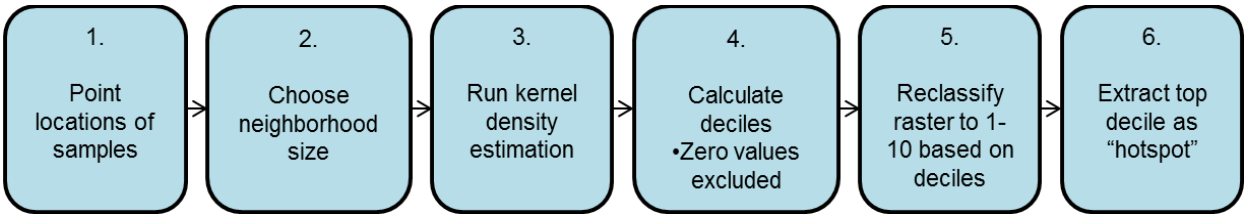

Figure 19. Schematic of process for identifying kernel density "hotspots" for species diversity and biomass.

3.2.2 Spatial hotspot delineation using Getis-Ord Gi*

Spatial hotspot detection methods are often applied in terrestrial contexts (e.g., Nelson and Boots 2008, Bouchet et al. 2015), and have more recently been applied to marine systems (e.g., Kuletz et al. 2015, Maina et al. 2016, Harvey et al. 2017). Here we use the Getis-Ord Gi* statistic to determine if measures of diversity and biomass cluster spatially. Getis-Ord Gi* is a spatial hotspot approach that detects spatial clustering of either high or low values (density, relative abundance, diversity). "Hotspots" are identified where the spatial pattern of clusters are greater than expected from spatial patterns generated from random processes (Getis and Ord 1992). For example, one site with a high value of fish biomass may be interesting but will not be identified as a statistically significant hotspot unless the neighbouring sites also have high values. Getis-Ord Gi* is calculated using the equation below:

$$G_i^*(d) = \frac{\sum_j w_{ij}(d)x_j}{\sum_{j=1}^{n} x_j}$$

Where *i* is the site location, *x* is the value of feature *i* (i.e., diversity or biomass) and w_{ij} is the spatial weights matrix created using a distance threshold (*d*). The Gi* statistic represents the local sum for a feature (e.g., fish biomass) and its neighbours is compared proportionally to the sum of all features in the study area. When the local sum is significantly different from the expected sum (based on the z-score), then that site is identified as hotspot (high values) or a cold spot (low values).

3.2.2.1 Getis-Ord Gi* analyses

Getis-Ord Gi* analyses were carried out to identify areas of high nearshore habitat diversity (section 3.2.3.1), fish and invertebrate diversity (section 3.2.3.2), and fish and invertebrate productivity (section 3.2.4.2) following the algorithm in Figure 20. Analyses were run in the toolbox in ArcMap 10.4 using a fixed distance band chosen using the MDNN, as for the KDE analyses, and Euclidean distance. Calculated neighbourhood sizes were 1 km (section 3.2.3.1) and 10 km (sections 3.2.3.2 and 3.2.4.2). The false discovery rate correction was applied, which accounts for multiple testing and spatial dependence. The outputs of the Getis-Ord Gi* tool are the input points with new attributes indicating each point's categorization as a hotspot, cold spot, or neither (neutral), along with a statistical confidence (90, 95, or 99%) for the hot and cold spots. Using the Minimum Bounding Geometry Tool, convex hull polygons were drawn around groups of hotspot points (i.e., confidence ≥90%) containing 10 or more points. The resulting polygons were then buffered by 1 km.

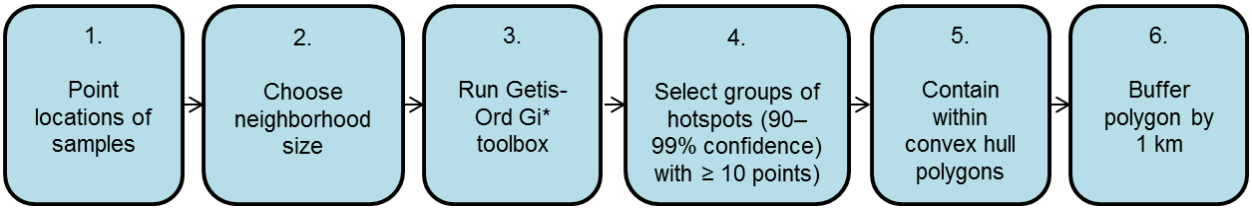

Figure 20. Schematic of process for identifying Getis-Ord Gi "hotspots" for species diversity and biomass.*

3.2.3 Areas of high biodiversity

To examine spatial patterns of diversity in the NSB, we conducted separate analyses for nearshore habitat richness and species diversity.

3.2.3.1 Nearshore habitat richness hotspots

Although there are extensive surveys in targeted areas along the coast of BC, there are no systematic surveys of nearshore species that span the entire coastline of NSB. Due to a lack of spatial coverage for species level data, we developed an approach for mapping habitat richness using a measure of habitat complexity as a proxy for species diversity. For this analysis, we first created a nearshore polygon to delineate the spatial extent of the analysis. A layer delineating the nearshore area and internal waters (Figure 21) was created as follows. The BC coastline was buffered by 2 km and all enclosed areas were filled in (i.e., in cases where the buffer touched itself to form a hole, such as when an inlet mouth narrowed). Using the 100 m-resolution depth raster from BCMCA (Gregr 2012), areas with depths 20 m or shallower were selected, buffered by 250 m to reduce harsh edges, and appended to the coastal buffer. Upon review, two areas with channel mouths slightly larger than 4 km had internal waterways that warranted being included in the nearshore layer and were manually enclosed: Squally Channel between Gil and Campania Islands, and Portland Inlet between Truro and Wales Islands.

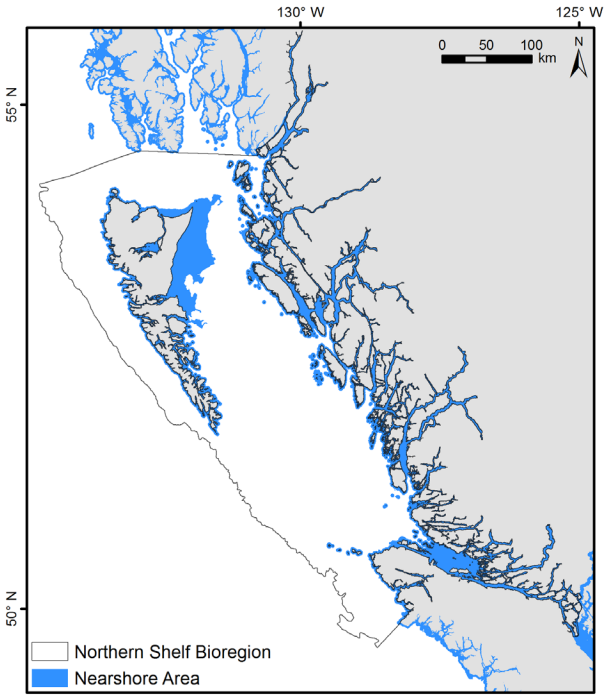

Figure 21. Nearshore area delineation for habitat diversity analysis.

Within the developed nearshore area polygon, we assembled spatial layers representing eight habitat features (eelgrass, surfgrass, canopy-forming kelp, estuaries, areas of high rugosity, and hard, mixed, and soft substrate). Layers for eelgrass, surfgrass, canopy-forming kelp, and estuaries were assembled as part of an assessment of nearshore EBSA features[3]. The kelp and eelgrass layers consist of polygons and ShoreZone biobands available from the British Columbia Marine Conservation Analysis (BCMCA), and the estuary layer is from the Pacific Estuary Conservation Program, most recently updated in 2014, but originally developed in 2007 (Ryder et al. 2007). We used the BCMCA layer representing areas of high rugosity that was developed using the Benthic Terrain Modeller ArcGIS tool and the NRCAN 75 m bathymetry model. Finally, for substrate type, we used three layers representing hard, mixed, and soft substrate in nearshore waters from a bottom patch model developed by Gregr et al. (2013).

The eight layers were overlaid in ArcMap, and the number of habitat features within 1 km x 1 km planning units was calculated using spatial joins (Figure 22, centre). The number of habitat features was used in a hotspot analysis (Getis-Ord Gi*) as described in section 3.2.2.1. Habitat richness is limited by areas with available data. Unsampled areas (i.e., data gaps) cannot be distinguished from a known habitat absence in this analysis.

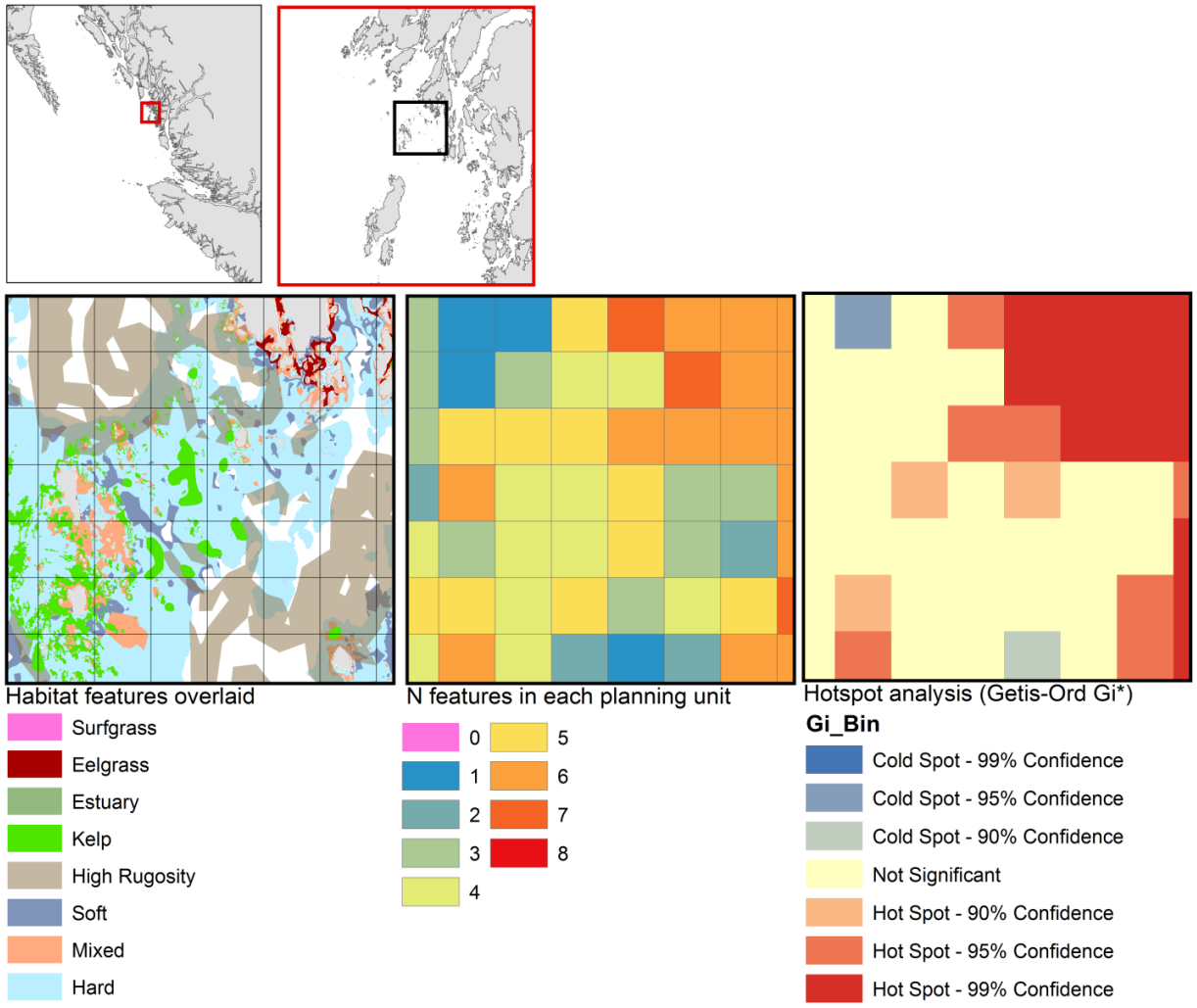

Figure 22. Left: Overlaid habitat features. Centre: Number of habitat features in each planning unit. Right: Hotspots of habitat complexity.

3.2.3.2 Species diversity hotspots

To examine the spatial distribution of alpha diversity on the shelf, we calculated Shannon Diversity (described in section 2.2.5) using catch records from the DFO synoptic trawl and PHMA longline surveys (see Appendix A). The two surveys have complementary spatial coverage, with the PHMA surveys occurring in more coastal areas (20–260 m) and the synoptic trawl surveys occurring on deeper shelf areas (50–1300 m).

CPUE (kg/hr or count/hook/hr) was calculated for species-level taxa within each tow or set and used as input to the *diversity* function in the R package 'vegan'. Kernel density estimates and Getis-Ord G* hotspot analyses, as described in sections 3.2.1.1 and 3.2.2.1, were carried out for each of the three diversity datasets: PHMA fishes, synoptic fishes, and synoptic invertebrates.

3.2.4 Areas of high productivity

We used fish and invertebrate biomass as proxies for examining spatial patterns of productivity in the NSB. We also map areas of high primary productivity as explained in section 2.2.5 of Part 1 of this paper.

3.2.4.1 Primary production hotspots

As previously described (section 2.2.5), we used two different metrics as proxies of primary productivity for the EBSA reassessment analysis. Hotspots of primary production from both mean chlorophyll a concentration and bloom frequency indices were mapped using the top decile method, similar to the approach described in section 3.2.1. These hotspot maps can be used to highlight IAs for primary productivity for the EBSA process.

3.2.4.2 Biomass hotspots

To examine the spatial distribution of productivity on the shelf, we calculated the total biomass (total CPUE) recorded in the DFO synoptic trawl (see Appendix A). CPUE (kg/hr) was summed across all taxa (species-level and higher-level taxa) within each tow or set. Kernel density estimates and Getis-Ord Gi* hotspot analyses, as described in sections 3.2.1.1 and 3.2.2.1, were carried out for each dataset: fishes and invertebrates.

3.3 RESULTS

3.3.1 Areas of high biodiversity

3.3.1.1 Nearshore habitat richness

Of the 37276 1-km planning units within the delineated nearshore area, 95% (35255) contained one or more habitat features and only 11 (< 0.1%) contained all eight features (Figure 23). The hotspot analysis identified about 20% of the nearshore as hotspots (Figure 24), with 5.8% or 2164 km^2 of coastal areas identified as habitat richness hotspots with 99% confidence category (Figure 25; Table 5). The hotspots in the highest confidence level were concentrated in the central coast area around Calvert Island and Bella Bella. More scattered high confidence hotspots were located in Chatham Sound and in multiple inlets and bays on Haida Gwaii. In terms of EBSA designation, we propose the highest confidence hotspots as the most important areas for habitat richness (Figure 25).

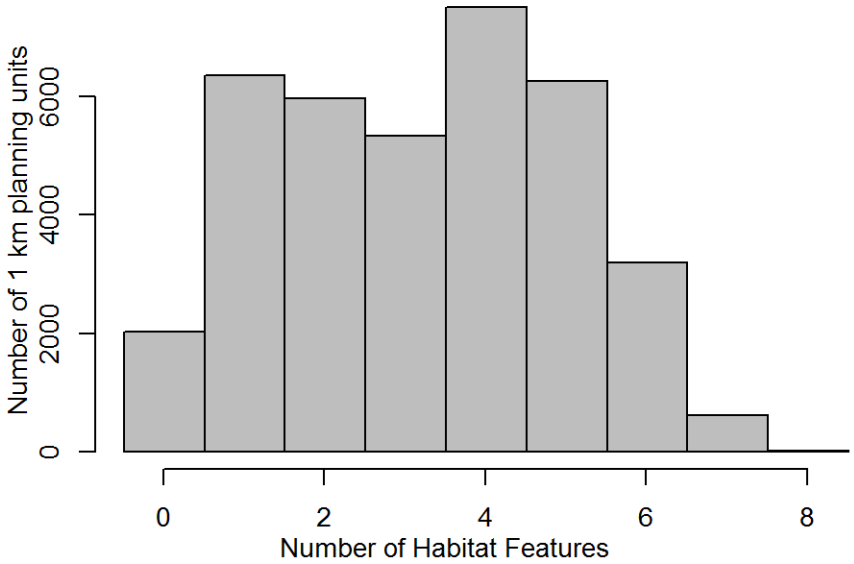

Figure 23. Summary of the number of 1 km planning units populated with different numbers of habitat features.

Table 5. Number of planning units in each of the habitat richness hotspot categories.

Hotspot Category	Number of Planning Units	Percent of Planning Units
Not a hotspot	29901	80.2
Hotspot – 90% Confidence	1747	4.7
Hotspot – 95% Confidence	3464	9.3
Hotspot – 99% Confidence	2164	5.8

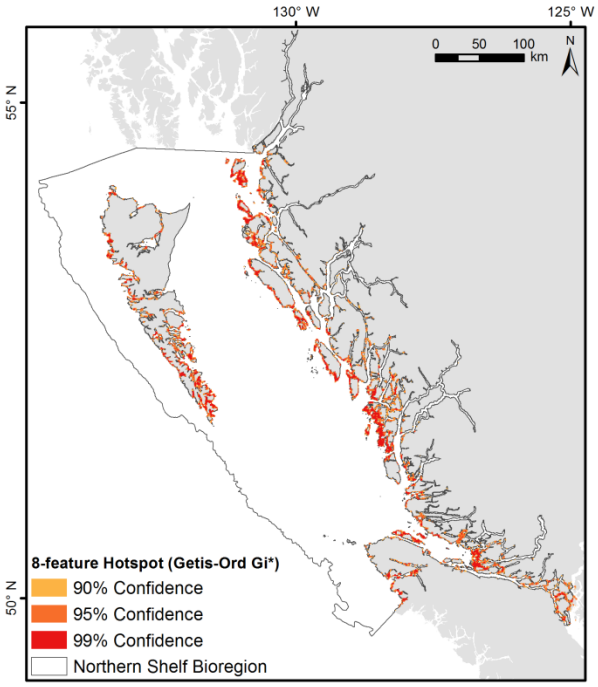

Figure 24. Hotspots identified for the number of habitat features (maximum of 8) occurring within 1 km planning units using the Getis-Ord Gi hotspot analysis, showing for all hotspot categories.*

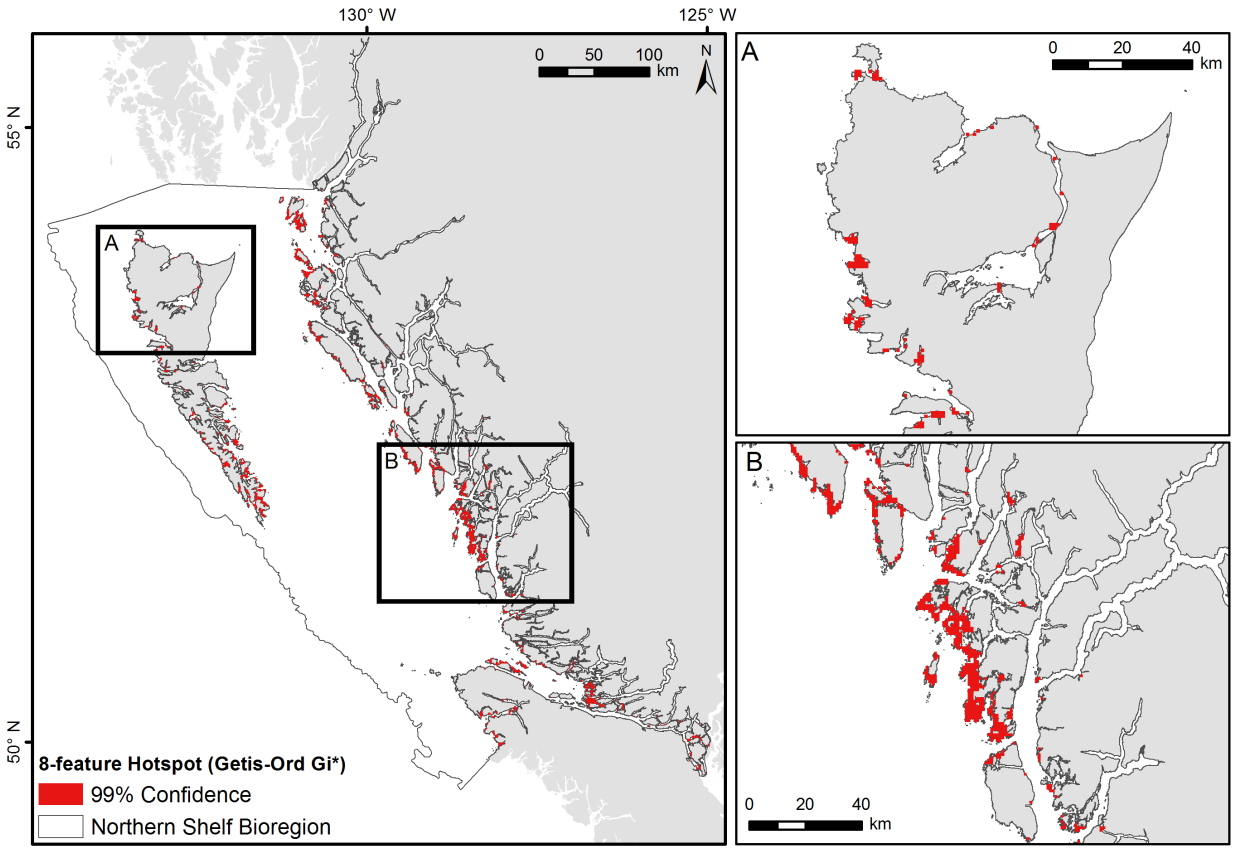

Figure 25. Example close view of hotspots identified for the number of habitat features (maximum of 8) occurring within 1 km planning units using the Getis-Ord Gi hotspot analysis, showing for only the highest hotspot category (99% confidence). A) Graham Island, Haida Gwaii; B) Queens Sound, Central Coast.*

3.3.1.2 Benthic fish diversity hotspots

Mean observed benthic fish diversity (measured by H') calculated from the synoptic trawl surveys and the PHMA surverys was similar (H'=1.54, and H'=1.56, respectively; Table 6). Mean observed benthic invertebrate diversity across the NSB was 0.44.

Table 6. Shannon diversity (H') mean,standard error and range by trawl tow (synoptic surveys) or longline set (PHMA surveys) by species group and survey type.

Analysis	Mean	Standard Error	Range
Invertebrates – Synoptic trawl surveys	0.44	0.01	0.00 – 2.07
Fishes – Synoptic trawl surveys	1.54	0.01	0.00 – 2.75
Fishes – PHMA longline surveys	1.56	0.01	0.09 – 2.32

The KDE top decile and Gi* hotspot results for benthic fish diversity are shown in a series of maps (Figure 26–Figure 28). The top decile hotspot approach (Figure 26b, Figure 27b; Figure 28a), shows the fish diversity hotspots from both surveys at the northwestern tip of Haida Gwaii and down the west side of Haida Gwaii along the slope. Other top decile diversity hotspots from the synoptic surveys are scattered throughout the shelf and troughs (Figure 26b). The top decile diversity hotspots from the PHMA surveys are also scattered and are located along the central coast and north coast near Dixon Entrance (Figure 27b).

The results of the Gi* benthic fish diversity hotspot analysis using the synoptic trawl data produced fewer hotspots but covered more area of the NSB than the synoptic top decile approach (Table 6, Figure 28). For the synoptic surveys the Gi* approach resulted in eight fish diversity hotspots that covered 9,398 km^2 amounting to 9.3% of the area of NSB. In contrast, the KDE top decile approach resulted in 37 areas identified as hotspots, but the hotspots were much smaller and dispersed where only 6,640 km^2 were identified as hotspots making up 6.5% of the area of NSB. Although the sizes of the hotspots varied with method, the areas that were highlighted by both the top decile and Gi* approach were generally the same, with one exception. A large hotspot was identified in and around Moresby Trough identified via the Gi* approach, whereas the top decile approach highlighted several small hotspots throughout the shelf and troughs. The results of the spatial hotspot approach indicate that the Moresby Trough area, in particular, had clusters of high diversity that were higher than expected due to chance processes.

For the PHMA survey, the Gi* approach resulted in only two hotspots that met our >10 hotspot points criterion (section 3.2.2.1), covering only 188 km^2 or < 0.2% of the area of NSB. These hotspots were identified in Dixon Entrance and northwest of Calvert Island on the central coast (Figure 28). In contrast, there were 36 KDE top decile hotspots identified along the central coast (including the area near Calvert Island, the southeastern coast of Haida Gwaii and slope of the northern tip of Vancouver Island). Interestingly, the Gi* hotspot identified in Dixon Entrance was larger than the top decile hotspot in the same area (Figure 28) suggesting that there are likely one or two high diversity sites here that are surrounded by moderately high diversity sites. The top decile approach pulls out the few top diversity sites, but the Gi* approach considers the neighboring sites in the context of those high diversity sites so they too get identified as hotpots.

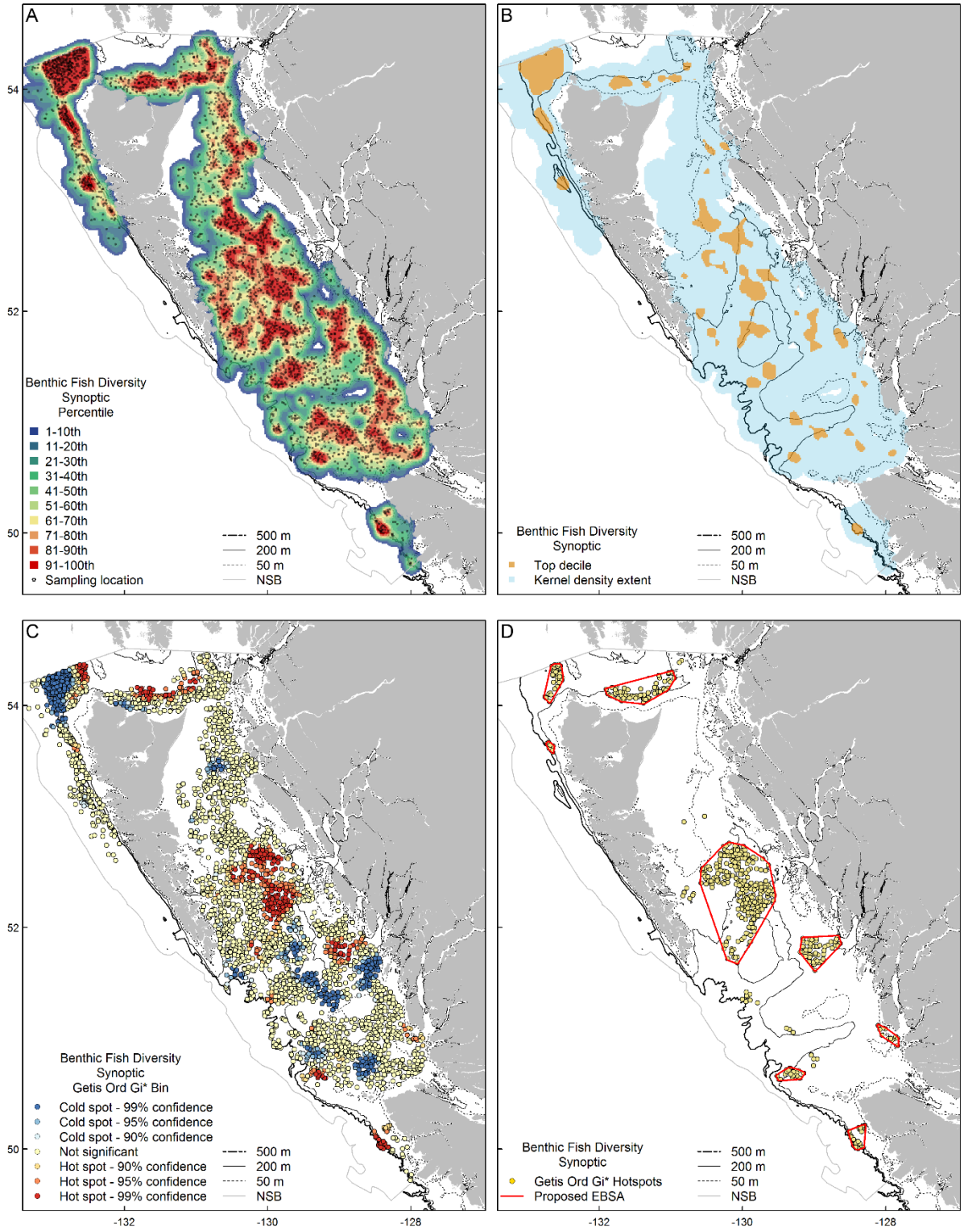

Figure 26. Benthic fish diversity (Shannon index) in the NSB from the DFO synoptic trawl surveys. A) kernel density estimate (KDE) of fish diversity, reclassified into deciles; B) top decile of KDE from A; C) Getis-Ord G analysis outputs of fish diversity, showing hot and cold spots; D) groups of hotspots (90–99% confidence) with ≥ 10 points from C, delineated with convex hull polygons.*

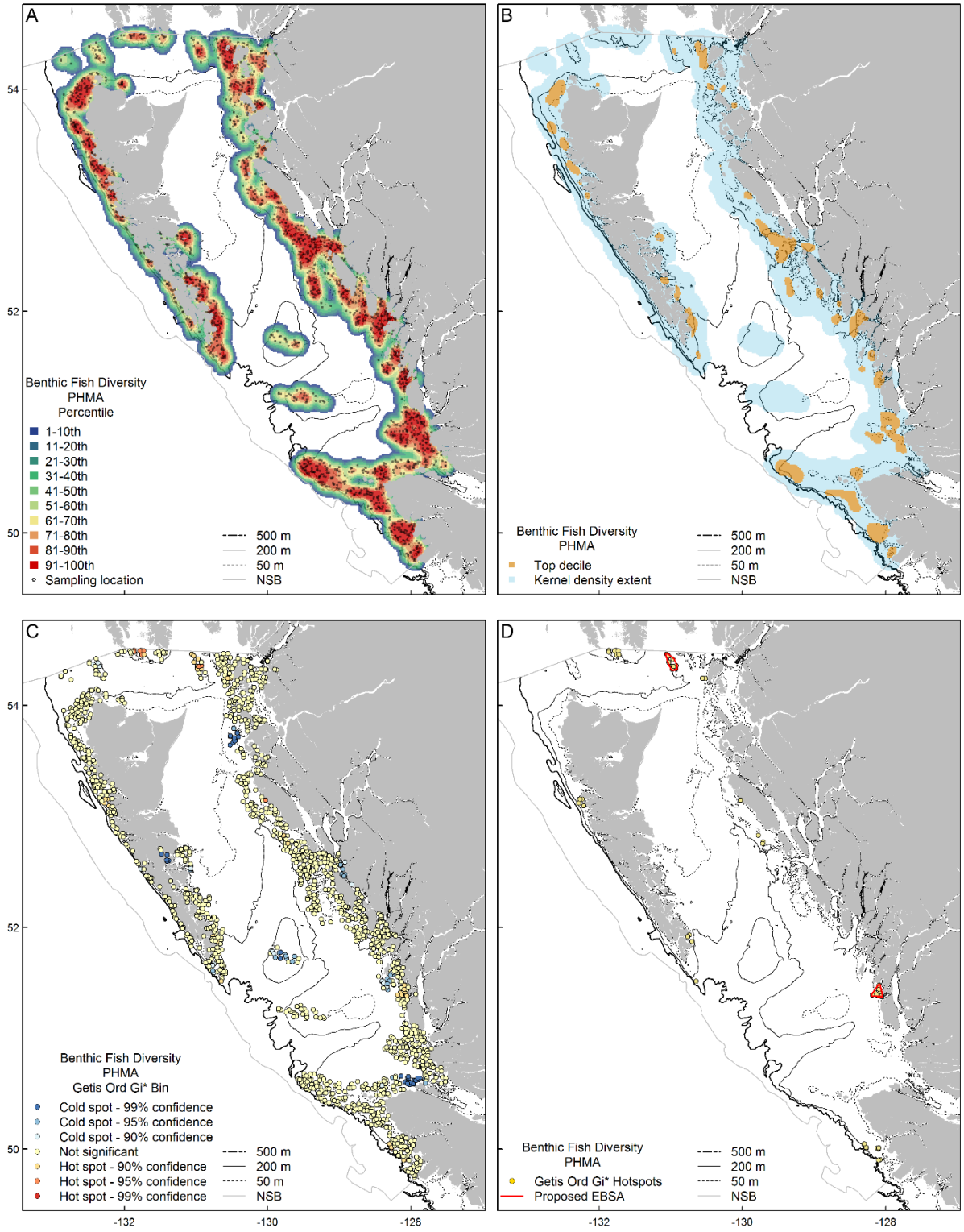

Figure 27. Benthic fish diversity (Shannon index) in the NSB from the PHMA longline survey. A) KDE of fish diversity, reclassified into deciles; B) top decile of KDE from A; C) Getis-Ord Gi analysis outputs of fish diversity, showing hot and cold spots; D) groups of hotspots (90–99% confidence) with ≥ 10 points from C, delineated with convex hull polygons.*

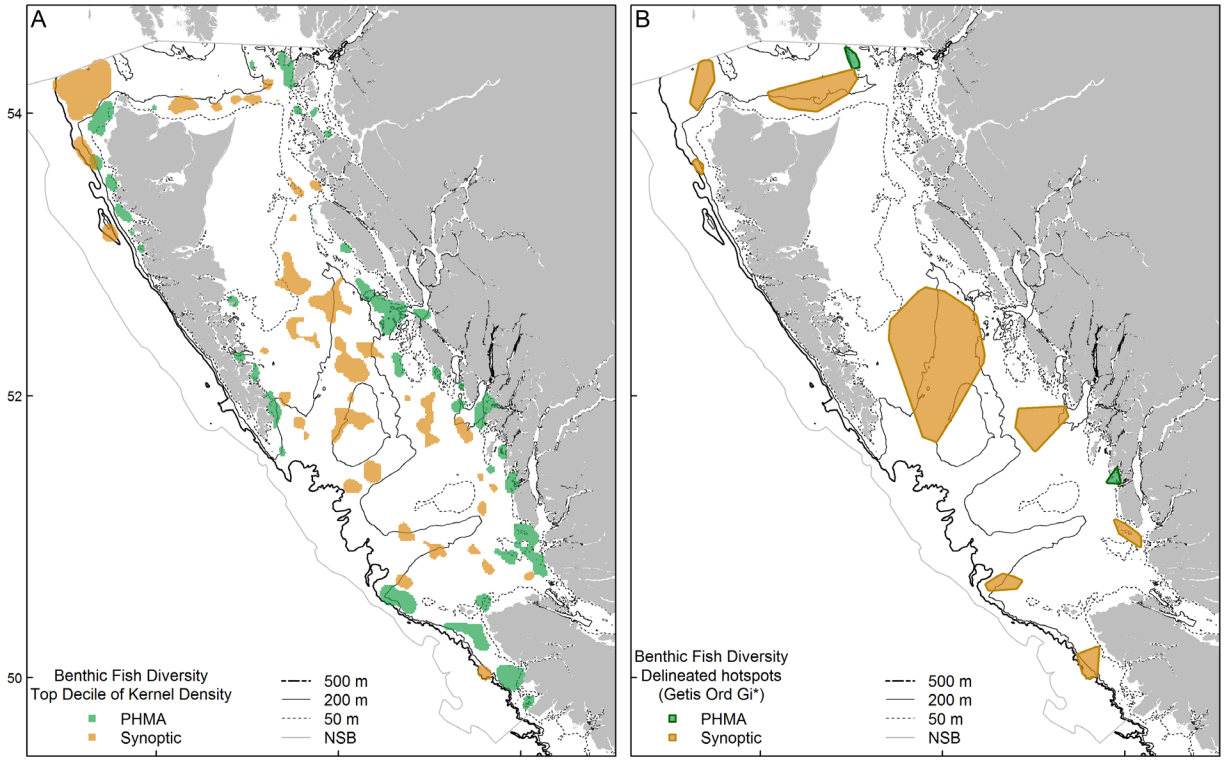

Figure 28. Summary of benthic fish diversity hotspots (Shannon index) in the NSB, for PHMA longline surveys (green) and synoptic trawl surveys (gold). A) top percentiles of kernel density estimates; B) polygons delineating groups of ≥10 Getis-Ord Gi hotspot points.*

3.3.1.3 Benthic invertebrate diversity hotspots

The KDE top decile and Gi* hotspot results for benthic invertebrate diversity are shown in Figure 29. We only had the synoptic survey to assess invertebrate diversity patterns in NSB. Similar to the fish diversity analysis, the KD top decile approach identified more hotspots that covered less area than the Gi* hotspot approach (Table 7, Figure 29). The KDE top decile identified 36 hotspots that covered 6,357 km^2 covering 6.3% of the area of NSB, whereas the Gi* approach identified 12 hotspots that covered 8,394 km^2 covering 8.3 % of the NSB. In general, both methods identified similar areas with a large hotspot in Moresby Trough and smaller ones in the eastern area of Dixon Entrance on the north coast. Both of these areas overlap with the fish diversity hotspots, strengthening support that these areas are important for species diversity. Interestingly, there are lower than expected diversity levels ("cold spots") for invertebrates in areas that were identified as fish diversity hotspots off the northwestern coast of Haida Gwaii and along the continental slope west of Haida Gwaii. Several small invertebrate diversity hotspots were also identified in Queen Charlotte Sound.

Table 7. Summary of area covered by the top decile and hotspot analyses for areas of high benthic diversity.

-	Kernel Density Top Decile		Getis-Ord Gi* Hotspot (90-99% confidence)	
Analysis	**Area (km^2)**	**Percent of NSB**	**Area**	**Percent of NSB**
PHMA Fish	5256	5.2	188	0.2
Synoptic Fish	6640	6.5	9398	9.3
Synoptic Invertebrate	6357	6.3	8394	8.3

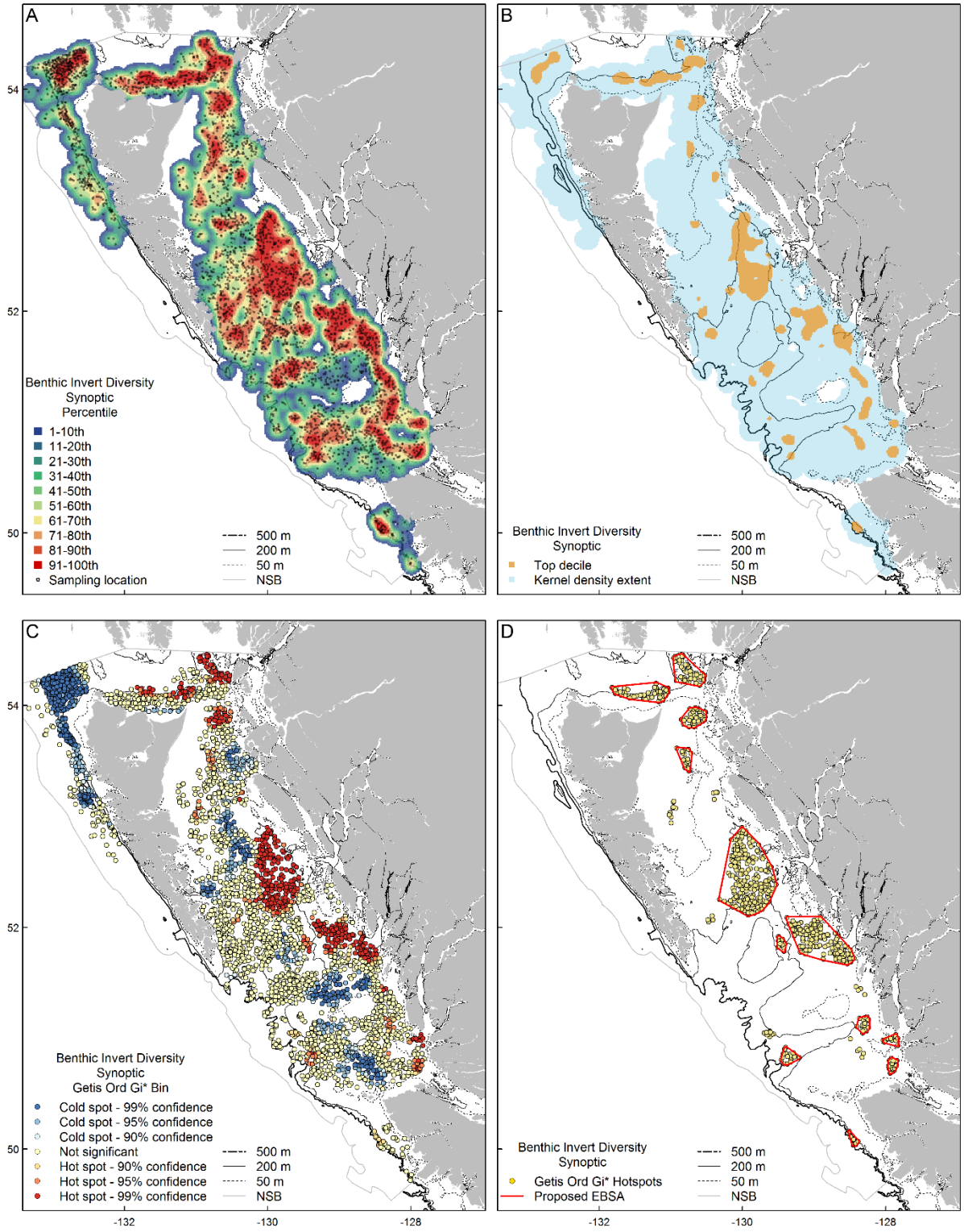

Figure 29. Benthic invertebrate diversity (Shannon index) in the NSB from the DFO synoptic trawl survey. A) kernel density estimate (KDE) of invertebrate diversity, reclassified into deciles; B) top decile of KDE from A; C) Getis-Ord Gi analysis outputs of invertebrate diversity, showing hot and cold spots; D) groups of hotspots (90–99% confidence) with ≥ 10 points from C, delineated with convex hull polygons.*

3.3.2 Areas of high biomass

To identify areas of high fish and invertebrate biomass, we summed the CPUE of all fish species and all invertebrate species caught within fishing events (tows) of the synoptic trawl surveys. PHMA longline survey data was not used for the biomass analysis because that catch is recorded as piece counts (individuals), and piece-to-weight conversion values were not readily available.

3.3.2.1 Fish biomass hotspots

The mean fish biomass was 1434.33 kg/hr with a maximum of 39364.64 kg/hr (Table 8). Maps of the hotspot analysis on fish biomass are shown in Figure 30. Areas of high biomass were located on the north coast on the east side of Dixon Entrance, the area just off the northwestern tip of Haida Gwaii, and the areas off northwestern Vancouver Island. These are also areas of high benthic fish diversity identified in the diversity hotspot analysis above.

Table 8. Biomass mean, standard error and range by trawl tow (synoptic surveys; kg/hr) by species group and survey type.

Analysis	Mean	Standard error	Range
Fishes – Synoptic trawl surveys	1434.3	38.4	19.9 – 39364.4
Invertebrates – Synoptic trawl surveys	21.4	1.1	0 – 2388.6

Similar to the diversity analyses, the KDE top decile approach identified more hotspots than the Gi* approach but, in contrast to the diversity analysis, here the KDE top decile also resulted in more total area identified as hotspots (Table 9). More hotspots that covered more area (6.5% of NSB area) were identified for the synoptic KDE top decile compared to the synoptic Gi* approach (6 hotspots, covering 3.4% of area of NSB). This highlights that the spatial hotspot method is more conservative when designating an area as a hotspot because not only does a site have to have a high biomass value, sites within a 10 km radius also have to have a high biomass value that deviates from what is expected under random circumstances. Another factor contributing to the lower number of hotspots using the Gi* method when compared to the KDE top decile method for all metrics and comparisons, is the rule-based criteria for delineating hotspots using the minimum convex polygon. Our method only selected hotspots for inclusion in a hotspot polygon if there were more than 10 sites in a cluster. There were no rules applied about the number of sites needed for an area to be highlighted in the percentile method. Therefore, in some cases as few as two points could be driving the observed pattern.

Table 9. Summary of area covered by the top decile and hotspot analyses for areas of high biomass.

-	Kernel Density Top Decile		Getis-Ord G* Hotspot (90-99% confidence)	
Analysis	**Area**	**Percent of NSB**	**Area**	**Percent of NSB**
Fishes – Synoptic trawl surveys	6641	6.5	3474	3.4
Invertebrates – Synoptic trawl surveys	6605	6.5	1469	1.4

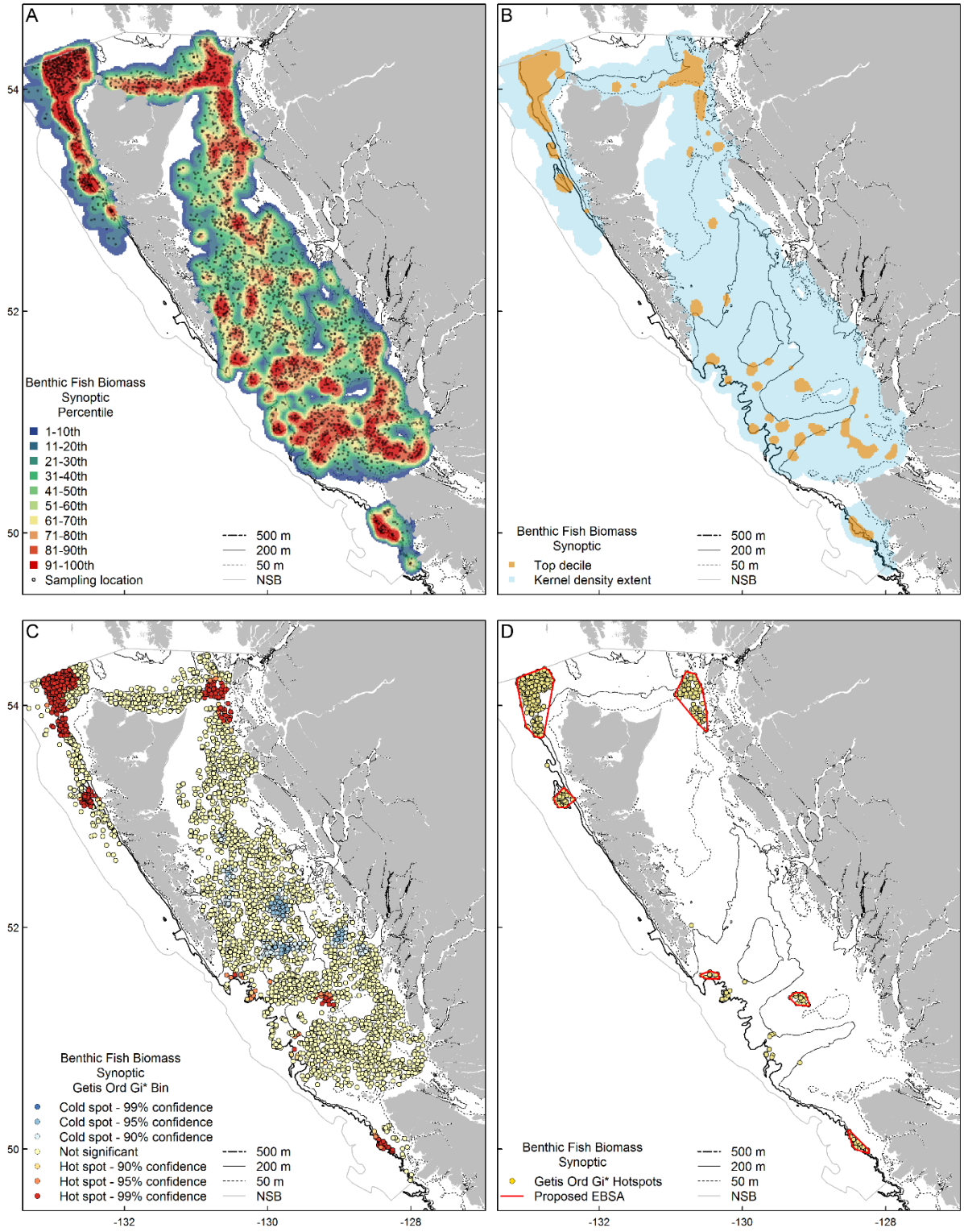

Figure 30. Benthic fish biomass in the NSB from the DFO synoptic trawl survey. A) kernel density estimate (KDE) of fish biomass, reclassified into deciles; B) top decile of KDE from A; C) Getis-Ord G analysis outputs of fish biomass, showing hot and cold spots; D) groups of hotspots (90–99% confidence) with ≥ 10 points from C, delineated with convex hull polygons.*

3.3.2.2 Invertebrate biomass hotspots

The mean invertebrate biomass for the synoptic trawls was 21.42 kg/hr with a maximum of 2388.64 kg/hr.

Invertebrate biomass hotspots were identified in the waters off the northwestern tip of Haida Gwaii (Figure 31) in a similar area to the benthic fish diversity hotspot and the fish biomass hotspots from both approaches and surveys (Figure 28, Figure 30, Figure 31). Interestingly, this area was identified as an invertebrate diversity “cold spot” from the Gi* method (Figure 29) highlighting that despite the fact that this is an area important for invertebrate productivity, it is not an area with high species diversity. The opposite was true for the slope off the west coast of Vancouver Island. This area was identified as an invertebrate diversity hotspot by both the Gi* and KDE top decile method (Figure 29), but it is not highlighted as an area of high invertebrate biomass by either method (Figure 31). The same area is identified as both a fish biomass and diversity hotspot (Figure 28, Figure 30).

Other areas identified as invertebrate biomass hotspots include the area on the eastern side of Dixon Entrance off the north coast and two areas in Moresby Trough (also an invertebrate diversity hotspot). Similar to the fish biomass hotspot analysis, the KDE top decile method resulted in more hotspots (n=38) that covered more area of the NSB (6.5%) than the Gi* method. The Gi* method resulted in six invertebrate biomass hotspots that covered only 1.5% of the area of NSB.

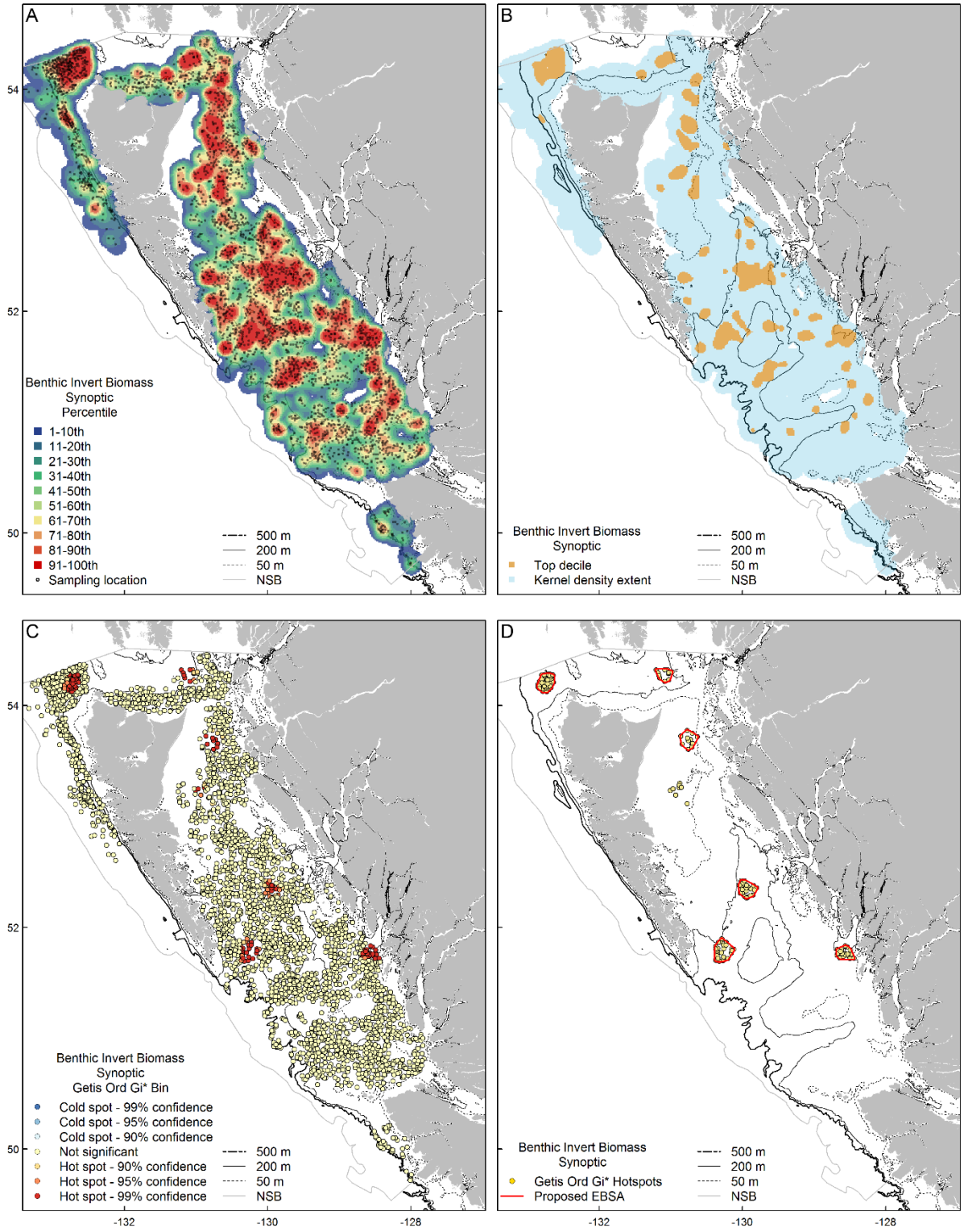

Figure 31. Benthic invertebrate biomass in the NSB from the DFO synoptic trawl survey. A) kernel density estimate (KDE) of invertebrate biomass, reclassified into deciles; B) top decile of KDE from A; C) Getis-Ord G analysis outputs of invertebrate biomass from the DFO synoptic trawl survey, showing hot and cold spots; D) groups of hotspots (90–99% confidence) with ≥ 10 points from C, delineated with convex hull polygons.*

3.3.2.3 Primary production hotspots

The surface primary productivity indices, mean ChlA concentration and bloom frequency, exhibited similar spatial patterns within the NSB (Figure 32). Both indices exhibited lower ChlA concentration near the shelf break and higher productivity in nearshore area. McIntyre Bay, Dogfish Bank, Chatham Sound, Caamaño Sound, Milbanke Sound, Queens Sound, Fitz Hugh Sound, Queen Charlotte Strait and Brooks Bay were areas identified as primary productivity hotspots by both indices and Dixon Entrance was identified as a primary production hotspot by the bloom frequency index. Areas of high primary production in the coastal and inlet areas were not evaluated because of gaps in the satellite data caused primarily by cloud cover.

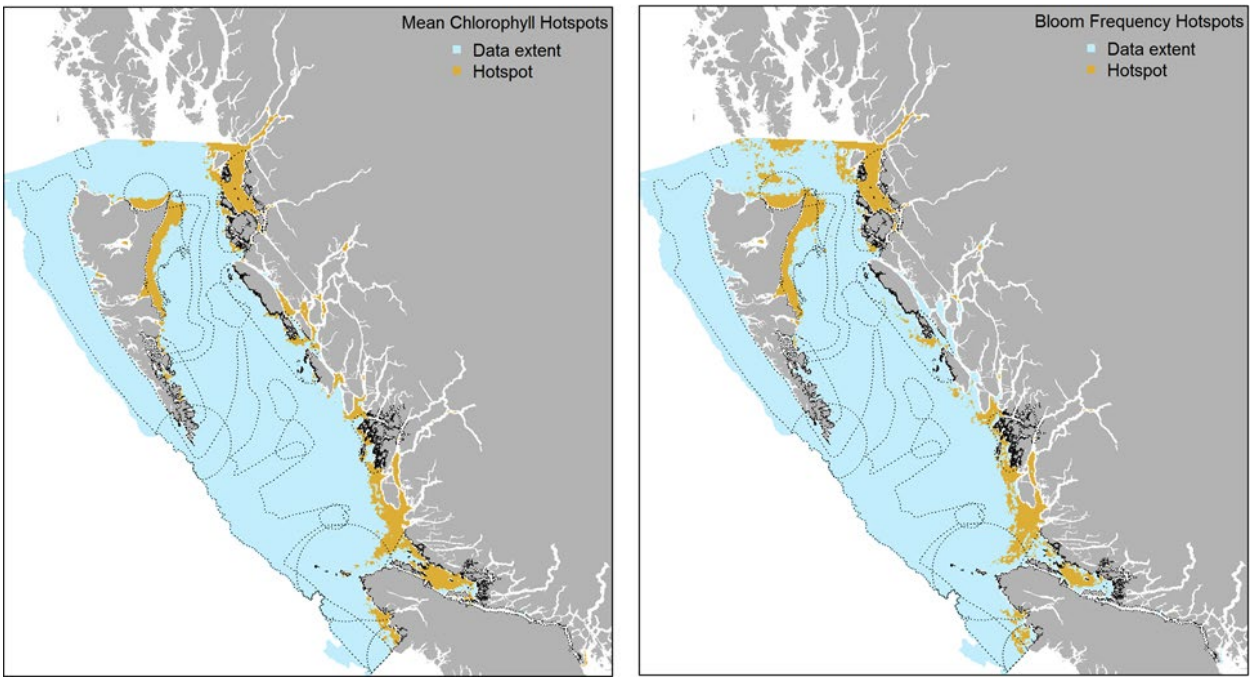

Figure 32. Hotspots of primary production derived from the top decile of mean chlorophyll A concentration (left) and the frequency of monthly plankton blooms (right) in the Northern Shelf Bioregion. Productivity indices were derived from surface chlorophyll data from the MODIS satellite at a resolution of 1 by 1 km. ESBA boundaries demarcated by the dotted lines.

3.4 PART 2 CONCLUSIONS AND DATA LIMITATIONS

In Part 2 of this paper, we provide maps of areas that fulfil the high biodiversity and high productivity EBSA criteria. This includes maps of: 1) nearshore areas of high habitat richness; 2) areas of high productivity (primary productivity, fish and invertebrate biomass hotspots), and 3) areas of high benthic species diversity (benthic fish and invertebrate diversity hotspots).

For the fish and invertebrate analyses, we presented two methods for identifying hotspots, defined as areas with a higher relative diversity or biomass. One area, the eastern side of Dixon Entrance, was the only area identified as important for both diversity and productivity for fish and invertebrates. Although not formally tested, the overlap in areas of high biodiversity and high productivity suggest links between diversity and ecosystem function (Duffy et al. 2007, Danovaro et al. 2008, Fisher et al. 2010). However, areas of overlap between diversity and biomass hotspots were not consistently observed across the NSB. For example, the western side of Dixon Entrance off north western Haida Gwaii was identified as an invertebrate biomass hotspot but the same area showed lower species diversity than expected by chance, suggesting that the high biomass in the area is dominated by few species. Similarly, the Moresby Trough area was identified as a fish and invertebrate diversity hotspot, but it was not generally recognized as high biomass hotspot. Low overlap between areas of high diversity and areas of high abundance was also observed in invertebrates on the Scotian Shelf (Ward-Paige and Bundy 2016), whereas similar to our analysis, Ward-Paige and Bundy (2016) observed higher overlap between areas of high fish biomass and fish diversity. More research on the links between the diversity and biomass hotspots, including an analysis of the species composition at the high biomass sites, will increase our understanding of what is driving the observed spatial patterns in diversity and productivity in the NSB. In addition, linking our results to patterns in primary productivity will also provide increased understanding of the observed patterns, and how they may change seasonally and over time.

3.4.1 KDE threshold versus spatial hotspot approach

The two hotspot approaches generally identified similar regions, but the spatial hotspot approach (Gi*) was more conservative in the number of areas that qualified as a hotspot. The utility of each hotspot approach depends upon the research objective. If the objective is focused on highlighting a species' distribution or core-use areas, then the KDE threshold approach is useful because the user can define the threshold based on the research objective and the ecology of the species. In some cases, a lower threshold or more than one threshold may be selected. For example, a study mapping hotspots for seabirds selected a top 25% density threshold to identify "core areas" and the top 50% density to delineate "shoulder areas" (Nur et al. 2011). Alternatively, if the objective is focused on highlighting the most important areas (based on the metric of interest), like in this study, as opposed to the range of values across space, then the Gi* approach has some advantages. First, the Gi* approach is more objective because it accounts for spatial patterns in the data and not a single user-defined cut-off point. It also provides a confidence value associated with the hotspot delineation, allowing for an assessment of uncertainty associated with the resulting hotspots, something that is lacking in the threshold approach. We conclude that both approaches are useful methods for identifying high use, aggregations or hotspots to inform the EBSA process. In a concurrent analysis, the data compiled for this study has applied the KDE top decile method to groundfish Ecologically Significant Species to identify core-use areas that could update the IAs for these species.

3.4.1.1 Limitations

The results of our analyses are limited by the input data and all of our analyses are focused on demersal or benthic organism so pelagic species are not considered. We assume that the

multispecies bottom trawl surveys sample a representative sample of the benthic fauna within the survey extent. However, we know that trawl surveys select larger organisms (small fish and invertebrates are missed) and therefore our analysis is biased towards larger fishes and invertebrates that are captured in trawl gear. As a result, our diversity estimates are lower than the true benthic diversity. However, given the trawl survey is standardized across the study region, it provides a relative measure of benthic diversity (and biomass) for comparison across space. Second, we know the synoptic trawl surveys actively avoid specific areas (Figure A 2) that may be important to species diversity and productivity. These are areas known to be vulnerable to trawl gear (coral aggregations, sponge reefs) and areas with rough and rocky terrain. Known coral aggregations (e.g., Learmonth Bank) and sponge reefs have been incorporated into EBSAs through targeted mapping and survey efforts, however areas of rough and rocky terrain that may have high productivity and biodiversity could be missed. Further research and the development of ecological models to better understand the distribution of diversity in NSB, including the influence of habitat variables, is needed to fill these gaps in sampling. Finally, it is important to note that the estimates of areas of high biomass in this analysis are derived from fishery-independent data and do not account for fishing pressure. Therefore, some areas of high productivity may be missed because of biomass extraction rates.

We compare two different survey types (different gear but also different units of CPUE; PHMA catches are recorded as counts and the trawls are recorded as weights) that are spatially complementary but have little spatial overlap. While we reclassify these surveys so they are internally comparable and then compare between them based on their ranks (i.e., deciles), we assume that a fish diversity hotspot from a longline survey is of similar importance to a fish diversity hotspot from a trawl survey, even though the magnitude of captures at those hotspots can be very different. Our results show that many of the hotspots from both surveys are overlapping, adjacent, or in close proximity, providing some support that this assumption is met.

The nearshore habitat richness analysis is also limited by the input data. The uncertainty and known gaps associated with the canopy-forming kelp, eelgrass meadow, and estuary layer are summarized in Rubidge et al. (in revision)[3]. As with all our analyses, hotspots will only be identified where data exist, and there are known gaps and uncertainty associated with all habitat layers used in this analysis. However, despite those limitations, the resulting habitat richness layer provides an initial assessment of habitat heterogeneity on BC's coast and fills a spatial gap from the previous process that did not complete a comprehensive EBSA analysis of nearshore areas in NSB. The habitat hotspot approach also provides an alternative for mapping biodiversity when species-specific survey data is unavailable. Finally, the habitat richness layer also highlights areas where multiple nearshore ecosystems are in close proximity allowing for nutrient exchange between different ecosystems (e.g., kelp forests and soft sediment beaches); an important consideration for sea-scape connectivity (Liebowitz et al. 2016) and MPA network design in NSB[4].

[4] Martone, R., Robb, C., Gale, K.S.P., Frid, A., McDougall, C., and Rubidge, E. in revision. Design Strategies for the Northern Shelf Bioregional Marine Protected Area Network. DFO Can. Sci. Advis. Sec. Res. Doc.

4 UPDATE TO SPONGE REEF EBSA

Sponge reefs were discovered in the NSB in the late 1980's (Conway et al 1991), and four areas were proposed as "Sponge Reef EBSAs" in 2006 by Clarke and Jamieson (2006a) given their uniqueness and ecological importance. In the original assessment against the DFO EBSA criteria, sponge reefs ranked high in Uniqueness, Aggregation, and Naturalness, and very low in Resilience. All four sponge reef areas were designated as EBSAs at the CSAS Peer Review Process in 2012 (DFO 2013). Since 2006, other areas have been identified as having the sponge reef geological signature (most recently in the Chatham Sound area, Figure 33; Shaw et al. 2018). Ecological surveys of geologically identified reefs throughout the NSB are underway and results indicate that the amount of live sponge present varies from area to area; however, only a small fraction of the geological reef area in NSB has been surveyed to date (A. Dunham, pers. comm.). Besides the reefs' ecological importance, which is well documented, the geological signature for the reef structure alone is enough for these areas to be designated EBSAs given their global uniqueness (Krautter et al. 2001). Therefore, we present an updated map of Sponge Reef EBSAs based on the geological signature of sponge reefs known to date in the NSB. We have buffered the geological signature reef polygons by 1 km to indicate the importance of sedimentation risk from nearby activities but the buffer size needed will vary greatly based on the area of live sponge on the reef, the substrate type surrounding the live sponge, and the currents (Tompkins-MacDonald and Leys 2008, Boutillier et al. 2013, Leys 2013). Research on the status of sponge reefs in the Pacific Region is ongoing and will be critical in informing management about how to protect and monitor these unique ecological communities[5] (DFO 2017).

[5] Dunham, A., Mossman, J., Archer, S., Davies, S., Pegg, J., Archer, E. In press. Glass sponge reefs in the Strait of Georgia and Howe Sound: Status assessment and ecological monitoring advice. DFO Can. Sci. Advis. Sec. Res. Doc.

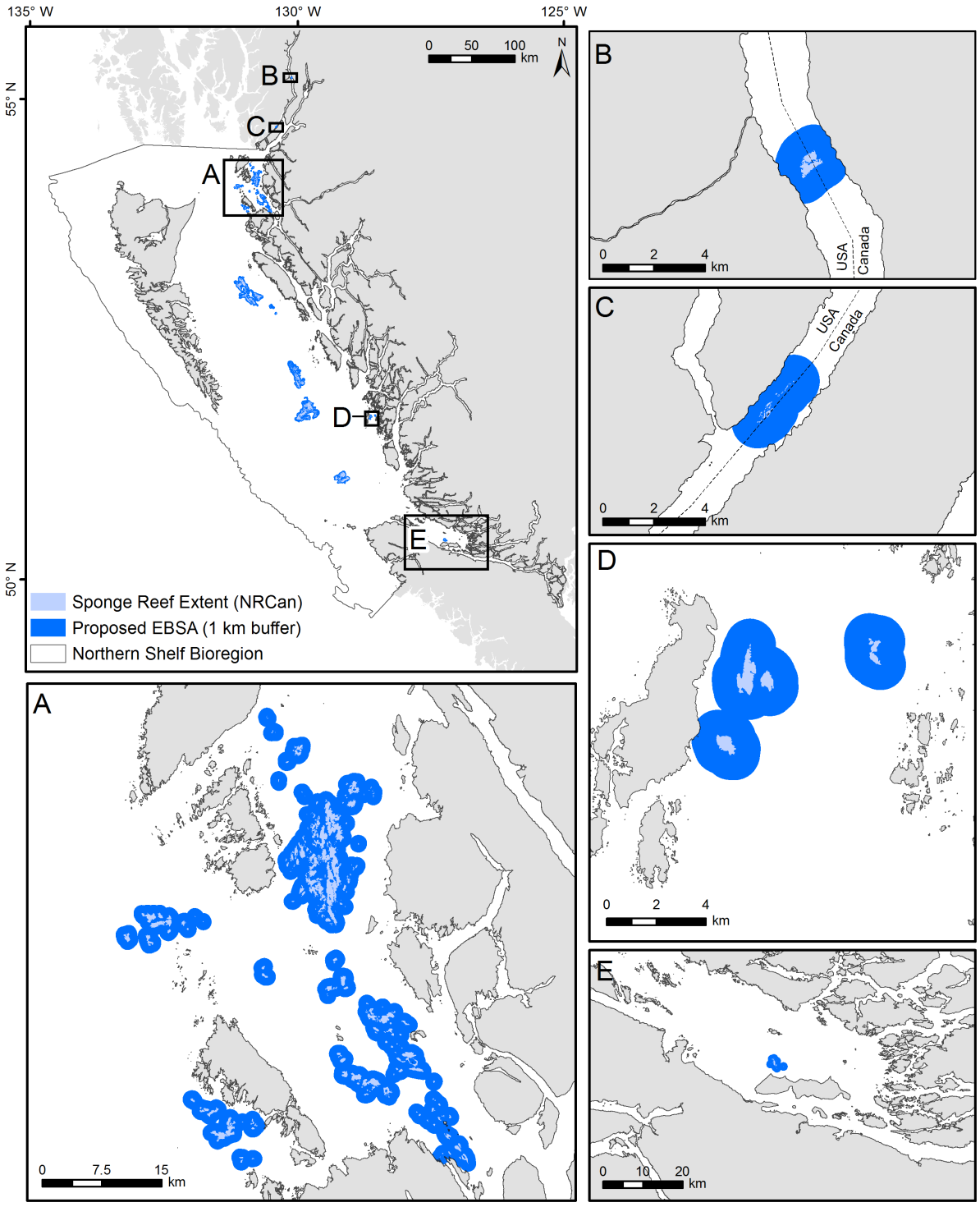

Figure 33. Extent of proposed updated Sponge Reef EBSA, which includes a 1 km buffer around all known hexactinellid sponge reef complexes in the NSB, as identified through multibeam signatures. Insets show updates to Sponge Reef EBSA from Clarke and Jamieson 2006a. A) Chatham Sound, B) Portland Canal, C) Pearse Canal, D) Central Coast, and E) Johnstone Strait.

5 DISCUSSION

Here we assessed the existing EBSAs with empirical data and identified important areas for biodiversity and productivity, two EBSA criteria that were not previously quantitatively assessed. Based on the literature and our results, we found both the KDE threshold and spatial hotspot approaches are appropriate to apply to species-specific data to highlight areas of importance for aggregation and "core-use" areas. To complete the EBSA reassessment analysis, we compiled and summarized multiple biological datasets. Now that the datasets are error-checked and compiled, they can be used in future analyses, to update existing DFO Important Areas for a number of species using the same approaches described in this paper for identifying areas of high diversity and productivity.

5.1 EXISTING EBSAS AND BOUNDARY REFINEMENT

The evaluation of the existing EBSA boundaries with available empirical data highlighted the ecological importance of these areas and overall supported the previous expert driven EBSA process. In general, the existing EBSA boundaries capture areas important to multiple species, including those listed in the original assessment as well as additional species not originally recognized. Furthermore, a recent study mapping marine mammal hotspots (Harvey et al. 2017) provided additional evidence that several EBSAs capture areas important for marine mammals similar to what we found here. The use of available empirical data to examine support for the existing EBSAs highlighted core areas within the existing EBSA boundaries that have both expert knowledge and empirical support for their ecological importance. However, despite the empirical support for the existing EBSAs, the shape and configuration of the EBSA boundaries often miss important areas (e.g., Hecate Strait Front), or appear larger than necessary to capture the ecological components within (e.g., Continental Slope EBSA). In addition, much of the information collected in Phase I of the previous EBSA process is difficult to track through to Phase II despite efforts for annotations and metadata by the authors (Clarke and Jamieson 2006a,b). This was due to the scale of the information collected from subject matter experts, which is too broad to support management decisions at finer scales within the EBSA boundaries.

DFO (2011) science advice recognizes the challenges with EBSA boundaries and scale considerations and recommends the inclusion of the EBSA subcomponents or properties (i.e. the important species, or features that meet the EBSA criteria) contributing to each map unit within the final EBSA map. For example, this can be done with a feature count or heat map approach (Wells et al. 2017), but the key is that the database of spatial layers used to develop the resulting EBSAs is readily available to managers once complete (via the Federal Geospatial Platform) so they can risk-manage human impacts within the EBSAs. Science advice recognizes that the hard boundaries of EBSAs are less important and can be "transparent" (DFO 2011) as the heat map or optimization approach reveals the transition from areas that are important to multiple features to areas that are important to fewer species. The feature count approach was conducted for the IAs identified by Clarke and Jamieson (2006a) but the underlying expert driven IAs were drawn at such a broad-scale that it was difficult to interpret the resulting map. The data compiled in Part 1 of this paper, in 5 x 5 km grids, can be used to highlight the core areas within the existing EBSAs that are important to the species with datasets available and used to develop heat maps to highlight areas important to multiple species and species groups.

5.2 MAPPING ECOLOGICAL HOTSPOTS

There has been some controversy surrounding the biodiversity hotspot approach to conservation prioritization (Kareiva and Marvier 2003, Cardillo et al. 2006), however, this mainly

relates to the strict definition of “biodiversity hotspot” which incorporates endemism and threat. We use the term “hotspot” more generally, to describe areas with higher relative values of diversity and productivity. Criticism against the more broadly defined “hotspot” term also exists and centres around the assumed static nature of these areas when in reality, particularly in ocean environments, they are likely to move seasonally and/or annually. Our analysis would be improved by incorporating a temporal component to determine how these hotspots change over time. In the Scotian Shelf, Ward-Paige and Bundy (2016) were able to examine patterns in diversity and abundance metrics over four fishing eras (defined by 6–19 year blocks) from 1970–2013 using DFO standardized trawl surveys. They found that the size and location of the hotspots changed over time however the Bay of Fundy was consistently identified as an area of high diversity across all four fishing eras (Ward-Paige and Bundy 2016). Further research is needed to compile datasets prior to 2003 in the Pacific Region for a temporal comparison of diversity and productivity to increase our understanding of temporal changes in the identified hotspots and areas that are consistently important over time. Analysis across seasons would also give insight to areas important for certain life history processes of focal species. Finally, a temporal analysis would also allow us to better understand future movements under climate change.

In our analysis, we used kernel density estimation to produce smooth interpolated surfaces of density and diversity. This approach is limited by the spatial coverage in sampling and does not incorporate any correlative analysis of environmental features that may improve the modelled surface. A next step for this analysis to better understand and predict species diversity and density patterns is to include environmental variables in an ecological model to improve our estimates of diversity and density across space. These models can be relatively simple examining few environmental variables (e.g., Tolimieri 2007) or more complex where multiple environmental variables are integrated in a machine-learning ecological model (e.g., Nur et al. 2011). In addition to incorporating environmental predictors into our modeled surface of density or diversity, we would also examine species richness and evenness separately. We completed the analysis for species richness and evenness but only presented the Shannon index (which incorporates both components of diversity) results here. The Shannon index is useful for providing a simple summary of diversity but it makes it difficult to compare communities that differ greatly in richness. Future efforts to map diversity, using similar methods as presented here, should include species richness and evenness metrics separately, but also measures of functional and phylogenetic diversity to ensure all levels of diversity are captured.

5.3 UNCERTAINTY AND GAPS/LIMITATIONS

A considerable gap in the EBSA process in NSB is the incorporation of First Nations and Local Ecological Knowledge (FNK, LEK), a gap that was not addressed in the reassessment analysis. Here, we focused on examining EBSA support with empirical datasets, but EBSAs will also be improved with input from local and First Nations knowledge. Currently there is an effort underway in the Pacific Region, to develop and update numerous marine spatial datasets for the MPA network planning process in the NSB. A subset of these, particularly those where little or patchy empirical data exist, will be a good starting point for FNK/LEK input to ensure data gaps are filled where possible. These updated layers can then be used in future EBSA information updates.

As previously discussed, our analysis is limited by the spatial coverage and quality of the data used. We have reported the limitations of our analyses for Part 1 and Part 2 of this paper in sections 2.5 and 0 respectively. Other gaps include species specific gaps like Olympia Oyster, Green Sturgeon, and Northern Fur Seal. For most of these, there are little empirical data available. Another gap in our analysis is the lack of assessment of existing EBSAs against the

Naturalness criterion. Naturalness, represented by areas that exhibit little to no anthropogenic pressure, is considered a secondary criteria or EBSA dimension that can be applied to prioritize areas after the other EBSA criteria are met (DFO 2004, 2011). Relative naturalness across the NSB is a difficult criterion to quantify without an effort to map all human activities across the planning region to highlight areas with lower anthropogenic pressure. Cumulative impacts research can inform the process on the varying degree of impacts to different habitat types across NSB (Ban et al. 2010, Murray et al. 2015), however, a simple index of the number of human activities per map unit would be a more straightforward way to identify areas of higher relative naturalness. Currently, there is an effort underway to map human use in the ocean to inform the MPA network planning process, and as part of the DFO Sciences' Ecosystem Stressors Program (Murray and Rubidge et al. in prep). Once complete, this dataset can be used to highlight areas that have higher relative naturalness to inform the EBSA process.

Communicating the impact of uncertainty in spatial data and spatial predictions is a difficult challenge, and a growing area of research and method development (e.g., Wenger et al. 2013, Gould et al. 2014). Although we have included a general description of the limitations and uncertainty in our analyses, we have not provided uncertainty maps for each data layer. DFO Science Advice recommends to include information about areas with no data (DFO 2011) and we have done this by including sampling maps showing gaps in sampling (Figure A 1) and untrawlable areas (Figure A 2) as well as explicitly showing areas with no data in maps included in figures 5 through 18.

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APPENDIX A. DATA SOURCES

1. DFO Synoptic Trawl Surveys

Since 2003, DFO Groundfish has carried out standardized, depth-stratified random bottom trawl surveys, referred to as synoptic surveys, in four regions of BC that cover the continental shelf of BC: West Coast Haida Gwaii (WCHG), Hecate Strait (HS), Queen Charlotte Sound (QCS), and West Coast Vancouver Island (WCVI). Synoptic surveys began in QCS in 2003 (Olsen et al. 2007), WCVI in 2004 (Workman et al. 2008a), HS in 2005 (Workman et al. 2008b), and WCHG in 2006 (Workman et al. 2007), and continue to be conducted in even-numbered years (WCVI and WCHG) and odd-numbered years (QCS and HS).

The following methods are summarized from the above sources as well as more recent survey reports (Williams et al. 2017, Nottingham 2018a,b,c).

The extent of the synoptic survey dataset is shown in Figure A 1. The synoptic surveys do not include inlets, enclosed waters, sensitive habitats (e.g., Hecate Strait glass sponge reefs, Learmonth Bank Red Tree corals, Rockfish Conservation Areas), areas that are not trawlable (Figure A 2), or the steep slope off the southwest part of Haida Gwaii. All species caught are weighed or counted and identified to the lowest possible taxonomic level.

The surveys follow a stratified random design, with each of the regions being split into depth and area strata. A proportional random sample of 4 km^2 (2 km x 2 km) grid cells within each stratum are selected to be surveyed. Depths between 50 and 500 m are divided into 4 depth strata in all regions except WCHG, where the depth range is 180–1300 m. The target tow duration is 20 minutes, except tows > 500 m in WCHG that are 30 minutes. The standard gear is an Atlantic Western IIA box trawl with 5 inch mesh.

Data was extracted from DFO's GFBio database on 28 November 2016, limiting the query to records quality-tagged as "fully usable". The synoptic dataset spans July 2003–June 2016, and includes samples from May–October, but most are from May–July.

2. PHMA Longline Surveys

The Pacific Halibut Management Association (PHMA) surveys are standardized, depth-stratified random longline surveys that are carried out at depths of 20–260 m (Archipelago Marine Research Ltd. 2002). All species caught are weighed or counted and identified to the lowest possible taxonomic level. The PHMA longline survey uses the same methods as the inshore rockfish survey that occurs in Johnstone Strait and the Strait of Georgia (Lochead and Yamanaka 2004); as of 2018, these two surveys are collectively referred to as the Hard Bottom Longline Survey (M. Surry, pers. comm.).

Data was extracted from DFO's GFBio database on 18 April 2017, limiting the query to records quality-tagged as "fully usable". The PHMA dataset spans August 2006–August 2016 and includes records taken in the months of August and September. The extent of the PHMA survey dataset is shown in Figure A 1.

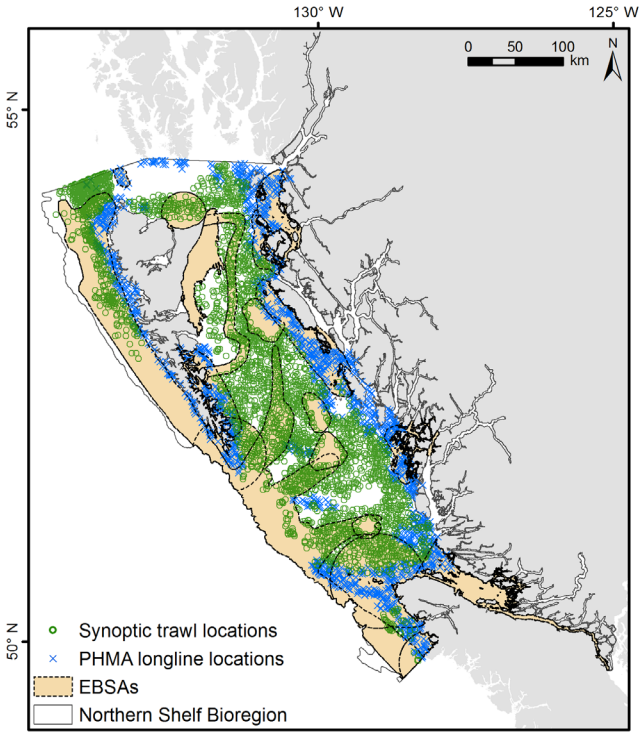

Figure A 1. Extent of the DFO synoptic trawl surveys and Pacific Halibut Management Association (PHMA) longline surveys in relation to existing EBSAs (Clarke and Jamieson 2006b) in the Northern Shelf Bioregion.

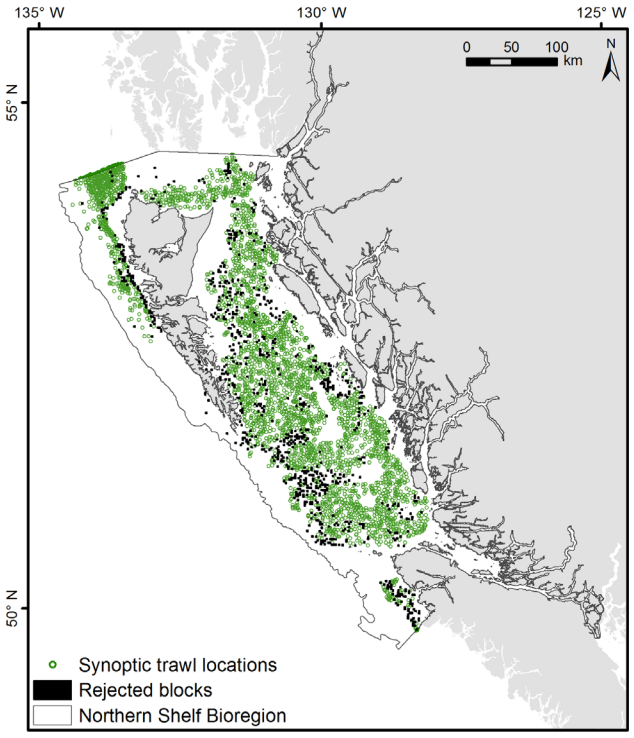

Figure A 2. Areas determined to be untrawlable ("rejected blocks") by DFO Groundfish for the synoptic trawl surveys.

3. DFO Pacific Herring Spawn Habitat Spawning Index

For a description of the Spawn Habitat Index see Section 2.2.1.

4. DFO Cetacean Program

Data was sourced from DFO Pacific Region's cetacean database. The database holds information from 48 at-sea surveys between 2002 and 2017. It contains information on the position of the vessel, the estimated detection distance from the vessel, the estimated position of the cetacean sighted, the number of individuals seen, the species identified and a number of other attributes. For details on how the cetacean data was processed see Section 2.2.4.

5. Raincoast Conservation Foundation

Raincoast Conservation Foundation carried out marine mammal surveys within the Northern Shelf Bioregion between 2004 and 2008. They recorded observations of nine marine mammals along standardized transects. Density estimates (number of individuals per km^2) of marine mammals were calculated by Raincoast at every nautical mile along transects using a Multiple Covariate Distance Sampling method (Williams and Thomas 2007, Best et al. 2015, Harvey et al. 2017). Data can be viewed and downloaded from OBIS-SEAMAP.

6. North Pacific Pelagic Seabird Database 2.0

The NPPSD 2.0 contains observations of marine birds and mammals within the North Pacific (Drew et al. 2015). The database is a collection of survey data from a number of different sources collated by the U.S. Geological Survey (USGS). NPPSD 2.0 contains 235,545 observations of marine mammals within the North Pacific between 1973 and 2012. Cetacean observations within BC for our cetacean species of interest (see Section 2.2.4) occurred between 1994 and 2010. Density estimates (number of individuals per km^2) of cetaceans were calculated by dividing species counts by the area sampled: transect length (1 km segments) multiplied by the estimated detection distance from the vessel. Data is available from USGS.

7. BCMCA Marine Mammal Workshop

The British Columbia Marine Conservation Analysis (BCMCA) provides analyzed spatial data about Canada's Pacific Ocean. BCMCA sourced the Sea Lion locations from the UBC Marine Mammal Research Unit and Sea Otter data from DFO. BCMCA processed the data which was reviewed and recommended at their Marine Mammals Experts Workshop. Data can be viewed or downloaded from bcmca.ca.

8. BCMCA Seabird Workshop

BCMCA provides analyzed spatial data about Canada's Pacific Ocean. BCMCA collated and analyzed seabird colony data derived from the Canadian Wildlife Service (CWS) and Parks Canada nesting bird colony databases. The databases include locations of known seabird breeding colonies in BC (Harfenist et al. 2002, Canadian Wildlife Service 2008). BCMCA processed the data which was then reviewed and recommended at their Seabird Experts Workshop. Data layers and metadata representing colonies for species of interest can be viewed at bcmca.ca.

9. Commercial groundfish bottom-trawl harvest logs

Since 1996, BC has had observers recording by-catch on all bottom-trawl fisheries (Ardron and Jamieson 2006). Groundfish bottom-trawl fishery observer records between 2007 and 2017 were pulled from the DFO Groundfish Fisheries Operations System (FOS) database.

10. DFO Shrimp Research Surveys

Fishery-independent swept-area trawl surveys are used for stock assessment purposes at index sites (DFO Shrimp Trawl IFMP 2014).

11. DFO Prawn Research Surveys

Stocks are monitored through fishery-independent surveys that gather data on growth, mortality, sex-ratio, and escapement (Boutillier and Bond 2000). Fisheries observers take biological samples of commercial catches, which DFO uses to estimate stock status.

12. DFO Geoduck Research Surveys

Geoduck dive surveys use randomly-placed transects within geoduck beds, with systematic sub-sampling of quadrats along each transect. Geoduck and horse clam numbers, as well as dominant algal species and dominant substrate types are recorded (Bureau et al. 2012).

13. DFO Abalone Research Surveys

Northern Abalone are monitored through SCUBA surveys at long-term index sites located in areas of known abalone habitat (COSEWIC 2009). Surveys followed the 'Breen' protocol, which uses a $1m^2$ quadrat for sampling (DFO 2016). Transects began at the upper edge of abalone habitat, and 16 quadrates were surveyed at depths between approximately 0 and 7m (DFO 2016). The location of sites where abalone were present were obtained from the DFO Abalone database for surveys between 2001 and 2016.

14. DFO Crab Research Surveys

DFO uses commercial style circular metal Dungeness traps (90 cm diameter, 26 cm high) with closed escape ports. Traps are baited with herring and soaked overnight for approximately 24 hours (Dunham et al. 2011).

15. DFO Sea Cucumber Research Surveys

Surveys are carried out by divers at randomly determined transect locations at each survey area. Number of Red Sea Cucumbers, substrate, and dominant algae are recorded at 5 m intervals along a 4 m wide swath from 18 m depth to the water's edge (Duprey et al. 2011).

16. DFO Red Sea Urchin Research Surveys

Within PFMA sub-areas of interest, survey locations are chosen on a marine chart and transects are systematically placed along the shoreline with a random starting point (Atkins et al. 2006). Areas of unsuitable substrate (sand and mud) were excluded from the survey areas. Transects were placed from shallow water to 15 m depth, which were then surveyed from deep to shallow. Along the transects, depth, substrate type, number and size of Red Sea Urchins, algae species and percent cover, as well as size of Northern Abalone, Green and Purple Sea Urchins were recorded within 1 m^2 transects.

17. DFO Green Sea Urchin Research Surveys

DFO Green Sea Urchin survey data are counted and measured in 1-m quadrat along the length of transects, which were placed perpendicular to the shore or to depth contours, from 10 m below low water line up to low water line (DFO 2015). The exact number of quadrats, the method of subsampling along transects, and the practice of subsampling within quadrats has been modified several times since 2002 to reduce the time-intensity of the design. Algae and substrate are also recorded.

18. DFO Scallop Research Surveys

As part of the exploratory fishery, surveys are required for each fishing location to assess local scallop biomass (DFO 2011).

19. DFO Clam Research Surveys

Beaches to be surveyed were selected from charts, with preliminary assessments done for presence of Manila Clams (*Ruditapes philipparum*). Surveys were designed to maximize the number of beaches that could be surveyed during a tide, and are not rigorous stock estimates. Clam-bearing areas are identified and aggregations of clams were found by digging test holes. 0.25 m2 or 1m2 quadrats were dug out to about 15 cm. Other intertidal species of all taxa observed on the beaches are also identified and recorded (Gillespie et al. 2004a). The data includes observations of live species and the presence of shells.

20. DFO Tanner Crab Research Surveys

Research trawl surveys were carried out between 1999 and 2003, using a Campelen 1800 shrimp trawl with rockhopper footgear, and supplementary trap surveys were carried out between 1999 and 2001 with top-loading conical traps with 40 mm mesh (Gillespie et al. 2004b). Tanner crab research survey data were gathered in PFMAs 23, 101, 102, 123-127, 130, and 142. Incidental species were also recorded.

21. DFO World Class Tanker Safety System Dive

Five SCUBA surveys were carried out between 2012 and 2015 to collected information on substrate types and associated algae and marine invertebrate species in a variety of habitats[6]. The surveys covered nearshore and inlet areas on the south east coast of Haida Gwaii and on the north coast of BC from Banks to Aristazabal Island. Dive transects from 0 to 60 feet depth were laid perpendicular to shore and were randomly selected throughout the study area. The survey targets 102 invertebrate and 59 algae species or species groups. However, divers were also allowed to document non-target species if they could identify them.

22. DFO World Class Tanker Safety System ROV

Five remotely operated vehicle (ROV) surveys were carried out along the north central coast of BC to collect data on epibenthic species and habitats. Species observations from two of those surveys were available and utilized in this paper. The 2014 surveys were located within Douglas Channel, Caamaño Sound and the waters around Banks Island between 50 and 300 meters depth. ROV transects locations were sighted using a random stratified design using six benthic substrate classes for stratification. The ROV field of view was approximately 2 meters. Species

[6] Davies, S.C. et al. in press. Benthic habitat mapping surveys of the nearshore in the North Central Coast and eastern Haida Gwaii, British Columbia.

abundance and habitat type were recorded post-hoc at 10 second intervals. The dataset used for this analysis contained 2255 observations of 12 different species or species groups.

23. Shellfish Fisheries

Crab

The crab trap fishery takes place in most coastal areas of BC. Almost 100% of the fishery is for Dungeness crab, although Red Rock crab (*Cancer productus*) is permitted and two species of King crab are licensed to be caught in the North Coast. Other crab species may not be retained commercially, but octopus (*Enteroctopus dofleini*) may be retained. The number of traps, soak times, and trap sizes are regulated. Traps must have escape rings to reduce bycatch and undersized catch (DFO Crab by Trap IFMP 2015).

Tanner Crab

An experimental commercial Tanner Crab (*Chionoecetes tanneri*) fishery ran between 1999-2003. Several types of trap were used, including 70 mm mesh top-loading pyramidal traps with or without escape rings, and 40 mm mesh top-loading conical traps. Traps were set off West Coast Vancouver Island , West Coast Haida Gwaii and Dixon Entrance (PFMAs 101, 124, 125, 126, 127, and 142). Incidental species were also recorded (Gillespie et al. 2004b).

Geoduck and Horse Clam

Horse clams (*Tresus* spp.) are generally harvested incidentally while geoduck (*Panopea generosa*) are being fished. Geoduck and horse clams are harvested by divers within quota blocks along the majority of the BC coast. Beds in the North Coast and Gulf (inside waters) regions are divided into sub-areas that are harvested every three years, while those along the west coast of Vancouver Island are harvested annually (DFO Geoduck and Horse Clam IFMP 2015).

Green Sea Urchin

Green Sea Urchins are hand-harvested by divers only on the east coast Vancouver Island (PFMAs 12, 13, 18, 19) (DFO Green Sea Urchin IFMP 2013).

Prawn

The target species for the prawn trap fishery is Spot Prawn, with small commercial fisheries for Coonstripe (*Pandalus danae*, Sooke Harbour) and Humpback shrimp (*P. hypsinotus*, Prince Rupert Harbour and Masset Inlet). Other shrimp species, as well as octopus (*Enteroctopus dofleini*), are reported as incidental catch. Several types of traps are permitted, with minimum mesh sizes, maximum volumes, and acceptable escape mechanisms for bycatch and undersized prawns. Number of traps and soak times are also regulated. The fishery takes place nearshore, from 40-100 m depths (DFO Prawn and Shrimp by Trap IFMP 2014).

Red Sea Urchin

The Red Sea Urchin commercial fishery is a dive-based fishery that occurs at depths of 18 m or less (DFO Red Sea Urchin IFMP 2013). The fishery takes place along the North and South Coasts, West and East coasts of Vancouver Island, and coasts of Haida Gwaii (PFMAs 1-29, 101-111, 121, 123-127, 142). No incidental species are taken.

Scallop

The scallop by trawl is a small exploratory fishery, in the Northern Strait of Georgia only (PFMA 13 and 14). Trawl nets are limited to 2 m width, and since 2004 the trawl fishery is limited to > 20 m (DFO 2013).

Sea Cucumber

Sea cucumber is a dive fishery for *Parastichopus californicus*. Between 1997 and 2007 openings were limited to about 25% of the BC coast; this area has expanded since 2008 (DFO Sea Cucumber by Dive IFMP 2014). Once an annual fishery, the sea cucumber commercial fisheries have generally changed to a 3-year rotational fishery since 2011. No incidental species are taken.

Shrimp

The commercial shrimp trawl fishery targets pink shrimp (*Pandalus borealis* and *P. jordani*) and sidestripe shrimp (*Pandalopsis dispa*r). Coonstripe (*P. danae*) and humpback (*P. hypsinotus*) shrimp are caught in smaller numbers, and flexed shrimp (*P. goniurus*) are also permitted. Retention of incidental spot prawns (*P. platyceros*), squid (*Loligo opalescens*), and octopus (*Enteroctopus dofleini*) may be retained with conditions. Beam trawls fish in more sheltered areas and the larger otter trawls use larger nets and can fish offshore. The nets are required to be modified to reduce bycatch. Fishing occurs in all major inlets along the BC coast, including parts of PFMAs 1-21, 23-29, 101- 111, 121, 123- 125, 127, 130, and 142 (DFO Shrimp Trawl IFMP 2014).

24. Other DFO trawl or longline surveys

Other DFO trawl or longline surveys including Sablefish Research and Assessment, Hecate Multispecies Trawl, IPHC Longline, Inshore Rockfish Longline, Joint Can–US Hake, Hake Stock Delineation, Hecate Strait Pacific Cod Monitoring. For a description of these surveys see Rubidge et al. (2016).

25. Geological Survey of Canada

See description of sponge reef polygons produced by the Geological Survey of Canada in Section 2.2.2.

APPENDIX A REFERENCES

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APPENDIX B. SPECIES LIST

Table B 1. List of species and faunal groups used in the EBSA reassessment.

Group	Common Name	Scientific Name
Fishes	Arrowtooth Flounder	*Atheresthes stomias*
	Butter Sole	*Isopsetta isolepis*
	Dover Sole	*Microstomus pacificus*
	English Sole	*Parophrys vetulus*
	Lingcod	*Ophiodon elongatus*
	Pacific Cod	*Gadus macrocephalus*
	Pacific Hake	*Merluccius productus*
	Pacific Halibut	*Hippoglossus stenolepis*
	Pacific Herring	*Clupea pallasii*
	Pacific Ocean Perch	*Sebastes alutus*
	Petrale Sole	*Eopsetta jordani*
	Rock Sole	*Lepidopsetta bilineata*
	Sablefish	*Anoplopoma fimbria*
	Widow Rockfish	*Sebastes saxicola*
	Yellowmouth Rockfish	*Sebastes reedi*
	Yellowtail Rockfish	*Sebastes flavidus*
Invertebrates	Coral (excluding sea pens)	Alcyonacea, Antipatharia, Scleractinia, and Anthoathecata spp.
	Dungeness Crab	*Metacarcinus magister*
	Geoduck	*Panopea generosa*
	Glass Sponges	Hexactinellida spp.
	Green Sea Urchin	*Strongylocentrotus droebachiensis*
	Northern Abalone	*Haliotis kamtschatkana*
	Spot Prawn	*Pandalus platyceros*
	Red Sea Cucumber	*Apostichopus californicus*
	Red Sea Urchin	*Mesocentrotus franciscanus*
	Shrimp	*Pandalus jordani, P. borealis, P. danae* and *P. hypsinotus* and *Pandalopsis dispar*
	Sponges	Porifera spp.
	Tanner Crab	*Chionoecetes tanneri*
Mammals	Blue Whale	*Balaenoptera musculus*
	Fin Whale	*Balaenoptera physalus*
	Grey Whale	*Eschrichtius robustus*
	Humpback Whale	*Megaptera novaeangliae*
	Killer Whale	*Orcinus orca*
	Sea Otter	*Enhydra lutris*
	Sperm Whale	*Physeter macrocephalus*
	Steller Sea Lion	*Eumetopias jubatus*
Birds	Cassin's Auklet	*Ptychoramphus aleuticus*
	Common Murre	*Uria aalge*
	Cormorants	*Phalacrocorax penicillatus* and *P. pelagicus*
	Glaucous-winged Gull	*Larus glaucescens*
	Pigeon Guillemot	*Cepphus columba*
	Rhinoceros Auklet	*Cerorhinca monocerata*
	Storm Petrels	*Oceanodroma furcata* and *O. leucorhoa*
	Tufted Puffin	*Fratercula cirrhata*

APPENDIX C. EBSA REASSESMENT SENSITIVITY ANALYSIS

There were large sample size disparities between inside and outside samples in the inside/outside comparison we present in Part 1 of this paper. These disparities were a result of the large size differences that exist between the EBSAs and the surrounding area – the NSB. The NSB is roughly 100,000 km^2 while the smallest EBSA, Learmonth Bank, is 230 km^2 and the largest EBSA, Shelf Break, is 24,000 km^2.

We completed the following sensitivity analysis by varying the sample size of the outside EBSA area – the area of the NSB outside of the EBSAs for which the species or feature was identified as important. The inside EBSA samples were compared to the original outside sample as well as three smaller outside samples. The reduced outside samples ranged from the original outside sample to the mean sample size of the EBSAs in the comparison. Reduced outside samples were random samples of the total, sampled without replacement. The subsequent inside/outside comparison followed the methods described in Section 2.3.

The results of the sensitivity analysis are shown in Figure C1 through Figure C6. Overall, our analysis demonstrated that the inside/outside comparison was not very sensitive to unequal sample sizes. In general, as outside sample sizes decreased confidence intervals tended to increase making it more difficult to detect a significant difference between inside and outside EBSAs.

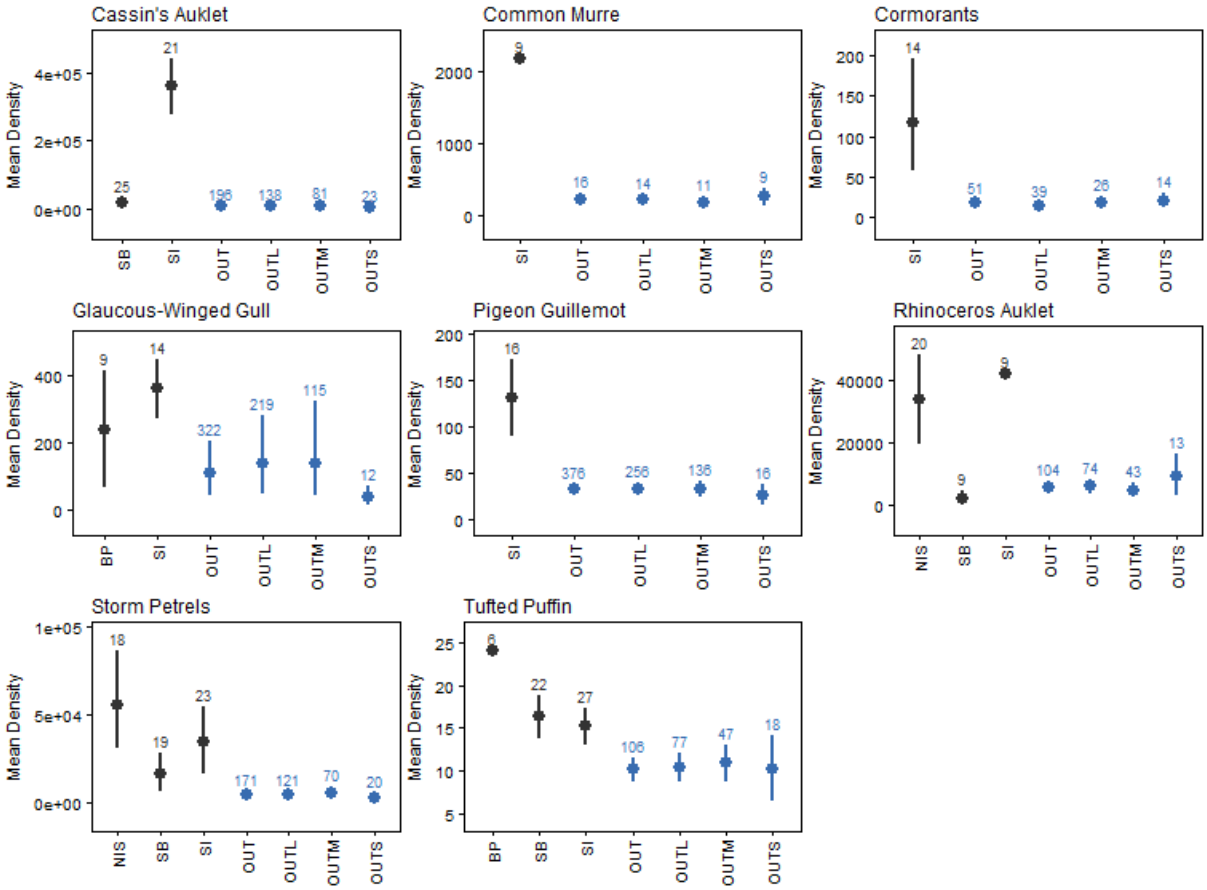

Figure C1. Mean density of birds evaluated in EBSA reassessment inside EBSAs and outside EBSAs at varying sample sizes. OUT represents the original outside sample. The three reduced outside sample sizes are represented by OUTL = outside large, OUTM = outside medium and OUTS = outside small. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units).

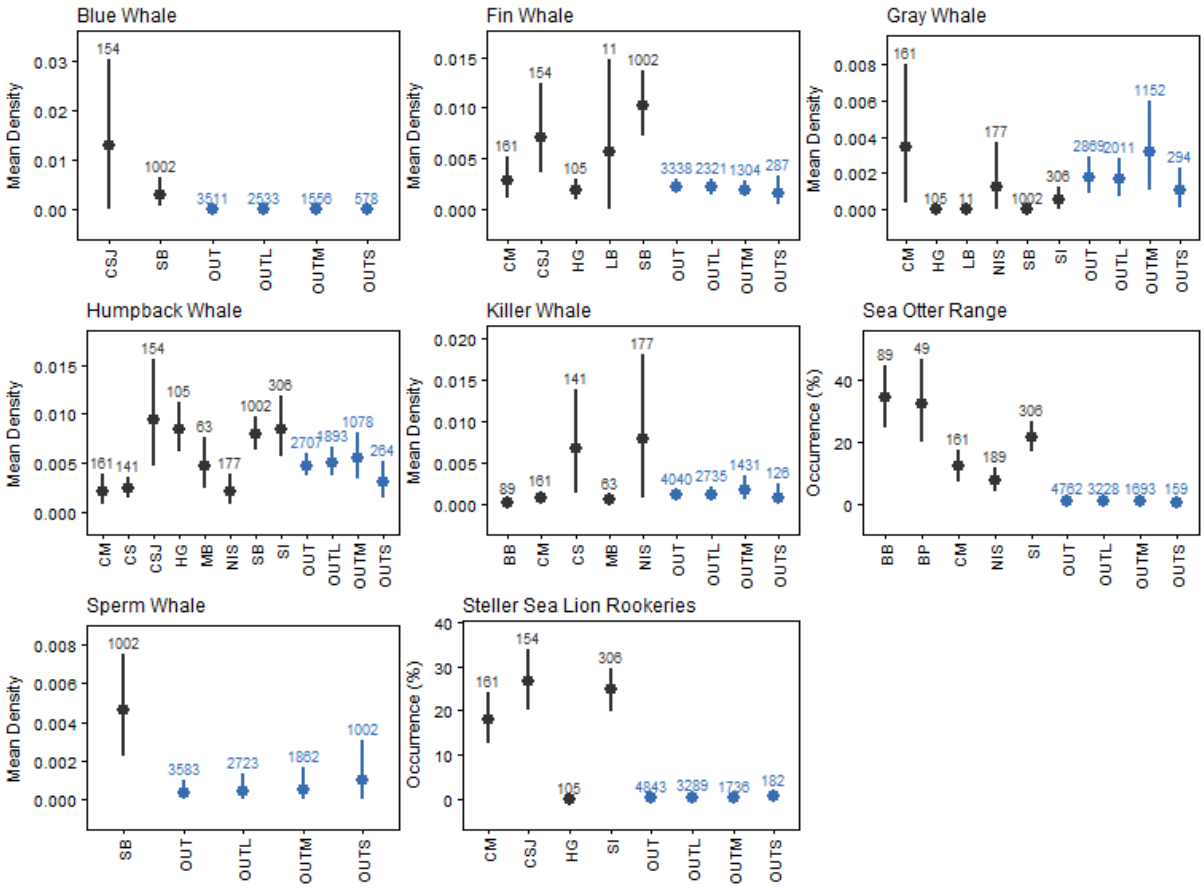

Figure C2. Mean density of cetaceans evaluated in EBSA reassessment inside EBSAs and outside EBSAs at varying sample sizes. OUT represents the original outside sample. The three reduced outside sample sizes are represented by OUTL = outside large, OUTM = outside medium and OUTS = outside small. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units).

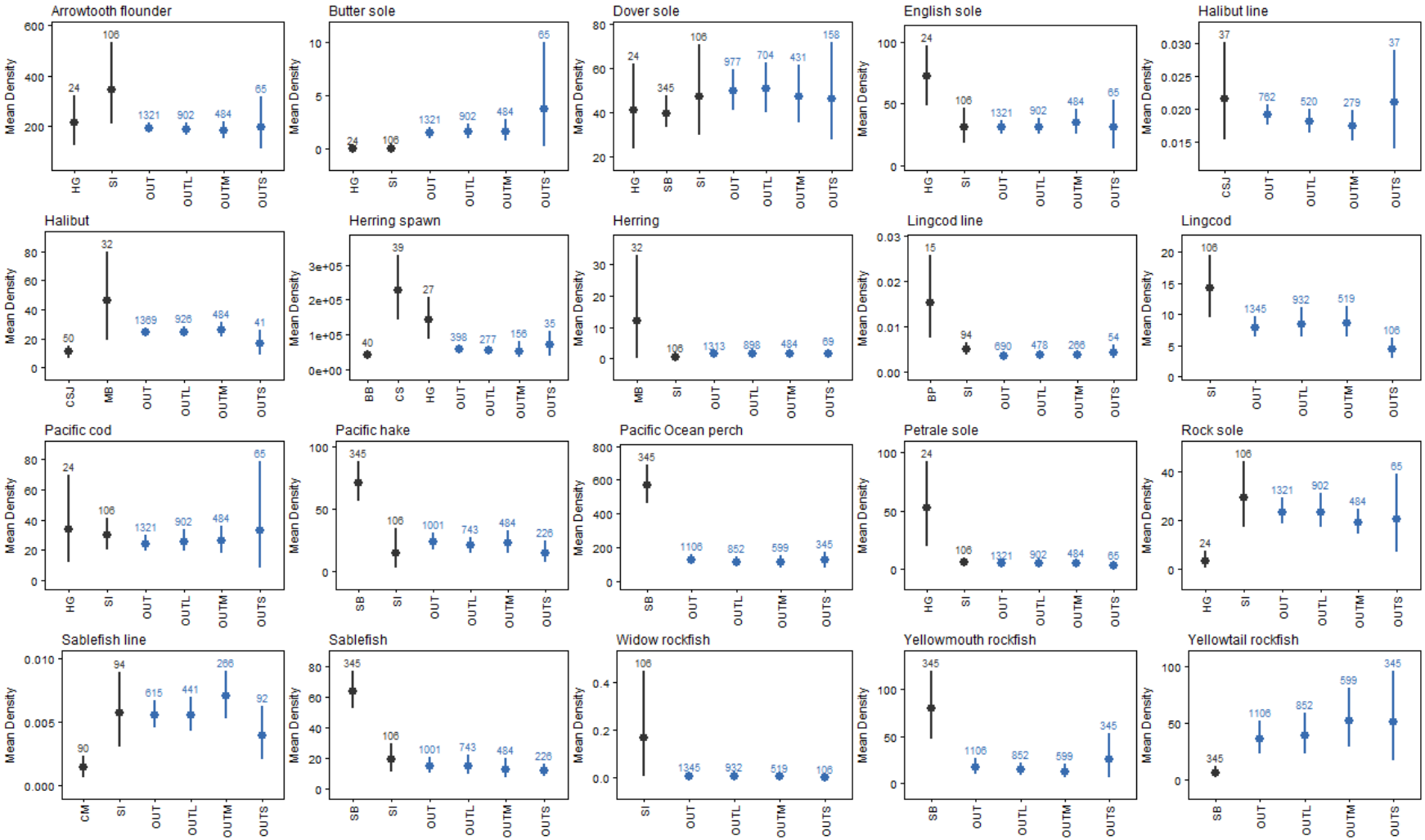

Figure C3. Mean density of fish evaluated in EBSA reassessment inside EBSAs and outside EBSAs at varying sample sizes. OUT represents the original outside sample. The three reduced outside sample sizes are represented by OUTL = outside large, OUTM = outside medium and OUTS = outside small. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units).

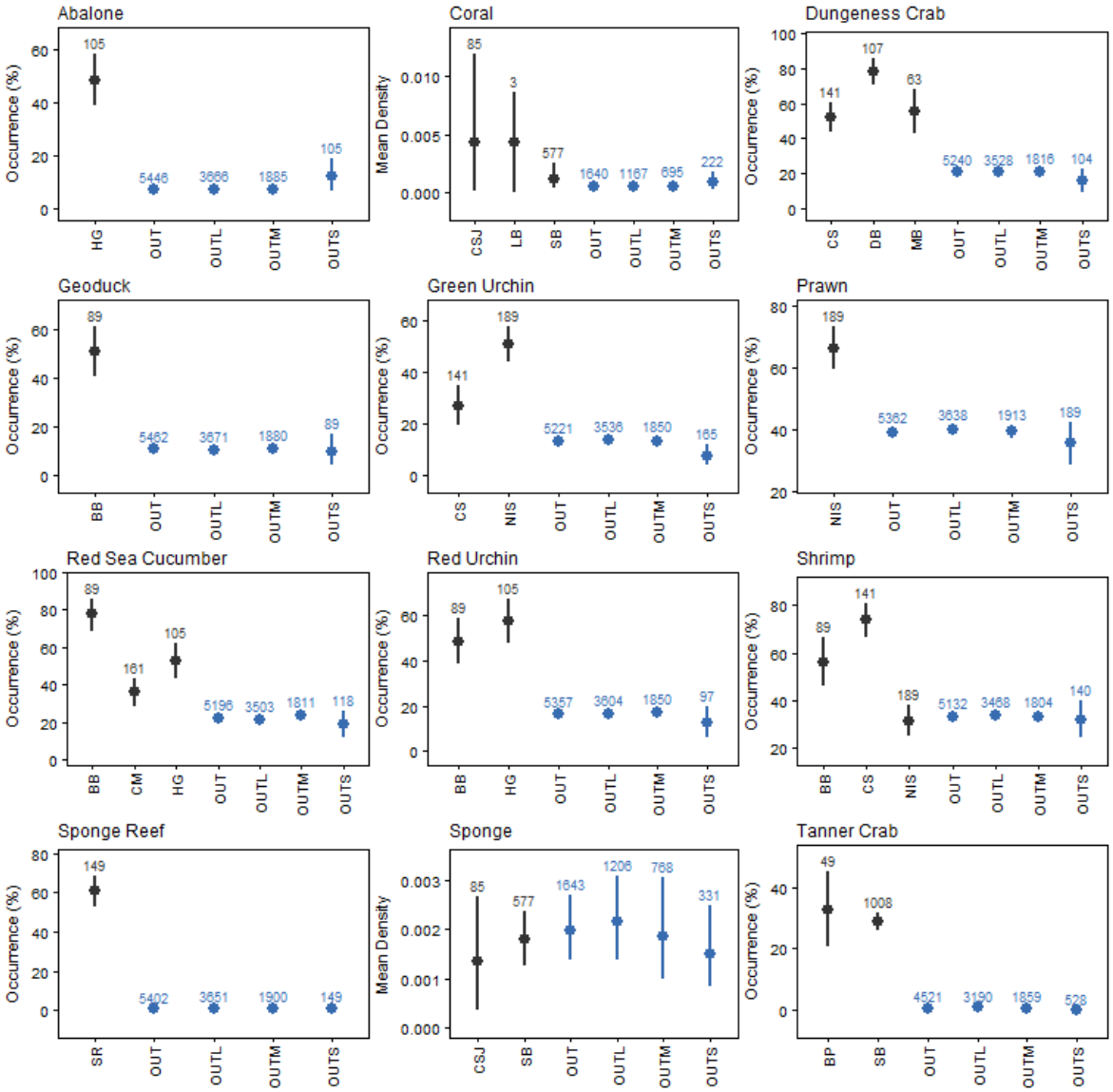

Figure C4. Mean density of percent occurrence of invertebrates evaluated in EBSA reassessment inside EBSAs and outside EBSAs at varying sample sizes. OUT represents the original outside sample. The three reduced outside sample sizes are represented by OUTL = outside large, OUTM = outside medium and OUTS = outside small. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units).

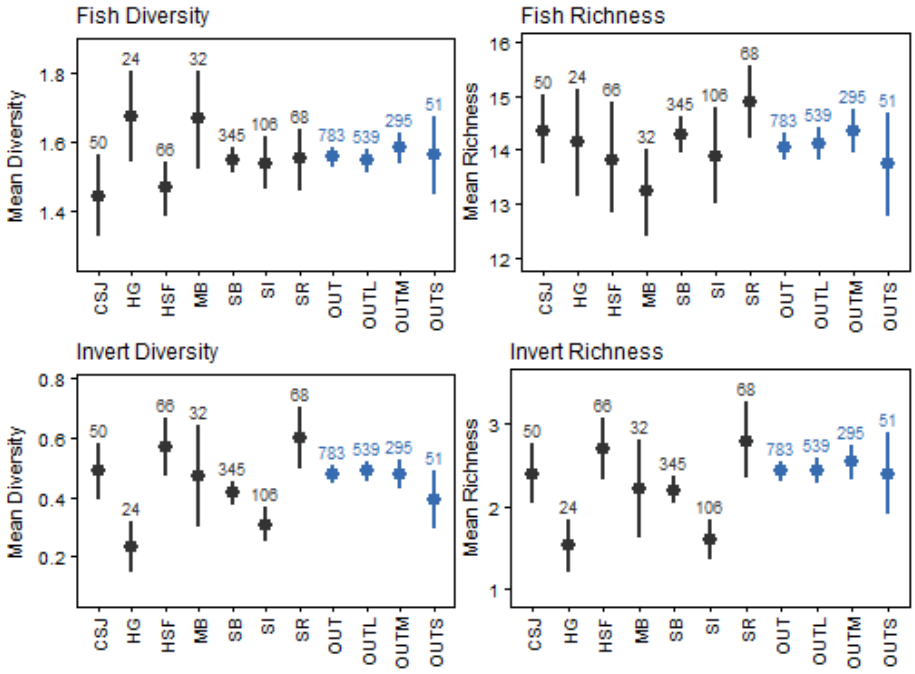

Figure C5. Mean diversity or richness of fish and invertebrates inside EBSAs and outside EBSAs at varying sample sizes. OUT represents the original outside sample. The three reduced outside sample sizes are represented by OUTL = outside large, OUTM = outside medium and OUTS = outside small. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units).

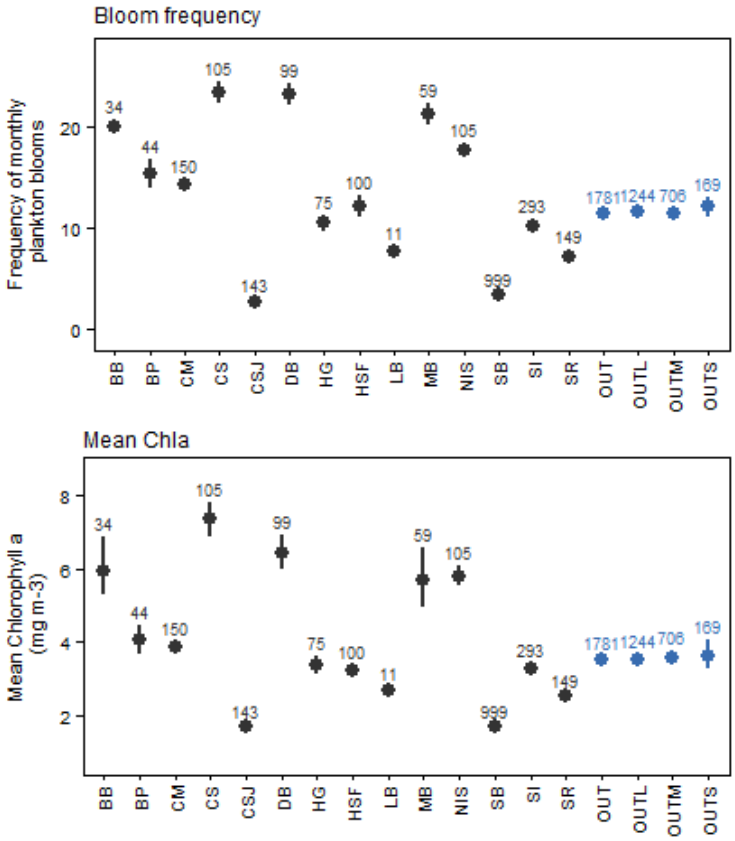

Figure C6. Mean diversity or richness of fish and invertebrates inside EBSAs and outside EBSAs at varying sample sizes. OUT represents the original outside sample. The three reduced outside sample sizes are represented by OUTL = outside large, OUTM = outside medium and OUTS = outside small. Bars around the points represent 95% confidence intervals. Numbers on error bars represent sample sizes (the number of 5 by 5 km planning units)