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Arctic Marine Biodiversity: Indicators for Monitoring Coral and Sponge Megafauna in the Eastern Arctic

Biodiversité Marine Arctique: Indicateurs pour un suivi de la mégaufaune de coraux et d'éponges dans l'est de l'Arctique

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GLOSSARY OF TERMS

Benthic-pelagic coupling: the processes whereby planktonic production in the water column provides organic matter that settles onto the seabed and/or is consumed by benthic communities, and nutrient fluxes from the seabed (e.g., remineralization) which provide nutrients to the water column and enhance planktonic primary production.

Bioengineer: or *Ecosystem Engineers* are organisms that alter the structure of the sea floor in ways that are used by other organisms. For example, large upright organisms can significantly alter bottom currents, burrowing animals can aerate sediments and branching and/or reef forming organisms can provide structural complexity. Ecosystem engineers can operate over spatial scales of meters to hundreds of kilometers (Great Barrier Reef is 2000 km long and has a major ecological significance both for the reef habitat itself and in influencing inshore environments through their dampening effect of wave action).

Biomarker: key molecular or cellular events produced in response to a specific environmental exposure

Infauna: aquatic animals that live in the substrate of a body of water, especially in a soft sea bottom

Epifauna: also called *epibenthos*, are aquatic animals that live on the bottom substratum as opposed to within it, that is, the benthic fauna that live on top of the sediment surface at the seafloor

Macroalgae: large aquatic plants or *seaweeds*

Macrofauna: organisms which are retained on a 0.5 mm sieve. Studies in the deep sea define macrofauna as animals retained on a 0.3 mm sieve to account for the small size of many of the taxa. Gill et al. (2011) define macrofauna as: infauna > 1cm and always sampled by quantitative grab

Megafauna: large animals of any particular region. The most common thresholds used in terrestrial studies are 44 kilograms (100 lb) or 100 kilograms (220 lb). Benthic ecologists use this classification for much smaller animals: > 5 mm, > 1 cm, or "readily visible in photographs". Gill et al. (2011) define megafauna as: includes both sessile and motile epifaunal organisms > 1 cm (or larger than 4 mm)

Meiofauna: metazoan animals that can pass unharmed through a 0.5 – 1 mm mesh but will be retained by a 30 – 45 μm mesh

Spicules: non-living secretions of some invertebrates including sponges made from either silica or calcium carbonate in the form of calcite or aragonite; spicules provide support for soft tissue structures and are a part of the skeleton

Taphonomy: the study of the processes (as burial, decay, and preservation) that affect animal and plant remains as they become fossilized

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ABSTRACT

Cold-water corals and sponges are important to ecosystem function and biodiversity in polar environments. The general distribution of these taxa in the Eastern Arctic has been determined from the bycatch of research trawl surveys for shrimp and Greenland halibut. Trawl survey data are not ideal for quantifying biomass and abundance of these organisms. However, at this time trawl survey data are the only data that provide a broad spatial coverage and annual time series. Here we discuss nineteen potential indicators for monitoring coral beds and sponge grounds. We suggest the ecological and biological properties of these habitats that they reflect. Established state indicators are drawn from the Arctic Council Circumpolar Biodiversity Monitoring Marine Plan and the Gully MPA monitoring plan, while stressor indicators are drawn from the European Commission Marine Framework Strategy Directive. Novel indicators are proposed for each; specifically a suite of geospatial state indicators which reflect trends in habitat fragmentation, reproductive processes and distribution, and stressor indicators to capture likely threats from changes to ocean acidification, ocean circulation and food supply in addition to those of fishing with bottom contact gear. Geo-referenced biomass/abundance data by species allow for the calculation of nine of the twelve state indicators. Further information on the proportion of live:dead fauna, percent infestation with zoanthid anemones and size structure completes the data requirement for state indicators. For six of the indicators we construct a six year (2005-2010) time series using trawl survey data from a common area (Shrimp Fishing Area 2EX) in the Eastern Arctic. We evaluate their performance as useful indicators to monitor coral beds and sponge grounds in light of climate change projections for this area. The need to have both state and stressor indicators is discussed.

RÉSUMÉ

Les coraux et les éponges des eaux froides sont importants à la fonction et à la biodiversité des écosystèmes en milieu polaire. La répartition de ces taxons dans l'est de l'Arctique a été déterminée d'après les prises accessoires des relevés au chalut de crevettes et de flétan du Groënland. Les données de relevés de chalut ne donnent qu'une idée approximative de la biomasse et de l'abondance de ces organismes, mais ce sont pour le moment les seules à couvrir une telle étendue ainsi que des séries temporelles. Le présent document traite de dix-neuf indicateurs possibles de surveillance des lits de coraux et d'éponges et évoque les caractéristiques écologiques et biologiques de ces habitats. Les indicateurs d'état établis sont tirés du *Circumpolar Biodiversity Monitoring Marine Plan* du Conseil de l'Arctique et du plan de surveillance de la ZPM du Gully, alors que les indicateurs de stress sont tirés de la directive-cadre stratégie pour le milieu marin de la Commission européenne. De nouveaux indicateurs sont proposés dans chaque cas, notamment une suite d'indicateurs d'état géospatiaux qui reflètent les tendances en matière de fragmentation de l'habitat, de processus de reproduction et de répartition des espèces, des indicateurs de stress pour déterminer tout risque relatif à un changement sur le plan de l'acidification, de la circulation de l'océan ou de la source d'alimentation des espèces ainsi que tout risque relatif à la pêche avec des engins mobiles de fond. Les données géoréférencées sur la biomasse et l'abondance de chaque espèce permettent de calculer neuf des douze indicateurs. Les autres données nécessaires pour établir les indicateurs d'état sont la proportion de faune vivante/morte, le pourcentage d'infestation par les anémones de la sous-classe des zoanthaires et la structure de taille. Pour six des indicateurs, nous avons établi une série temporelle de six ans (de 2005 à 2010) d'après les données de relevés de chalut d'une zone courante de l'est de l'Arctique (zone de pêche à la crevette 2EX). Notre recherche vise à évaluer le rendement et l'utilité de ces indicateurs pour surveiller les lits de coraux et d'éponges à la lumière des changements climatiques prévus dans cette zone. La nécessité de disposer à la fois d'indicateurs d'état et d'indicateurs de stress est également abordée.

INTRODUCTION

Cold-water coral and sponge are considered to be ecosystem engineers. Dense aggregations formed by these large structure-forming species (Figure 1) can alter bottom currents and provide niche space for other organisms often increasing biodiversity compared with surrounding areas (cf. Boutillier et al. 2010). The location of coral beds and sponge grounds can therefore be used as proxies for areas of high biodiversity. This linkage has been recognized by the United Nations General Assembly Resolution 61/105, which calls for the protection of vulnerable marine ecosystems, including cold-water corals, from destructive fishing practices due to the value of deep-sea ecosystems and the *biodiversity* they contain.

Corals and sponges also play an important role in ecosystem processes (Roberts et al. 2006, Bell 2008). For example, cold-water corals produce large amounts of nitrogen-rich mucus which has been shown to locally stimulate microbial activity and may function as a vector for carbon and nutrient cycling through the microbial loop (Wild et al. 2008). Sponges play a role in benthic-pelagic coupling and biogeochemical processing. The large amount of water processed by such benthic suspension feeders [Vogel (1977) reported that a 1 kg sponge filters 24,000 l daily] and empirical evidence for the magnitude of the carbon flux in some species, indicates that they form a strong link between the pelagic microbial food web and the benthos (e.g., Pile and Young 2006).

Due to their sessile nature and limited dispersal abilities both coral and sponge are very vulnerable to environmental change. Ocean acidification poses a threat to Canadian Arctic cold-water corals, especially to the scleractinian corals, such as *Desmophyllum dianthus*, whose skeleton is formed by aragonite (Maier et al. 2011) and to gorgonian corals (Figure 1) which secrete magnesium calcite (Orr et al. 2005, Hoffmann et al. 2010, Thresher et al. 2011). Arctic sponges may be less vulnerable to ocean acidification. In Canada, sponges are predominantly members of the Demospongiae or Hexactinellida, both of which have spicules made from silica. These non-calcifying sponges may benefit from negative impacts to corals caused by ocean acidification and climate change.

Changes to ocean circulation patterns may alter the food available to corals and sponges causing large-scale changes in distribution and abundance (ICES 2011). Piepenburg (2005) hypothesized that it may also trigger a regime shift in the overall carbon and energy budget in the Arctic from a 'sea-ice algae–benthos' system to one dominated by 'phytoplankton–zooplankton'. Changes to the oxygen minimum zone and/or to ocean acidification could also cause mass mortality events in these sessile organisms. The loss of ecosystem engineers due to a changing climate may produce some of the most profound and irreversible effects (Jordán and Scheuring 2002). Given the role of cold-water corals and sponges in the ecosystem and the potentially significant harmful effects of ocean acidification and climate change, monitoring of these benthic components should be of high priority, especially in the Arctic where a rapid rate of change in the physical environment has been observed (Anisimov et al. 2007). The distribution of corals and sponges in the eastern Arctic is comparatively well-known, in contrast to that of other benthic taxa. Kenchington et al. (2010a) analyzed multi-species stock assessment research trawl survey catch data and identified significant concentrations of coral and sponge throughout eastern Canada, including a number of Arctic regions as defined by the Conservation of Arctic Flora and Fauna (CAFF) Marine Expert Monitoring Group: Baffin Bay and Davis Strait, Hudson Strait and the Labrador Shelf. For the most part, only species considered to be vulnerable to bottom-contact fishing gear were assessed for that study as the work was done to identify vulnerable marine ecosystems as defined in international law (see FAO 2009). Using the same analytical approach, Wareham et al. (2010) focused on the Hatton Basin area in Davis Strait and the northern Labrador shelf and slope. In addition to an analysis of the vulnerable taxa, they included an assessment of coral diversity and an analysis of the soft corals (Nephtheidae) which are widespread and relatively insensitive to trawling impacts (Henry et al. 2003) but nevertheless form structural habitat that may be important to ecosystem function (Figure 2).

Subsequently, Kenchington et al. (2011) considered the density of coral and sponge beds, as well as benthic diversity and biomass, benthic remineralization and sediment pigment concentration in the identification of benthic ecologically and biologically significant areas (EBSA) in the Canadian Arctic (DFO 2011). The locations of significant concentrations of gorgonian corals, sea pens and sponges in Baffin Bay and Davis Strait are indicated in Figure 3. Kenchington et al. (2011) also identified areas of Hudson Strait that have relatively high concentrations of soft corals and sponges compared to other areas within the Hudson Bay Complex (Figure 4). The objectives of this manuscript are to review potential indicators for monitoring coral and sponge megafauna in the Arctic and where possible review their performance using available data.

MARINE BIODIVERSITY INDICATORS FOR MONITORING THE BENTHOS

REGIONAL CONTEXT

The Arctic Council is a high-level intergovernmental forum established under the Ottawa Declaration in 1996. The Council is formed by the eight member states with territory in the Arctic, six permanent observer states and five ad-hoc observer states. The Council oversees six Working Groups and four Programs and Action Plans. The Conservation of Arctic Flora and Fauna (CAFF) Working Group, the Circumpolar Biodiversity Monitoring Program (CBMP) and the Arctic Biodiversity Assessment (ABA) are of direct relevance to the development of indicators for monitoring marine biodiversity in the Canadian Arctic as they have already considered a number of indicators that could be relevant in a Canadian context. The CBMP Marine Plan was created by CAFF with the overall goal of “improving our ability to detect and understand the causes of long-term change in the composition, structure, and function of Arctic marine ecosystems, as well as to develop authoritative assessments of key elements of Arctic marine biodiversity (e.g., key indicators, ecologically pivotal and/or other important taxa)” (Gill et al. 2011). The Arctic Council has announced that a “full and comprehensive” Arctic Biodiversity Assessment will be released in 2013. Amongst other objectives, this report will provide a baseline of the current state of Arctic ecosystems and biodiversity for use in global and regional assessment of biodiversity.

GLOBAL CONTEXT

Parties to the Convention on Biological Diversity (CBD) adopted a revised and updated “Strategic Plan for Biodiversity 2011-2020” at their tenth meeting in Nagoya, Aichi Prefecture, Japan (COP decision X/2). Included in this plan are a set of biodiversity targets referred to as the Aichi Biodiversity Targets. Provisional technical rationale, possible indicators and suggested milestones for the Aichi Biodiversity Targets have been developed (UNEP/CBD/COP/10/9; http://www.cbd.int/doc/meetings/cop/cop-10/official/cop-10-09-en.pdf) and formerly recognized by the CBD Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) at its fifteenth meeting in November 2011 as a starting point to assess progress in the achievement of the Strategic Plan for Biodiversity 2011-2020 (UNEP/CBD/COP/11/2; http://www.cbd.int/doc/meetings/cop/cop-11/official/cop-11-02-en.pdf).

The Aichi Biodiversity Targets are formed around five strategic goals, three of which particularly require scientific advice:

A: address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society;

B: reduce the direct pressures on biodiversity and promote sustainable use; and

C: to improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity.

Under COP decision X/13, the Arctic Council was invited to provide relevant information and an assessment of Arctic biodiversity to SBSTTA. It was suggested that CAFF could contribute to the Convention process by providing "integrated circumpolar expertise, data and analysis to enable sound decision-making and place the status of Arctic biodiversity in a global context and, at the same time, apply international targets and tools developed under the Convention in a regional context" (UNEP/CBD/COP/11/2). The SBSTTA has recommended that the eleventh meeting of the CBD Conference of the Parties adopt a decision which would endorse the continued co-operation between the CAFF and the CBD (UNEP/CBD/COP/11/2).

ESTABLISHED INDICATORS FOR MONITORING CORAL AND SPONGE

Monitoring activities can be classified into two groups: 1) monitoring ecosystem components to collect information on long-term trends in response to environmental factors and to enable predictions on future states of the component in relation to environmental change and 2) monitoring threats or stressors to ecosystem components. The former are often referred to as state indicators, while the latter are referred to as threat or stressor indicators.

For each strategic goal within the Aichi Biodiversity Targets an indicator framework has been proposed around four questions (UNEP/CBD/COP/11/2):

1. How is the status of biodiversity changing?
2. Why are we losing biodiversity?
3. What are the implications of biodiversity loss?
4. What do we do about biodiversity loss?

These clear goals or objectives help to determine appropriate indicators and monitoring plans. To address the Aichi goals both state and stressor indicators are required. State indicators may document change but stressor indicators are needed to explain that change.

State Indicators Developed Through the Arctic Council

An overview report entitled "Arctic Biodiversity Trends 2010: Selected Indicators of Change" was released by the Arctic Council for the United Nations International Year of Biodiversity in 2010 and for the CBD's 3rd Global Biodiversity Outlook (CAFF 2010). The report provides an assessment of the status and trends in Arctic biodiversity based on a suite of 22 indicators of selected species, ecosystems and ecosystem services. One of these, *Indicator #17 Impacts of human activities on benthic habitat*, explicitly refers to cold-water coral reefs, coral gardens, and sponge grounds (no other benthic habitats are mentioned). Unfortunately, details of how this indicator might be monitored are lacking and no trends or other quantitative data are presented – instead the report focuses on the need for protecting these habitats (CAFF 2010).

Subsequently, the CAFF Marine Expert Monitoring Group recommended a number of state indicators for the benthos in their Arctic Marine Biodiversity Monitoring Plan developed for the Circumpolar Biodiversity Monitoring Program (Gill et al. 2011) but did not specifically recommend indicators for coral and sponge. Benthic species (excluding fish and plankton which are dealt with separately) were divided into three Focal Ecosystem Components: Macrofauna and megafauna; Macroalgae (coastal); Meiofauna and microbes. The recommended indicators for the macrofauna and megafauna are listed in Table 1. Cold-water corals and sponges are classified as megafauna under this scheme (see Glossary).

Table 1. Parameters and Indicators suggested by the Marine Expert Monitoring Group of the Circumpolar Biodiversity Monitoring Program for Benthic Macrofauna and Megafauna (Gill et al. 2011).

Parameters	**Indicators**
Abundance	Abundance; community composition
Biomass (wet weight, dry weight or ash-free dry weight)	Biomass; community composition Size-frequency distribution (for selected species: snow crabs, ophiuroids, and bivalves)
Species Composition	Diversity indices (Shannon, Simpson)
Barcoding and other genomics	Distribution

All of these indicators have a role in monitoring benthic biodiversity in the Arctic. There are a number of established diversity indices that can be calculated from standardized abundance or biomass data. These include the Shannon and Simpson indices listed in Table 1 as well as other metrics such as beta-diversity, taxonomic distinctness etc. Community composition or species richness coupled with a corresponding degree of taxonomic relatedness may confer resistance of coral beds and sponge grounds to climate change (ICES 2011). Taxonomic relatedness is a measure of the genetic relatedness of species through their genealogy as embodied in the Linnaean classification system. It assumes that there is a direct relationship between taxonomic relatedness and ecological similarity among species, although this may not always be true (cf. Bevilacqua et al. 2012). Taxonomic relatedness must be high enough so that there is a certain amount of functional redundancy to the system, yet low enough to ensure a diversity of responses to environmental change among species contributing to the same ecosystem function (response diversity) (Elmqvist et al. 2003). The combination of response diversity and functional redundancy of the ecosystem determine its intrinsic ability to compensate for perturbations without seriously altering ecosystem function (ICES 2011). However, these properties are not easily assessed and can operate in multiple dimensions responding in non-linear ways (Loreau 2004).

State Indicators Developed for the Gully MPA

Another suite of indicators have been proposed to monitor cold-water corals in the Gully Marine Protected Area on the Scotian Shelf (DFO 2010, Kenchington 2010). These were developed for the conservation objective “Protect seafloor habitat and associated benthic communities” *(numbered as in the original reports*):

13. Coral distribution, density and size structure by species at selected monitoring sites within the MPA.
14. Coral diversity at selected monitoring sites within the MPA.
15. Proportions of live and dead corals, by species, at selected monitoring sites within the MPA.
16. Proportion of live corals at selected monitoring sites within the MPA that show zoanthid over-growths and the extent of over-growth in any affected colonies.

Gully MPA Indicators 13 and 14 address similar properties to those proposed by Gill et al. (2011) and J. Nelson (unpublished manuscript) (Table 1). However, Indicators 15 and 16 offer additional perspective to the state of the ecosystem. The taphonomy of cold-water coral skeletons in Canadian waters has recently been studied (Edinger and Sherwood 2011) which has given more confidence to the interpretation of Indicator 15. The dead skeletons of *Primnoa resedaeformis* and *Keratoisis* spp. have an estimated longevity of more than 1000 years. Estimated longevities of dead coral skeletons for other species are much shorter: less than 1 year for *Paragorgia* spp., less than 10 years for *Paramuricea* spp., and less than 20 years for *Stauropathes arctica*. Given the friability of some of the skeletons after death it will be important to monitor this indicator under defined sampling conditions, ideally using *in situ* imagery.

Indicator 16 could be a very important indicator as environmentally-stressed colonies may be more susceptible to parasitic infestation. A biological threat to mature cold-water corals is colonization by zoanthid anemones, which can kill the colony by growing over top of the coral polyps and progressively eliminating the host gorgonian tissue while using the skeletal structure for support and protection (Carreiro-Silva et al. 2011). A zoanthid (*Epizoanthus* sp.) has been observed in the Northeast Channel, off southwestern Nova Scotia, where it has been found predominately on the gorgonian coral *Primnoa resedaeformis* (Buhl-Mortensen and Mortensen 2005). Additionally, *Epizoanthus norvegicus* has been observed growing on the corals *Paragorgia arborea* and *Primnoa resedeaformis* on the Norwegian coast (cf. Carreiro-Silva et al. 2011). Parasitic worms and copepods also have been identified in gorgonian corals (Buhl-Mortensen and Mortensen 2005), but none have been described as lethal in Canadian waters. Other diseases brought about by bacterial and fungal pathogens have been described for tropical taxa (Peters 1997) but little is known about their occurrence with cold-water species.

Stressor Indicators Developed for the European Commission Marine Framework Strategy Directive

The areas where cold-water corals and sponges occur in the Eastern Arctic are also areas where commercial fishing takes place (hence the justification for the stock surveys). Bottom-contact fishing poses a high threat to coral and sponge habitats (e.g., ICES 2008, Heifetz et al. 2009, ICES 2009, Boutillier et al. 2010, CAFF 2010) and indicators which reflect this threat seem *prima facie* to be very appropriate. The European Commission (2008) has developed environmental indicators to measure the effects of fisheries on the marine ecosystem in support of its Marine Framework Strategy Directive. There are three indicators for the benthos which are meant to describe the spatial distribution of fishing activities. These could be considered for the Eastern Canadian Arctic:

> **Distribution of fishing activities** is an indicator of the spatial extent of fishing activity. It would be based on the total area of grids (3 km x 3 km) within which VMS records were obtained, each month. It would be reported in conjunction with the indicator for 'Aggregation of fishing activities'.
>
> **Aggregation of fishing activities** is an indicator of the extent to which fishing activity is aggregated. It would be reported in conjunction with the indicator for 'Distribution of fishing activities'. It would be based on the total area of grids (3 km x 3 km) within which 90% of VMS records were obtained, each month.
>
> **Areas not impacted by mobile bottom gears** is an indicator of the area of seabed that has not been impacted by mobile bottom fishing gears. This indicator could be reported annually and would state the total proportion of the area by depth stratum that has not been fished with bottom gear in the preceding one year period. However, annual reporting may not be necessary if fishing activity is light. This

indicator responds to changes in the distribution of bottom fishing activity resulting from catch controls, effort controls or technical measures (including MPA established) and to the development of any other human activities that displace fishing activity (e.g., wind farms).

The data requirements for these indicators are VMS positional and registration data with a preference for position reports every half hour. Speed information is needed to distinguish fishing events from transit but is not always available in Canadian VMS data.

Similar indicators for environmental threats could also be developed related to the timing and duration of anomalous events. However, these should be based on the physiological tolerance limits of the dominant taxa. Unfortunately, for most cold-water corals and sponges, such limits are not well known.

Phenology (the annual timing of ecological events) in the marine environment may be altered dramatically by climate change (ICES 2011). The decoupling of phenological relationships has important ramifications for trophic interactions by altering food-web structure that may lead to ecosystem-level changes in biomass and productivity. At the species level, phenology can be critical for recruitment success. For populations that rely on temperature as an environmental cue, climate change could have serious effects on phenology. The timing, duration and magnitude of the Arctic phytoplankton bloom may influence recruitment success and productivity. In the Arctic, ice algae are an important component of the benthic food web (McMahon et al. 2006) and changes to sea ice patterns are expected to impact benthic communities.

PROPOSED GEOSPATIAL INDICATORS FOR MONITORING CORAL AND SPONGE AGGREGATIONS

Spatial configuration refers to the spatial properties and arrangement, position, or orientation of habitat patches within the broader survey area. Spatial ecology has always been an important dimension for the interpretation of ecological phenomena and there are many aspects of configuration as well as methods and indices for representing them (e.g., Fortin and Dale 2005, Maguire et al. 2005).

The analyses of coral and sponges in Eastern Canada conducted by Kenchington et al. (2010a) were based on geostatistics. A geospatial model was developed (Kenchington et al. 2009, Kenchington et al. 2010b) using kernel density analysis (cf. Silverman 1998) to identify significant concentrations of corals and sponges. Sea pen fields, gorgonian coral beds and sponge grounds form dense aggregations. By constructing equal-density polygons using different catch levels, the authors were able to determine the minimum catch weight which corresponded to the main sponge or coral aggregations. Polygons were constructed around those concentrations primarily for their identification, but they could also be used to give a measure of “habitat area”.

Metrics describing coral and sponge habitat can be constructed from individual patches (e.g., mean patch area and shape) using attributes of their statistical distribution (e.g., mean, maximum, variance) of the corresponding patch variable (e.g., size, shape). The spatial relationship among patches, or patch configuration can also be quantified using nearest-neighbour and other statistics capturing information on the relative position of the patches within the survey landscape.

Kenchington et al. (2010a) showed that there are differences in catchability of coral and sponge between the Campelen and Alfredo trawls used to conduct shrimp and Greenland halibut surveys in the Eastern Arctic. These surveys also have minimal spatial and bathymetric overlap and, consequently, will have different communities of coral and sponge. When evaluating trends in these indicators it will be important to select a constant area for the analyses and to make comparisons with surveys using a single trawl gear. These indicators can also be calculated from photographic data and measured over smaller spatial scales.

Patch area and density: The habitat area occupied by corals and sponges can be expressed using summary statistics drawn from the population of habitats or patches in the broader survey landscape (e.g., mean, median, maximum, variance, etc). Patch density is the number of patches per unit area. **Patch perimeter** is usually highly correlated with Patch area but in some cases may have better distributional properties and so could be seen as an alternative to Patch area.

Nearest neighbour measurements: Isolation/Proximity: Isolation or proximity refers to the tendency for patches to be relatively isolated in space from other patches. If d_{ij} is the nearest-neighbour distance from patch i to another patch j of the same type, then the mean nearest-neighbour distance over all patches is a measure of relative isolation.

Connectivity: Isolation/Proximity of patches can be interpreted in terms of connectivity. If ecological or oceanographic knowledge governing the dispersal of gametes or larvae is available then the information can be used to predict a neighbourhood size that reflects a gamete dispersal range or other ecological process. The number of patches that fall into the neighbourhood size could then become a measure of connectivity.

Dispersion: Dispersion refers to the tendency for patches to be regularly or contagiously distributed (i.e., clumped) with respect to each other. Dispersion can be calculated for patches, tow locations with coral or sponge bycatch or individuals.

These geospatial indicators could also be used to monitor coral reefs and mounds, including the cold-water coral *Lophelia* reefs common in Norwegian Arctic waters (CAFF 2010). All of these indicators will reflect biological and ecological properties such as reproductive success, ecosystem function, ecosystem resilience and intra-specific genetic diversity.

OTHER POTENTIAL INDICATORS

Biomarkers have a high potential for use as indicators of environmentally-induced stress in corals and sponges, including the toxic effects of exposure to chemical contaminants. Biomarker responses are measured in individuals and so may act as early warning signals of wide-scale population or ecosystem-level change (Marques et al. 2007), and marine sponges have been reasonably well studied (see review by Müller et al. 2000). A full review of these markers is beyond the scope of this paper; however, we wish to draw attention to their potential for monitoring the health of corals and sponges in the Arctic.

INFORMATION SOURCES AND LIMITATIONS

Trawl survey data are widely used to develop indices of biomass and abundance and it is not surprising to see them included in monitoring plans for the benthos. However, there are a number of issues with this type of data when applied to coral and sponge bycatch. Trawl survey data, in general, typically have distributions that are highly skewed, often with the standard deviation higher than the mean (Grosslein 1971). Coral and sponge bycatch data are typically highly right-skewed, in addition to having many zero hauls. Fisheries scientists have explored the best options for analyzing this type of data. A widely used approach is the minimum variance unbiased estimators, if the data follow the delta distribution (Pennington 1983). This calculation involves separating the zero catches from the positive catches and assumes that the positive catches follow a log-normal distribution. However, Syrjala (2000) and others have shown that even this estimate of the mean is not unbiased if the data do not follow a delta distribution (zero catches are not true zeros, for example). If this is the case zero-inflated distributions (Binomial or Poisson) can offer a better approach for calculating estimators (see Smith et al. 2009, for an example of using zero-inflated negative binomials for scallops). Such distributions are in part a result of the survey design. Usually trawl surveys are designed to improve the precision of estimates by incorporating information on the spatial variability of the target species. This may increase variance and lower precision of non-target bycatch such as coral and sponge.

The quality of coral and sponge bycatch data (biomass, abundance, species composition) from trawlers is also *highly* problematic. Some taxa are fragile and are mainly represented in the catch as broken fragments rendering the abundance data unreliable. This is particularly true of the large gorgonian corals and some of the sponge species. The degree of fragmentation may depend on many variables (bottom type, catch weight, gear type) other than species, making it difficult to make generalized adjustments to the data to correct for this problem. Further, some bycatch may pass entirely through the nets. Consequently, null catches may not be indicative of zero coral or sponge in an area (see comments above). The Northern Shrimp Research Foundation (NSRF) and DFO joint industry/government shrimp surveys in NAFO areas 2G and 0B provide additional insight into the scope of this problem. On these surveys there are essentially two nets, the main trawl cod end and a Linney bag attached to the belly of the trawl. The Linney bag collects what goes through the trawl mesh and is there to get a signal of small shrimp, however it also provides information on coral bycatch that passes through the meshes. These data show that data recorded as null data using the data from the main trawl cod end has a 32.6% error, that is 32.6% (range 20.6 to 42.6%) of the Linney bags (N=482) contained coral when no coral were found in the main trawl cod end. Although these results are specific to this area and this gear type it reinforces the importance of not interpreting null data to mean coral absence on the bottom.

Finally, many of the Arctic cold-water corals and sponges are long-lived species with slow growth rates and low recruitment (Boutillier et al. 2010, CAFF 2010). Consequently, even if the above-mentioned problems could be resolved, data on their abundance and biomass collected from research trawl survey bycatch is unlikely to be sensitive to change over short time scales unless mass mortality events occur.

EVALUATION OF INDICATORS FOR CORALS AND SPONGES IN THE EASTERN ARCTIC

One of the objectives of the CBMP Marine Plan (Gill et al. 2011) is to “identify existing datasets and information that can be aggregated to map biodiversity and to establish baselines and retrospective trends in Arctic marine biodiversity”. Data are readily available which allow for an initial exploration of some of the indicators described above. Here we examine in more detail six state indicators calculated from research vessel trawl bycatch data:

1. Mean biomass trends of selected corals and sponge from research vessel surveys in the Eastern Arctic;
2. Patch area (for sponge grounds, sea pens, large and small gorgonian corals);
3. Patch density (number of patches as per 2);
4. Isolation/Proximity of sponge grounds;

5. Connectivity between sponge grounds; and
6. Dispersion of sponge grounds and sea pen fields.

DATA SOURCES

In order to evaluate the proposed indicators we chose a common area (Shrimp Fishing Area 2EX) that had been sampled for six consecutive years (2005 to 2010) by the NSRF-DFO shrimp survey. These surveys were conducted on an industry vessel, the *Cape Ballard*, with DFO providing the scientific advice on sample design and analysis of the data collected (DFO 2009). The first of the on-going annual survey series was conducted in the summer of 2005 with data available for analysis through to 2010. Although the surveys are conducted with a Campelen trawl, it was modified in 2008 to reduce the number of trawl tear-ups. That year the foot gear was increased to 21” (from 14”) and the fishing line floated, raising the net an additional 7” off bottom. These modifications may have affected the catch of some species. Collectively these surveys provided 241 records of coral, 226 records of sponge, 422 null coral records and 437 null sponge records from depths between 128 m and 731 m (Figure 5).

The data for the spatial indicators were drawn from these same surveys. Kenchington et al. (2010a) established that 40 kg of sponge delineated sponge grounds in the Eastern Arctic biogeographic zone with this gear. Consequently, equal density polygons were constructed using the 40 kg threshold (Figure 6). Similar thresholds for significant concentrations of sea pens, large gorgonian coral and small gorgonian coral were 0.05 kg, 15 kg and 0.05 kg, respectively (Kenchington et al. 2010a).

In testing the *performance* of these indicators we classify an indicator as “good” if it has a distribution that allows for statistical analyses either in its raw state or through transformation. The variance should be less than the mean and significantly different from zero.

MEAN BIOMASS TRENDS

The trawl surveys in Shrimp Fishing Area 2EX (SFA2EX) identify five groups of corals and one sponge group in the bycatch, although not all of these taxa were recorded for each year of the survey data (2005-2010). Each of these groups forms distinct functional groups which should be considered separately. The sea pens are found on soft bottoms and are comprised of at least 4 species (*Anthoptilum grandiflorum*, *Halipteris finmarchica*, *Pennatula grandis* and *Umbellula lindahli*). The large gorgonian-type corals are found on hard bottoms and include *Acanthogorgia armata*, *Paramuricea* spp., *Primnoa resedaeformis, Paragorgia arborea, Radicipes* spp. and *Keratoisis ornata* as well as unidentified species. The small gorgonian-type corals include species such as *Acanella arbuscula* and *Anthothela grandiflora.* These latter two groups have skeletons of magnesium calcite and so may be affected by ocean acidification. The stony corals include *Flabellum* spp. and *Desmophyllum* spp. cup corals which produce aragonite external skeletons and are also vulnerable to changes in ocean acidification. The soft corals primarily include members of the family Nephtheidae with at least one species of the Alcyoniidae (*Anthomastus* spp.). We have low confidence in the biomass data for the soft corals as they are often attached to rocks and separation from the rock is difficult.

The trawl surveys followed a depth stratified random design that implies different sampling probabilities over strata (Smith 1996). It is important to use the sampling design to calculate different probabilities for the estimates of mean and variance and to create confidence intervals by bootstrapping (Smith 1997). Smith and Robert (1998) show that such design-based variances produce correct results for the population variance even when the distribution is skewed and/or auto-correlated (and the mean is unbiased).

Stratified means were calculated for each of the functional groups along with their standard errors and 95% bootstrap confidence levels (Table 2, Figure 7) (Smith 1997). The data show large variance and irregular means over the time series. Catches of the smaller taxa (sea pens, small gorgonians, stony corals and soft corals) were all small with stratified mean values less than 1 kg. It is unlikely that these biomass estimates would be able to detect change including cataclysmic population loss. The biomass estimates for the sponges and large gorgonian corals were large enough to be distinguishable from zero; however they show high levels of inter-annual variability over the sampling period. This is particularly true for the large gorgonian corals and the variability in those means may be a result of catchability and recording issues. Data on the sponges are more reliable as they were reported properly throughout the time series, however the design efficiency for this and the other taxa should be evaluated. The increase in sponge in the 2008 survey (Table 2, Figure 7) is likely real and related to chance stations falling in the sponge grounds.

Table 2. Estimates of Shrimp Fishing Area 2EX Mean Biomass (Kg/Km^2) with Associated Standard Error and 95% Confidence Intervals for Each of Sponges, Sea Pens, Large and Small Gorgonian Corals, Stony Corals and Soft Corals (Nephtheidae).

Year	Biomass Estimate	Sponge (all Porifera)	Sea Pens	Large Gorgonian Corals	Small Gorgonian Corals	Stony Corals	Soft Corals
2005	Mean	1272.2	0	17.44	0	0	0
	SE	572.9		10.40			
	Lower 95% CI	396.3		0.40			
	Upper 95% CI	2574.4		40.91			
2006	Mean	775.5	0	303.31	0	0	0.028
	SE	251.9		211.95			0.028
	Lower 95% CI	306.6		13.56			0.000
	Upper 95% CI	1290.0		726.56			0.105
2007	Mean	1088.7	0.589	254.43	0.880	0.233	0.971
	SE	314.6	0.511	200.41	0.702	0.184	0.624
	Lower 95% CI	414.2	0.000	11.83	0.005	0.000	0.124
	Upper 95% CI	1763.1	1.219	610.73	2.584	0.684	2.208
2008	Mean	3173.7	0.234	68.70	0.118	0.215	0.060
	SE	616.5	0.106	68.55	0.036	0.215	0.034
	Lower 95% CI	2132.0	0.037	0.00	0.057	0.000	0.007
	Upper 95% CI	4394.0	0.470	206.00	0.190	0.538	0.128
2009	Mean	552.1	0.193		0	0	0.025
	SE	324.6	0.100				0.019
	Lower 95% CI	88.5	0.025				0.000
	Upper 95% CI	1377.9	0.416				0.066
2010	Mean	731.4	0.132	191.02	0.153	0.136	0.055
	SE	177.3	0.093	190.75	0.095	0.061	0.022
	Lower 95% CI	418.6	0.000	0.00	0.017	0.029	0.014
	Upper 95% CI	1061.2	0.318	509.20	0.383	0.263	0.101

PATCH AREA AND DENSITY

<u>Sponge Grounds</u>

The patch area (km^2) was calculated for each of the sponge grounds circumscribed by the 40 kg significant weight threshold determined by Kenchington et al. (2010a) as indicative of significant concentrations of sponge. The area for each sponge patch (N=33) was calculated using the

Spatial Analyst tools in ArcGIS v.10 (ESRI 2011). The data were log10-transformed and fit the normal distribution after transformation (Shapiro-Wilk $W = 0.964$, $P = 0.328$) with equal variances (Levene $F = 1.63$, $P = 0.19$). Patch density and summary statistics for patch area are provided in Table 3. Univariate ANOVA showed that the mean patch size did not differ between years ($F = 1.31$, $P = 0.29$) (Figure 8).

The patch area indicator has good distributional properties for statistical analyses. Also, it did not show any significant difference in the mean area occupied by sponge catches greater than 40 kg over the six years of the surveys (Figure 8). This meets with our expectation, given that the sponges are long-lived and have low natural birth, mortality and growth rates (Boutillier et al. 2010). Nevertheless, this indicator may be sensitive to mass mortality events and given that it is derived from ongoing surveys we recommend it for future monitoring.

Table 3. Density and Area of Sponge Grounds (Patches) in Shrimp Fishing Area 2EX.

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Patch Density	6	3	10	7	3	4
			Patch Area (km^2)			
	90.2	164.8	112.3	134.1	118.7	191.8
	77.2	57.7	40	115.9	33.7	49.2
	10.2	14.4	32.6	61.7	33	19.9
	8.3		25.8	46.8		14.3
	6.4		23.3	21.2		
	2.9		20.9	18.8		
			14.3	12		
			14.2			
			13.5			
			12.1			
Log 10-transformed						
Mean	1.17	2.27	1.64	2.13	2.31	2.06
Standard Error	0.34	0.48	0.27	0.32	0.48	0.42
Maximum Area	90.2	164.8	112.3	134.1	118.7	191.8

In contrast, patch density (number of sponge patches in the SFA2EX area) and the maximum patch area have high inter-annual variation (Table 3, Figure 6). This is a consequence of the distance between survey points relative to the size and location of the sponge grounds. Patch density is subject to change if the survey by chance samples isolated sponge over 40 kg. The random positioning of the survey points over 40 kg also will change the shape of the 40 kg sponge patches, causing inter-annual variability in the maximum area indicator [note: Kenchington et al. (2010a) combined the survey data from multiple years to achieve stability in patch location and area]. For these indicators the years were grouped into two bins (Table 4), composed of three data points (consecutive survey years). The variances were statistically equivalent using Levene's test for unequal variances for both indices across bins ($P > 0.05$). T-tests for equality of the means for each index also were all non-significant (Table 4). Therefore, we recommend that patch density and maximum patch area be considered as indicators for coral and sponge grounds and that these are re-assessed over three year periods. Both of these indices are derived from the data used to assess patch area and so are easily generated.

Table 4. t-Tests of the Maximum Patch Area and Patch Density of Sponge Grounds (Patches) in Shrimp Fishing Area 2EX. Bins used for Data Analyses and Mean and Standard Error are Indicated.

Indicator (Mean ± S.E.)	**Bin Configuration (Years)**		***t* ratio; *P***
	(2005, 2006, 2007)	**(2008, 2009, 2010)**	
Maximum Patch Area (km^2)	122.43 ± 22.12	148.20 ± 22.25	0.821; 0.458
Patch Density	6.3 ± 2.0	4.7 ± 1.2	-0.707; 0.519

Sea Pen Fields

The patch area (km^2) was calculated for each of the sea pen fields circumscribed by the 0.05 kg significant weight threshold determined by Kenchington et al. (2010a) as indicative of significant concentrations of sea pens caught using Campelen trawl gear in this area. Sea pen fields are not as widespread as the sponge grounds and no significant concentrations were detected in 2007 due to the chance location of the trawl stations (Table 5).

The area for each sea pen patch (N=15) was calculated using the Spatial Analyst tools in ArcGIS v.10 (ESRI 2011). Patch area estimates were highly variable (Table 5), which we also attribute to poor survey design efficiency for these organisms. The data were log10-transformed but did not fit the normal distribution after transformation (Shapiro-Wilk W = 0.830, P = 0.012) and maintained unequal variances (Levene F = 4.24, P = 0.04). A non-parametric rank sum test (Kruskal-Wallis Test) found no significant difference in sea pen patch area among survey years (*Chisq* = 2.205, P = 0.698). Binning the data improved the variance structure (Levene F = 1.54, P = 0.24). *t*-tests of the binned data found no significant difference in mean patch size of the sea pen fields (Table 6).

Table 5. Density and Area of Sea Pen Fields (Patches) in Shrimp Fishing Area 2EX.

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Patch Density	4	1	0	3	4	2
			Patch Area (km^2)			
	23.7	35.5		6.0	19.8	39.1
	5.6			5.4	138.0	20.4
	19.3			651.5	5.6	
	6.2				5.6	
Log 10-transformed						
Mean	1.05	1.55		1.44	1.23	1.45
Standard Error	0.35	0.71		0.41	0.35	0.50
Maximum Area	23.7	35.5		651.5	138.0	39.1

The Maximum Patch Area was log 10-transformed prior to analysis. The variances of both the transformed Maximum Patch Area and Patch Density were statistically equivalent across bins by Levene's test for unequal variances ($P > 0.05$) and no significant difference between the mean values in each bin was detected with *t*-tests (Table 6). Binning the data across 3 years is recommended for these data.

Table 6. t-Tests of the Patch Area, Maximum Patch Area and Patch Density of Sea Pen Fields (Patches) in Shrimp Fishing Area 2EX. Bins used for Data Analyses and Mean and Standard Error are Indicated.

Indicator (Mean ± S.E.)	**Bin Configuration (Years)**		***t* ratio; *P***
	(2005, 2006, 2007)	**(2008, 2009, 2010)**	
Log 10-transformed Patch Area (km^2)	1.15 ± 0.36	1.35 ± 0.73	0.691; 0.503
Log 10-transformed Maximum Patch Area (km^2)	1.46 ± 0.36	2.18 ± 0.29	1.977; 0.173
Patch Density	2.5± 1.04	3.0 ± 0.85	0.372; 0.734

Large and Small Gorgonian Corals

The selected area for assessment, SFA2EX, and the design efficiency of the survey for the gorgonian corals were not suited for further analyses. Patches were inconsistently sampled over this time frame and area (Table 7). Lower catch thresholds for both the large and small gorgonian corals (0.5 kg and 0.01 kg, respectively) were examined to see whether additional data could be collected from the SFA2EX area. However all records were outside of SFA2EX and so did not alter the results. Due to this distribution of patches the other geospatial indicators were not assessed for these corals.

Table 7. Density and Area of Large and Small Gorgonian Coral (Patches) in Shrimp Fishing Area 2EX.

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
			Large Gorgonians			
Patch Density	0	0	1	1	1	2
			Patch Area (km^2)			
			2.2	1.7	6.1	14.9
						21.4
			Small Gorgonians			
Patch Density	0	1	0	1	0	2
			Patch Area (km^2)			
		31.0		64.2		33.1
						19.8

ISOLATION/PROXIMITY OF SPONGE GROUNDS

Nearest neighbour distances among sponge patches in SFA2EX were determined by measuring the straight line distance between pairs of patches using ArcGIS v.10 (ESRI 2011) distance measure tools (Figure 9). The nearest neighbour distances are provided in Table 8. Duplicate measures were discounted (i.e., measurements from A to B and B to A were only recorded once). Distributional issues with the data required a 4th root transformation in order to approximate a normal distribution. Although the data distribution was greatly improved by this transformation the Shapiro-Wilk W test rejected H_0 (W = 0.955; P = 0.003). Levene's test showed equality of variances (F = 1.22, P = 0.305). A non-parametric rank sum test (Kruskal-Wallis Test) found no significant difference in average nearest neighbour distances among survey years (*Chisq* = 10.554, P = 0.061).

Table 8. Nearest Neighbour Distances (km) between all Possible Pairs of Sponge Patches in Shrimp Fishing Area 2EX (Figure 6) for each of Six Consecutive Years.

Survey Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
	454.28	421.50	472.68	512.57	162.15	166.37
	441.16	377.78	467.69	501.52	121.24	146.40
	410.18	70.11	466.17	463.96	55.07	105.98
	352.01		462.41	458.59		77.82
	299.92		457.78	403.03		68.16
	167.50		452.39	396.93		40.88
	141.75		357.62	356.59		
	113.67		353.99	351.26		
	111.10		349.71	350.75		
	95.27		337.20	302.52		
	94.46		331.11	241.16		
	73.86		317.30	194.60		
	58.39		315.66	180.63		
	54.79		314.73	162.73		
	43.56		310.77	161.31		
			308.84	148.14		
			307.45	114.50		
			238.55	108.11		
			236.57	75.80		
			236.38	61.67		
			231.22	46.56		
			226.63			
			200.32			
			186.07			
			183.67			
			171.63			
			157.56			
			157.34			
			156.45			
			153.06			
			151.72			
			150.46			
			136.75			
			123.73			
			117.89			
			108.98			
			108.60			
			98.98			
			96.07			
			83.08			
			80.14			
			62.54			
			43.23			
			34.74			
			29.51			
4th Root Mean	3.53	3.94	3.76	3.89	3.20	3.11
Std. Error	0.16	0.35	0.09	0.13	0.35	0.25

CONNECTIVITY OF SPONGE GROUNDS

Information on the timing and duration of gamete release can be used to track larval movement using oceanographic models. Such trajectories can be used to evaluate connectivity among sponge patches and to set population neighbourhood sizes. Webdrogue (http://www.bio.gc.ca/science/research-recherche/ocean/webdrogue/index-eng.php) is a graphical user interface that calculates drift predictions using circulation derived from the tides, the seasonal mean circulation, wind-driven circulation, and surface-wind drift (Hannah et al. 2000). The model for the Arctic has recently been updated (Hannah et al. 2008).

The reproduction of the cold-water Arctic sponge, *Geodia barretti,* has been studied in Norway (Spetland et al. 2007). The onset of reproduction coincides with the phytoplankton bloom. Just after the phytoplankton spring bloom is over in early summer, gametes are released, when organic matter sedimentation is highest. In the vicinity of the SFA2EX, the phytoplankton bloom is initiated in late June and runs on average 8 weeks ending in mid-August (Fuentes-Yaco et al. 2007). Sponge larvae are uniformly non-feeding and short-lived (except for rare known exceptions), generally staying only a few hours in the water column (Maldonado and Bergquist 2002) and settling in the vicinity of parental populations (Mariani et al. 2003). With such high levels of larval retention (Mariani et al. 2006) it is likely that connectivity among the patches is very low and that the patches are highly inbred. The significant patches of sponges likely are the connectivity neighbourhood for this functional group. Application of Webdrogue confirmed this hypothesis with no detectable larval movement in simulated drift trajectories. Formation of isolated patches may be through chance transport events, rather than mediated through predictable currents.

DISPERSION OF SPONGE GROUNDS

Isolation/proximity was also determined directly from the ArcGIS v.10 platform using the Average Nearest Neighbour Distance tool in the Spatial Statistics toolbox (ESRI 2011). This tool produces average measures among all pairs of patches but does not transform the data. Instead it assumes data independence and therefore the mean value that it produces may not be a true estimate of the population mean. The tool evaluates dispersion from the spatial pattern of the patches or individual tow locations with sponge bycatch, using either the point spread as the base area or a user-defined fixed area. The Nearest Neighbour Index that is calculated is the ratio of the observed distance divided by the expected distance (calculated from a hypothetical random distribution with the same number of features covering the same total area). Values greater than 1 indicate a dispersed pattern and values less than 1 indicate a clustered or aggregated pattern. This analysis assumes that the patches being measured are free to locate anywhere within the study area and are located independently of one another. This assumption is unlikely to be true over large spatial areas where substrate type and bottom currents influence species distributions, but may be true over smaller spatial scales. *Z* scores are used to test the statistical significance of the null hypothesis of random distribution.

Table 9 provides the mean distances calculated with this tool for both patches and individual tow locations with sponge bycatch for each survey year, along with the corresponding statistics evaluating dispersion. An example of the dispersion of patches for the 2005 survey is shown in Figure 10. Each year the sponge patches tended towards a uniform distribution (as opposed to random or aggregated). Changes in this ratio towards aggregation could indicate habitat fragmentation, which could affect reproductive capacity. Individual tow locations with sponge by-catch were mildly but significantly clustered in 2005 and 2006 but randomly distributed in 2007, 2008, 2009 and 2010.

The mean nearest neighbour distances (Table 9) were log10-transformed while the Nearest Neighbour Index ratio was arcsine-transformed. Both measures followed a normal distribution after transformation as assessed by the Sharpiro-Wilk *W* test (P = 0.13, P = 0.38, respectively). Linear regressions of each transformed index with year were non-significant indicating no significant trend in the data. The data were further analyzed by Bin (Table 4). Levene's test supported equality of variances in all instances (P> 0.05) and *t*-tests were non-significant. Trend lines for these metrics are illustrated in Figure 11.

Table 9. Mean Nearest Neighbour Distances (km) Between all Possible Pairs of Sponge Patches in Shrimp Fishing Area 2EX (Figure 6) and for Each Tow Location with Sponge By-Catch for Each of Six Consecutive Years. Mean Distances were Calculated with the Average Nearest Neighbour Distance tool in ArcGIS v.10 (ESRI 2011). Expected Distances Are Used to Calculate the Nearest Neighbour Index with Corresponding Z-Scores.

Sponge Patches	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Observed Mean Distance	95.08	172.66	66.31	83.17	77.13	63.97
Expected Mean Distance	41.66	42.64	36.95	43.27	20.66	24.93
Average Nearest Neighbour Index	2.28	4.05	1.79	1.92	3.73	2.57
z-score	6.01	10.10	4.81	4.67	9.05	5.99
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Individual Tows with Sponge						
Observed Mean Distance	21.29	22.39	20.37	20.23	29.84	31.17
Expected Mean Distance	26.61	26.33	21.77	20.16	33.22	27.86
Average Nearest Neighbour Index	0.80	0.85	0.94	1.00	0.90	1.12
z-score	-2.20	-1.81	-0.88	0.05	-0.95	1.20
p-value	0.03	0.07	0.38	0.96	0.34	0.23

DISPERSION OF SEA PEN FIELDS

Because only one patch was observed in the SFA2EX area in 2006 and none were recorded in 2007 (Table 5), isolation/proximity, dispersion and connectivity indices could not be fully evaluated as the time series was insufficient being less than 5 years (Gill et al. 2011). Mean nearest neighbour distances and the associated Nearest Neighbour Index calculated with the Average Nearest Neighbour Distance tool in ArcGIS v.10 (ESRI 2011) show distant and dispersed patches (Table 10).

Table 10. Mean Nearest Neighbour Distances (km) Between all Possible Pairs of Sea Pen Patches in Shrimp Fishing Area SFA2EX for Each of Four Years when the values can be calculated. Expected Distances Are Used to Calculate the Nearest Neighbour Index with Corresponding Z-Scores.

	2005	**2008**	**2009**	**2010**
Observed Mean Distance	92.63	89.67	137.80	115.84
Expected Mean Distance	28.00	22.17	35.33	0.17
Average Nearest Neighbour Index	3.31	4.05	3.90	680.72
z-score	8.83	10.09	11.10	1838.97
p-value	<0.001	<0.001	<0.001	<0.001

SAMPLING APPROACHES FOR CORAL AND SPONGE MEGAFAUNA

The indices discussed in this paper are calculated from research trawl survey bycatch data. There are many advantages to this type of data. Trawl surveys provide broad spatial coverage usually following a stratified random design. The bycatch data can be related to changes in the associated data on the target species, thus allowing for integrated interpretation of trends, and in many cases associated physical data are collected. The Canadian surveys in the Eastern Arctic are not fixed station surveys and so are not expected to show trends over the time series evaluated. This type of survey design is preferable to fixed station designs which would only document local depletion at each station (e.g., Rooper et al. 2011). However, we know that trawlers are not good quantitative samplers of corals and sponges for the reasons discussed above.

Ideally, *in situ* monitoring stations should be established in strategic locations and surveyed periodically (at 5 to 10 year intervals or adaptively informed by environmental or anthropogenic factors). Baseline underwater camera surveys are planned for Davis Strait, Southern Baffin Bay and Lancaster Sound in 2012. If completed as planned these stations would give much more precise information on abundance, species composition, proportion of live:dead coral and proportion of parasitized coral colonies at key locations in the Eastern Arctic. Such precision may be necessary to document gradual changes in coral and sponge-dominated communities.

SUMMARY

Nineteen potential indicators for monitoring corals and sponges in the Eastern Canadian Arctic were considered (Table 11). Four were put forward by the Arctic Marine Biodiversity Monitoring Plan (Gill et al. 2011), three from the Gully Marine Protected Area monitoring plan (Kenchington 2010), three from the European Commission (EC 2008) and one from an ICES study group (ICES 2011). The remainder are novel contributions drawn primarily from geospatial statistics and known stressors. We examined in detail six of these indicators: *Mean biomass* trends of selected corals and sponge from research vessel surveys in the Eastern Arctic; *Patch area* and *Patch Density* of sponge grounds, sea pen fields, large gorgonian corals and small gorgonian corals; *Isolation/Proximity* of sponge grounds; *Connectivity* between sponge grounds; and *Dispersion* of sponge grounds and sea pen fields. A summary of the indicators discussed in this paper is presented in Table 11. Geo-referenced biomass/abundance data by species allow for the calculation of nine of the twelve state indicators. Further information on the proportion of live:dead fauna, percent infestation with zoanthid anemones and size structure completes the data requirement for state indicators.

Due to concerns over the reliability and performance of biomass estimates from trawl surveys (and more so with abundance), the use of mean biomass is not recommended. The other indicators were calculated from the spatial array of sponge and coral patches. These were also determined from trawl survey data but only to locate high density areas relative to other areas. The location of these patches, especially ones made including more than one set, is relatively stable from year to year as expected for sessile fauna with long life-spans and low recruitment. All of the geostatistic-based indicators performed well in our initial assessment on the sponges. That is they had distributional properties, including variances smaller than the mean values, that were amenable to hypothesis testing using either parametric or non-parametric statistics. They also showed no significant trend across the six year study which accords with expectation. It remains to be seen whether those indicators are sensitive to environmental or other change but we consider them to be good candidates for future monitoring of coral beds and sponge grounds, and hence of biodiversity. Sea pen fields were amenable to assessment of patch area, patch density and maximum patch area indicators. However, the survey failed to detect significant concentrations of sea pens in one year, and only detected one patch in another. With only four years sampled the isolation/proximity, connectivity and dispersion indicators could not be analyzed.

We advocate the use of underwater camera surveys (video, photo) for the collection of data for assessing abundance, biomass and diversity trends. Such data collections are anticipated for the 2012 field season and if successfully collected could provide improved baseline data for those indicators. The geospatial indicators can also be calculated from these surveys, albeit over a smaller spatial scale.

The choice of indicators must relate to clear questions or objectives. The CBD SBSTTA identifies these as "policy questions". Regardless of whether the questions link to policy, they do articulate clear questions that help to shape the appropriate indicators. The Gully MPA monitoring plan (DFO 2010, Kenchington 2010) has developed objectives such as: "Protect seafloor habitat and associated benthic communities", which also provide a framework for developing indicators.

Although threat indicators have yet to be assessed they are critical to the interpretation of changes to the state indicators. Figure 12 illustrates how change to the physical environment can initiate a response in a state indicator. If only state indicators are monitored then it may be impossible to answer the linked question "*Why are we losing biodiversity*". Equally, if only stressor indicators are monitored then changes to benthic biodiversity must be assumed. Our proposal places a greater emphasis on state indicators in order to document change through a range of biological and ecological properties affecting the structural species forming these habitats. We then select indicators that measure known threats to coral and sponge, namely fishing with bottom contact gear, ocean acidification, changes to circulation and food supply. An indicator framework of some type is useful to ensure that these linkages are in place. Table 12 places the 19 indicators proposed in this document into the indicator framework proposed by the CBD SBSTTA (UNEP/CBD/SBSTTA/15/2; http://www.cbd.int/doc/meetings/cop/cop-11/official/cop-11-02-en.pdf), illustrating that they can be made consistent with global initiatives. Note that in this framework, state indicators may also be stressor indicators. This is especially true for sea pen fields, coral beds and sponge grounds which are habitat proxies for biodiversity.

Table 11. A Summary of Potential Indicators for Monitoring Coral and Sponge Grounds in the Arctic. Level of Confidence is derived from Statistical Evaluation in the Text and from Published Literature.

Indicator (Source)	Primary Link with Biological/Ecosystem Property	Data Source/Sampling Tool	Level of Confidence in the Data
State Indicators			
1. Abundance (CAFF[1], Gully[2])	Biodiversity; ecological function; reproductive success	Trawl Survey; Common gear and area	Low
		In situ Photographic/video Transects	High
2. Biomass (CAFF, Gully)	Ecological function; reproductive success	Trawl Survey; Common gear and area	Low
3. Distribution (CAFF)	Ecosystem resilience; ecosystem function; genetic diversity	All records; Trawl surveys; Fisheries Observers	Medium
4. Diversity Indices (e.g., Shannon, Simpson, Evenness, Taxonomic Redundancy, Response Diversity) (CAFF, Gully)	Biodiversity, ecosystem resilience; ecosystem function; genetic diversity	Trawl Survey; Common gear and area	Low
		In situ Photographic/video Transects	High
5. Size Structure (Gully)	Ecological function; reproductive success	*In situ* Photographic/video Transects	Medium
6. Live:Dead ratio (Gully)	Mortality rate; Physiological stress	*In situ* Photographic/video Transects	Medium
7. % zoanthid cover (Gully)	Physiological stress	Trawl Survey; Common gear and area	Medium
		In situ Photographic/video Transects	High
8. Patch area	Biodiversity; ecological function; reproductive success	Trawl Survey; Common gear and area	High
9. Patch density	Reproductive success	Trawl Survey; Common gear and area	Medium
10. Patch Isolation/Proximity	Reproductive success; genetic diversity	Trawl Survey; Common gear and area	High
11. Patch Connectivity	Reproductive success; genetic diversity	Trawl Survey; Common gear and area	Medium
12. Patch Dispersion	Reproductive success	Trawl Survey; Common gear and area	High
Stressor Indicators			
13. Distribution of fishing activities (MSFD)	Fishing mortality; Abundance/Biomass	VMS data	High
14. Aggregation of fishing activities (MSFD)	Fishing mortality; Abundance/Biomass	VMS data	High
15. Areas not impacted by mobile bottom gears (MSFD)	Ecological function; reproductive success	VMS data	High
16. Timing and duration of anomalous events	Abundance/Biomass	Various	Low
17. Timing of phytoplankton bloom	Reproductive success; productivity	Chl *a*; satellite data	Medium
18. Timing, duration and path of sea ice melt	Productivity	Satellite data	Medium
19. Biomarkers	Physiological stress	Various	High

[1]CAFF: Conservation of Arctic Flora and Fauna; [2]Gully: the Gully Marine Protected Area Monitoring Plan (DFO 2010, Kenchington 2010)

Table 12. Placement of the Nineteen Proposed Indicators in Context with the Questions and Closest Operational Indicators in the Proposed Indicator Framework for Assessing Progress Towards the Implementation of the Strategic Plan for Biodiversity 2011-2020 and Achievement of the Aichi Biodiversity Targets as Detailed by the Subsidiary Body on Scientific and Technological Advice for the Convention on Biological Diversity (UNEP/CBD/SBSTTA/15/2). [Bracketed numbers refer to decisions and processes endorsing the indicator]

Proposed Indicators for Coral and Sponge	"Policy Question" (CBD SBSTTA)	CBD SBSTTA Operational Indicators
State Indicators		
1. Abundance	How is the state of biodiversity changing?	Trends in condition and vulnerability of ecosystems
2. Biomass		Trends in condition and vulnerability of ecosystems
3. Distribution		Trends in the extent of selected biomes, ecosystems and habitats (VII/30, VIII/15)
4. Diversity Indices (e.g., Shannon, Simpson, Evenness, Taxonomic Redundancy, Response Diversity)		Trends in condition and vulnerability of ecosystems
5. Size Structure		Trends in condition and vulnerability of ecosystems
6. Live:Dead ratio		Trends in condition and vulnerability of ecosystems
7. % zoanthid cover		Trends in condition and vulnerability of ecosystems
8. Patch area		Trends in the extent of selected biomes, ecosystems and habitats (VII/30, VIII/15)
9. Patch density		Trends in the extent of selected biomes, ecosystems and habitats (VII/30, VIII/15)
10. Patch Isolation/Proximity		Trends in fragmentation of natural habitats (VII/30, VIII/15)
11. Patch Connectivity		Trends in fragmentation of natural habitats (VII/30, VIII/15)
12. Patch Dispersion		Trends in fragmentation of natural habitats (VII/30, VIII/15)
Stressor Indicators		
13. Distribution of fishing activities	Why are we losing biodiversity?	Trends in the area, frequency, and/or intensity of destructive fishing practices
14. Aggregation of fishing activities		Trends in the area, frequency, and/or intensity of destructive fishing practices
15. Areas not impacted by mobile bottom gears		Trends in the area, frequency, and/or intensity of destructive fishing practices
16. Timing and duration of anomalous events		Trends in climatic impacts on community composition
17. Timing of phytoplankton bloom		Trends in incidence of hypoxic zones and algal blooms
18. Timing, duration and path of sea ice melt		Trends in climatic impacts on community composition
19. Biomarkers		Trend in emission to the environment of pollutants relevant for biodiversity
3. Distribution		Trends in extent, and rate of shifts of boundaries, of vulnerable ecosystems
6. Live:Dead ratio		Trends in coral reef condition
7. % zoanthid cover		Trends in coral reef condition

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FIGURES

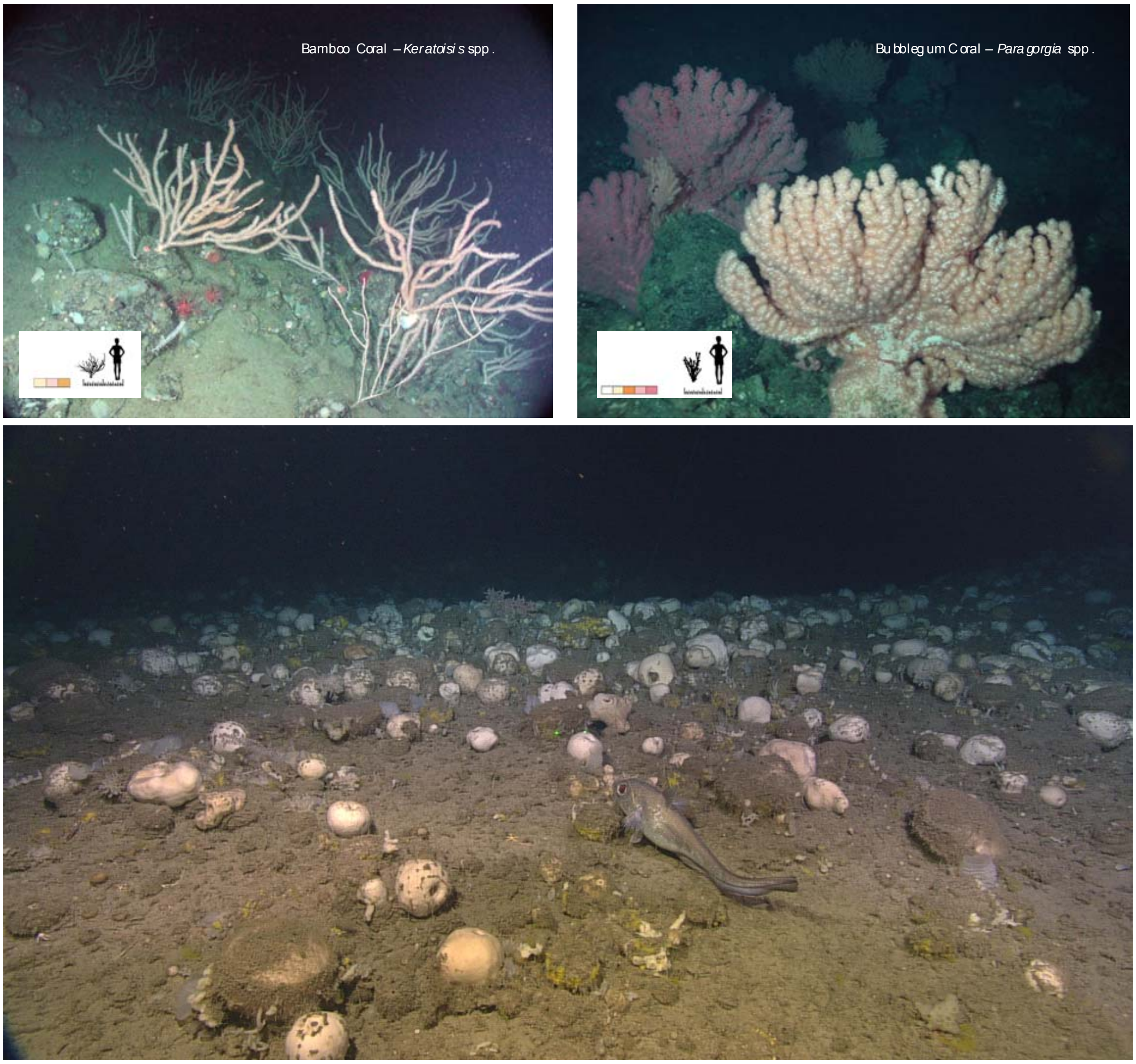


Figure 1. Examples of structure-forming coral and sponge known to occur in the Canadian Arctic (Upper left: Keratoisis *spp.; Upper right:* Paragorgia arborea*; Lower: Sponge grounds on Flemish Cap dominated by species of* Geodia *which also occur in the Arctic).*

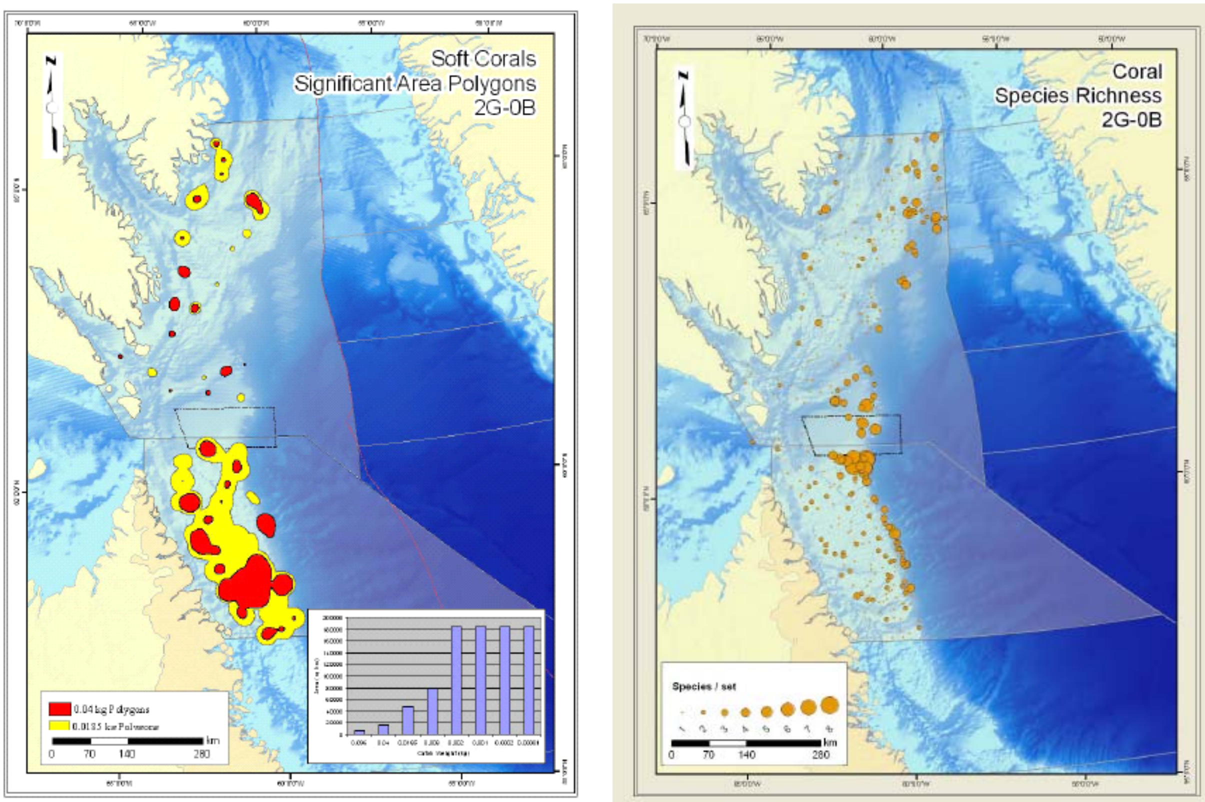


Figure 2. Left: Location of significant concentrations of soft corals (Nephtheidae) from the Labrador Shelves and Davis Strait areas (from Wareham et al. 2010). Right: Coral species richness from the Northern Shrimp Survey bycatch (from Wareham et al. 2010). The location of the voluntary Coral Conservation Closure is indicated by a box at the outflow of Hudson Strait.

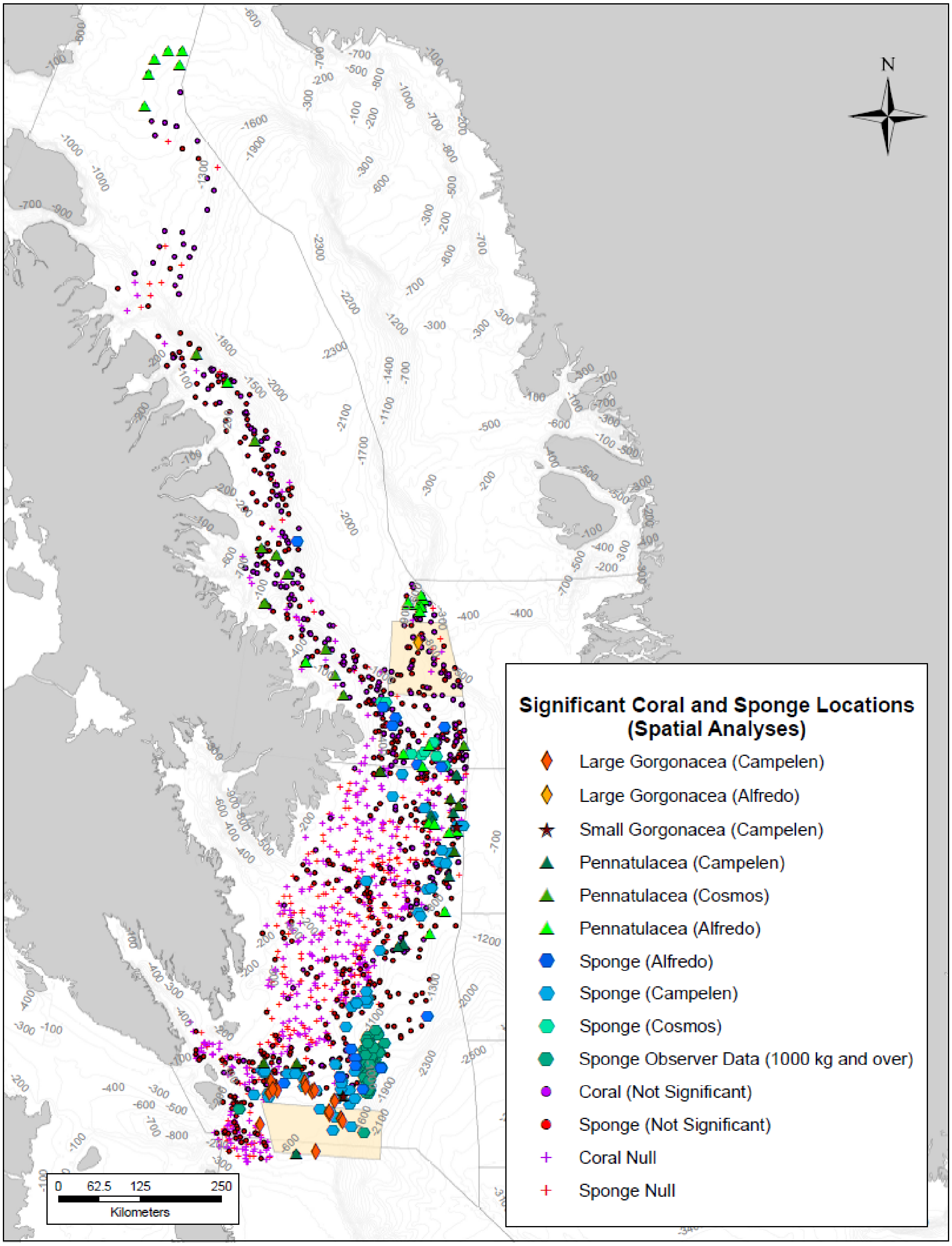


Figure 3. Location of significant concentrations of gorgonian corals, sea pens and sponges in south and central Baffin Bay and Davis Strait. Smaller concentrations of coral and sponge and null records (no coral or no sponge in trawl) are also indicated. Note that null records do not necessarily equate to absence of coral or sponge on the sea floor. The location of the Hatton Basin voluntary closure area put in place by the fishing industry is identified to the east of Hudson Strait. The Narwhal Over-wintering Site and Deep-Sea Coral Conservation Area is indicated further north. Both are shown in a shade of pink (from Kenchington et al. 2011).

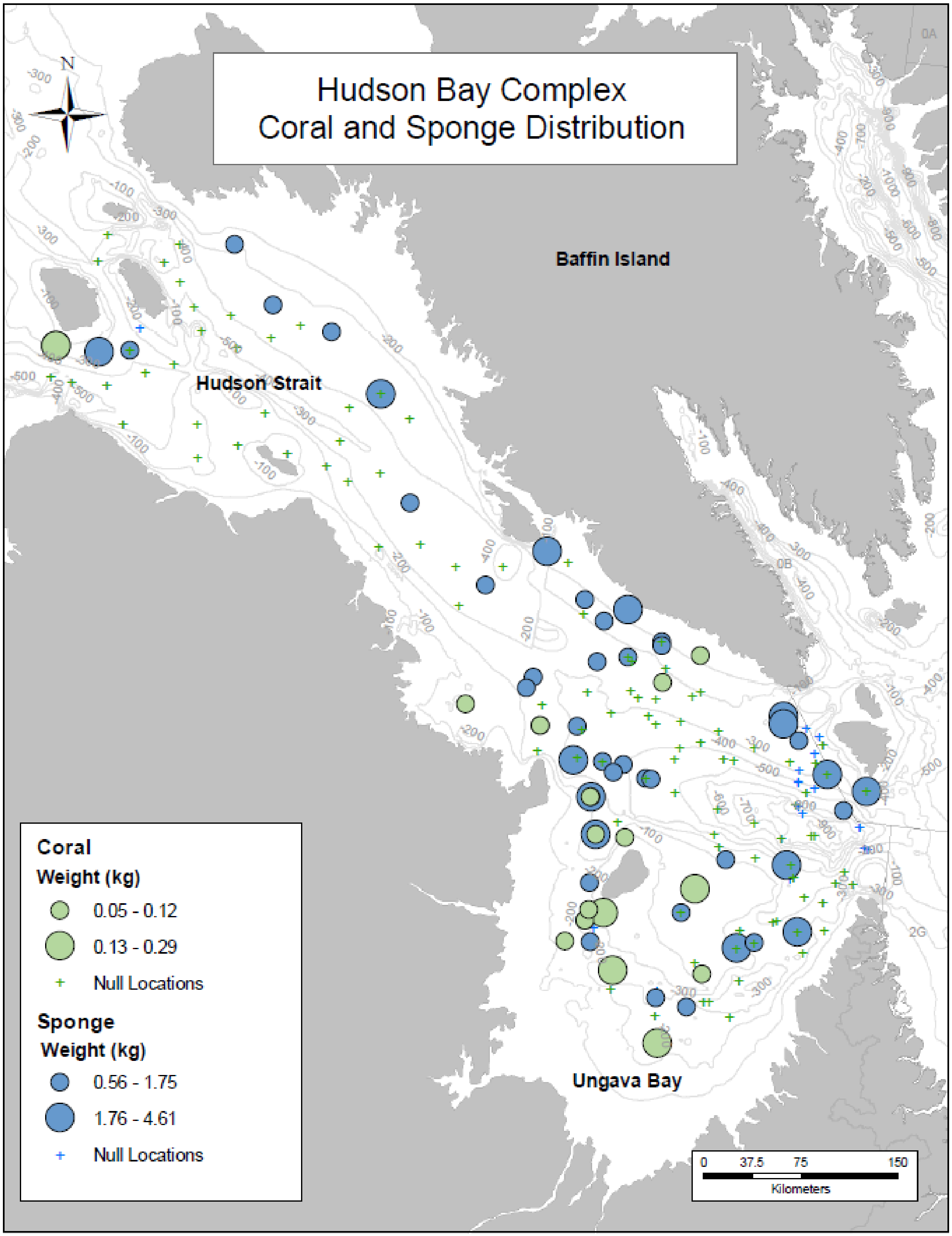


Figure 4. Location of significant concentrations of Nephtheid soft corals and sponges in Hudson Strait collected from research vessel surveys. Smaller concentrations of coral and sponge and null records (no coral or no sponge) are also indicated (from Kenchington et al. 2011).

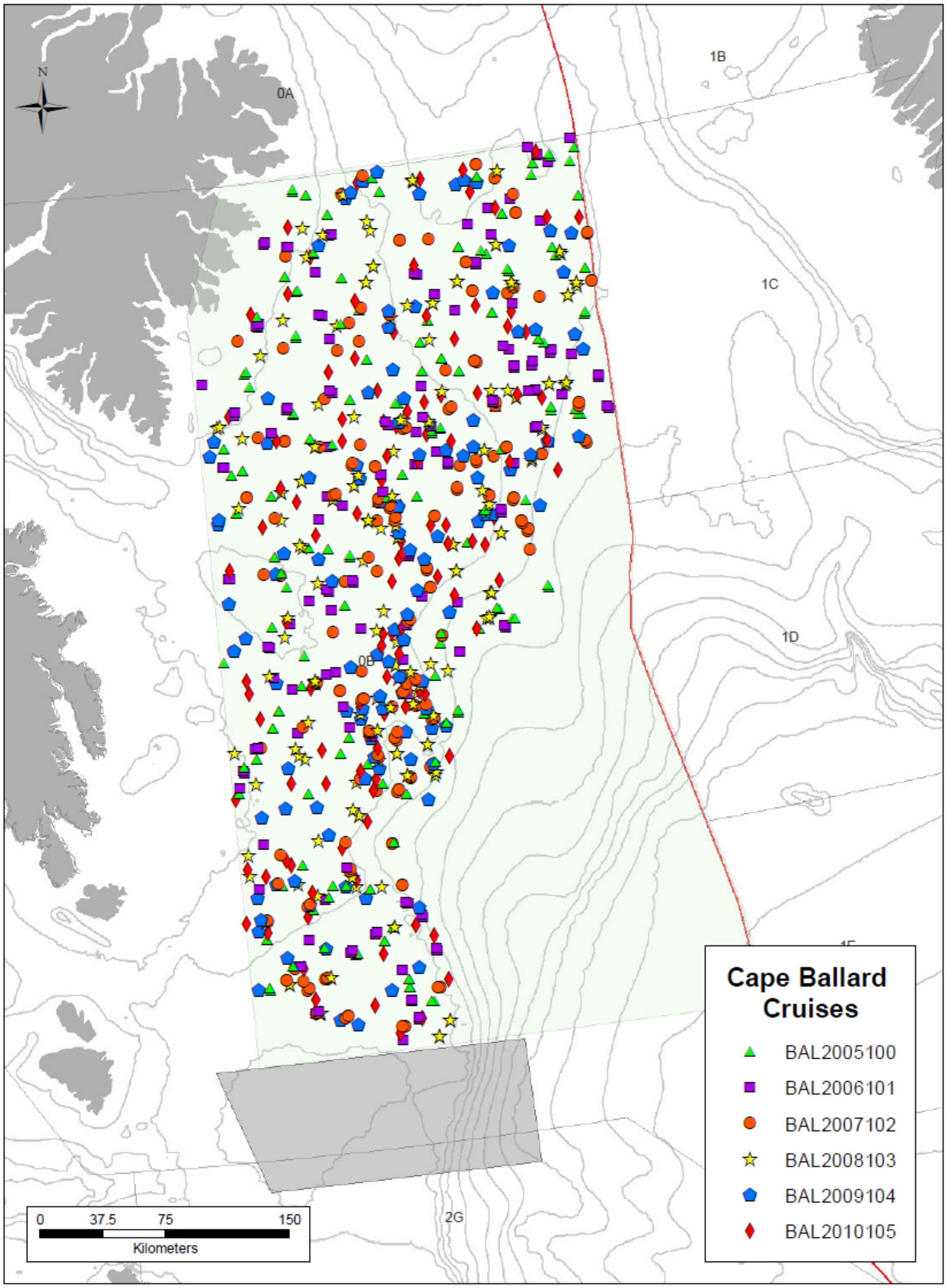


Figure 5. Common area and location of trawl stations (2005-2010) from the Northern Shrimp Research Foundation and DFO joint industry/government shrimp surveys in Shrimp Fishing Area 2EX (green shaded area) using the vessel Cape Ballard*. Different colours represent different survey years. The location of the Hatton Basin voluntary closure area put in place by the fishing industry is shaded grey. 200 m depth contours are indicated.*

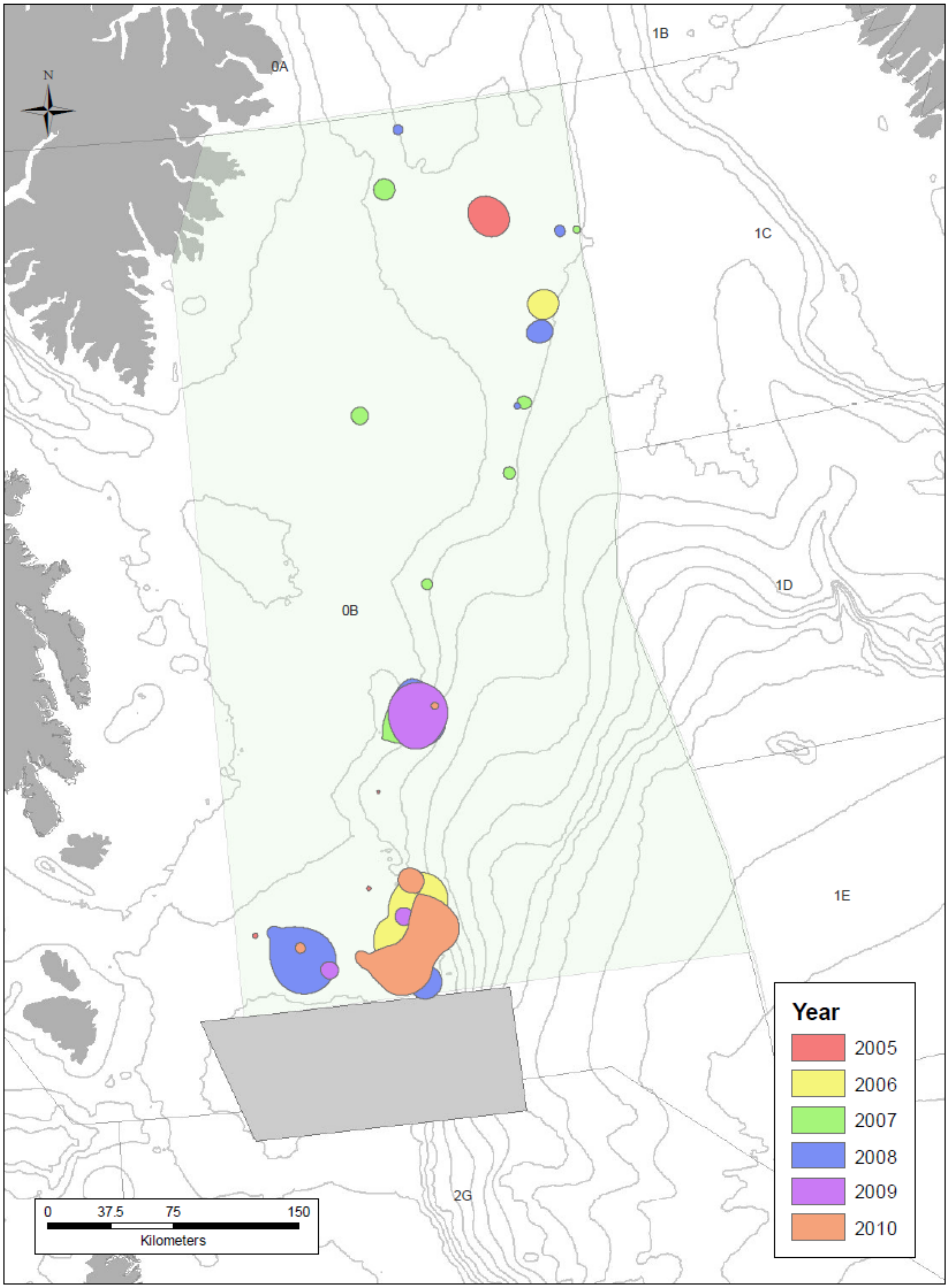


Figure 6. Location of sponge patches in each of six annual surveys with Campelen trawl gear in Shrimp Fishing Area 2EX (green shaded area) derived from catches greater than 40 kg. The location of the Hatton Basin voluntary closure area put in place by the fishing industry is shaded grey. 200 m depth contours are indicated. These patches were used to calculate the geospatial indicators for sponge grounds.

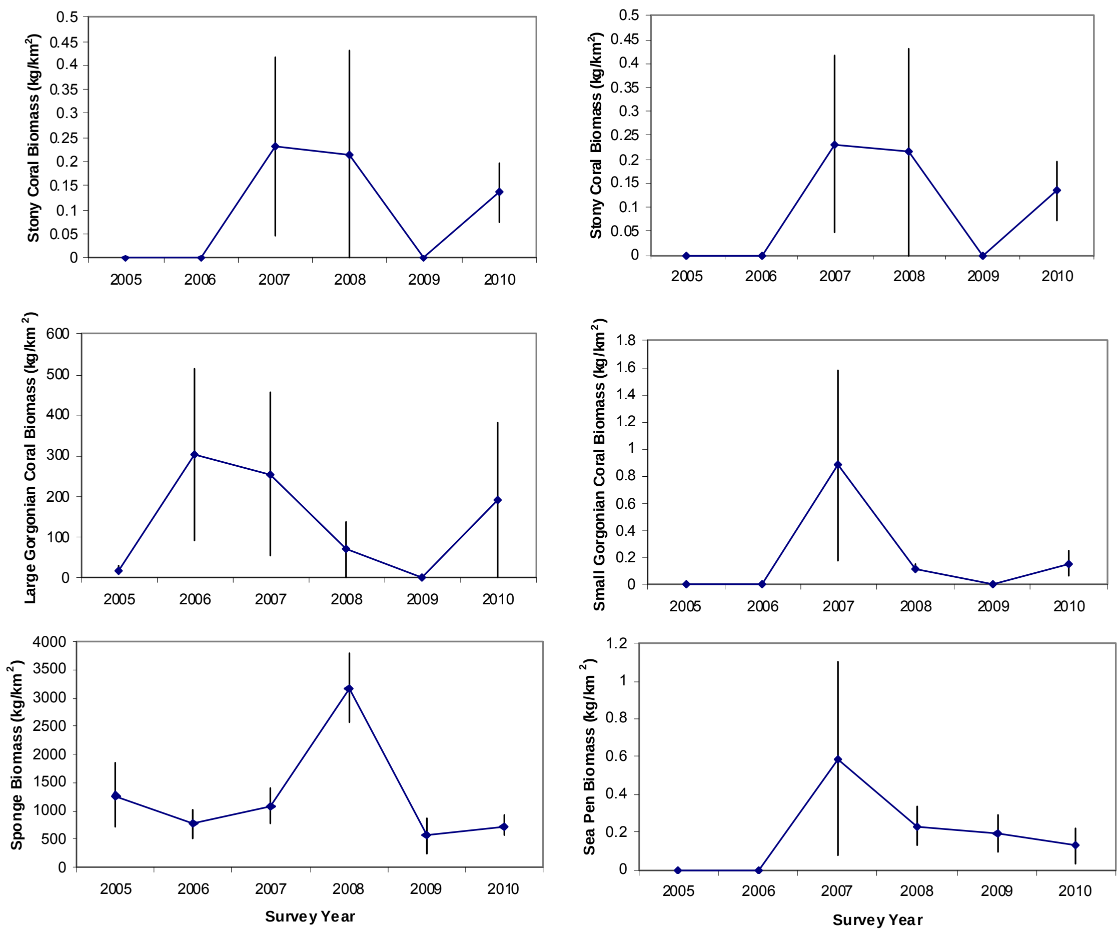


Figure 7. Stratified mean biomass (solid circle) and standard error (kg/km^2) (bars) of selected ecosystem components for Shrimp Fishing Area 2EX in each of six years (2005-2010).

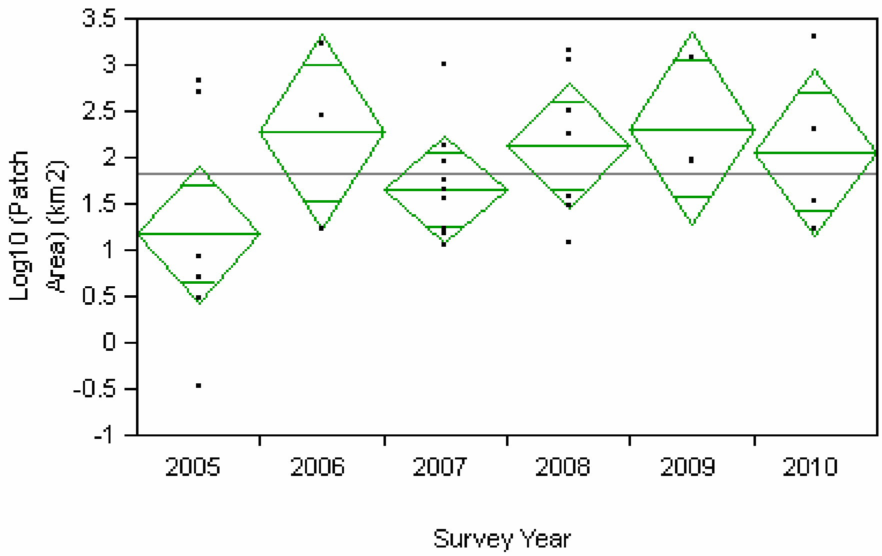


Figure 8. Transformed mean sponge patch area (km^2) for Shrimp Fishing Area 2EX in each of six years (2005-2010). The grand mean is represented by a solid black line. Lines within the green diamonds represent the mean and 95% confidence intervals. Individual patch areas are represented as black points.

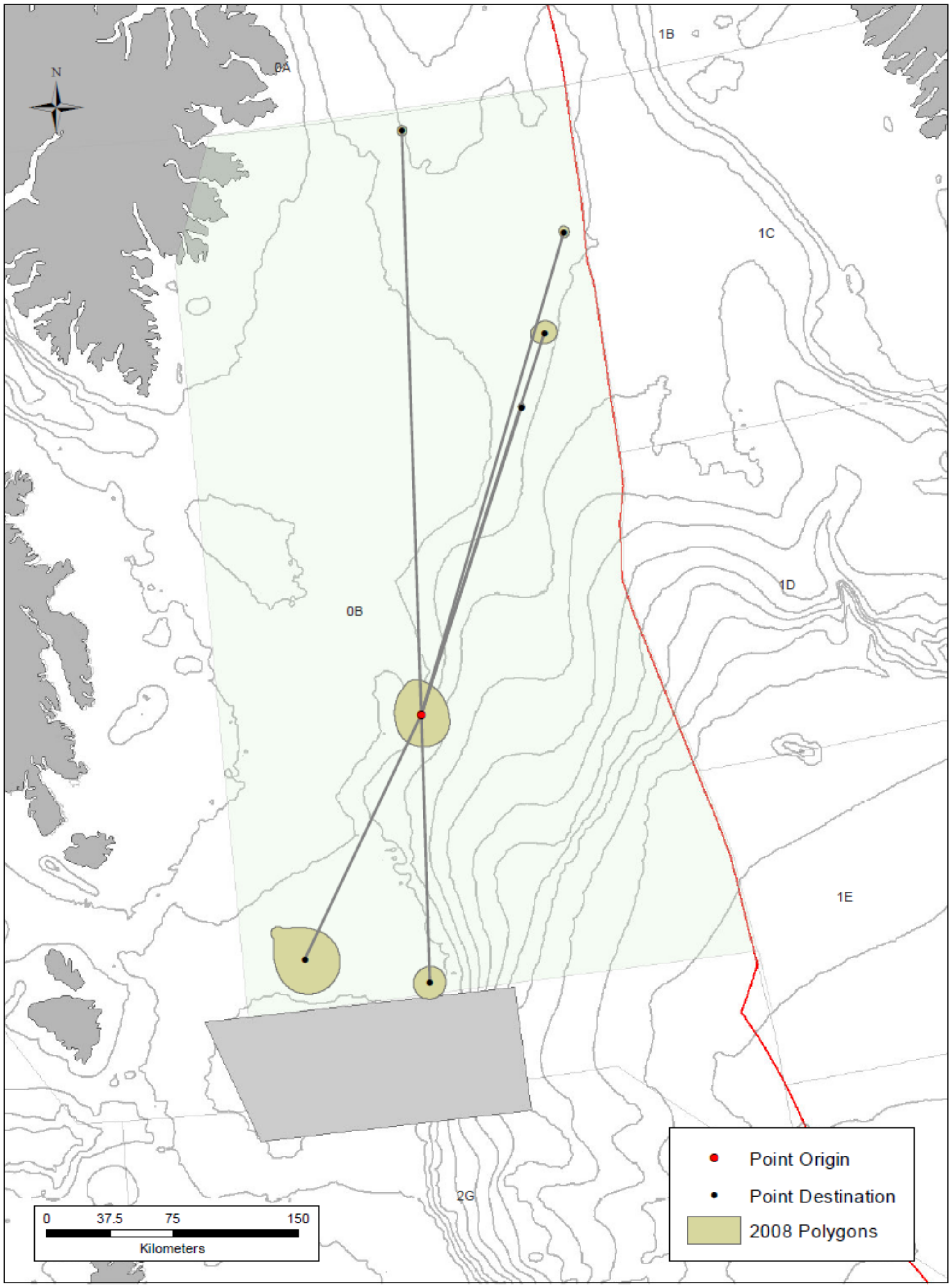
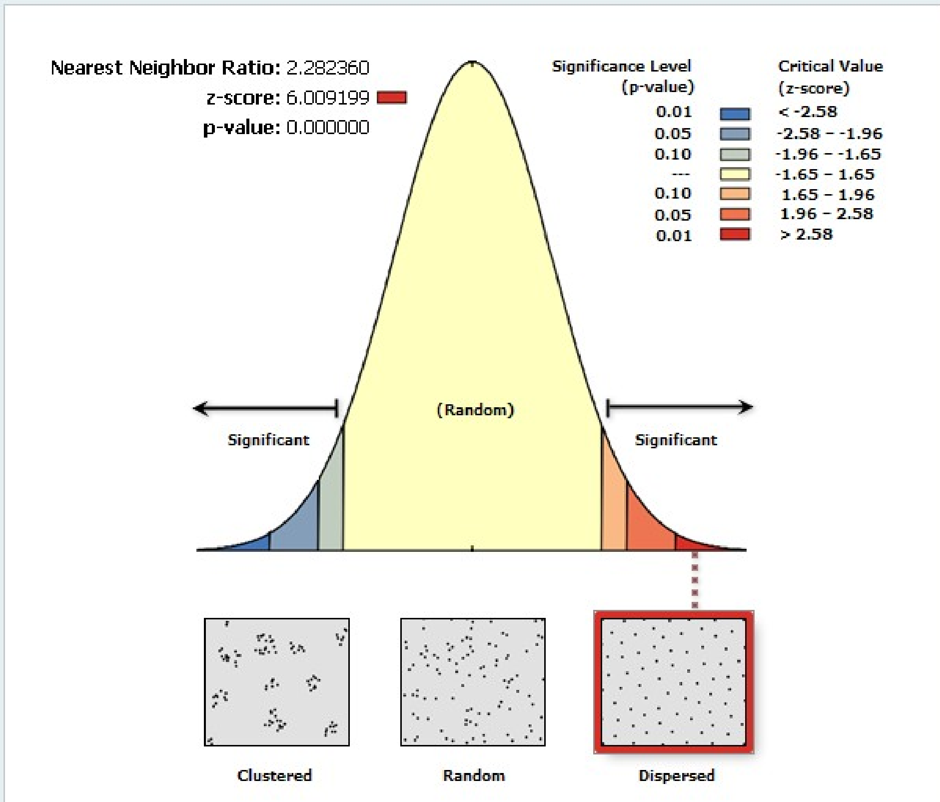


Figure 9. Illustration of the calculation of nearest neighbour distances between sponge patches in Shrimp Fishing Area 2EX. In this example the distances are calculated from the patch with the red circle to all other patches. This calculation is performed for all possible combinations of patches within the area.



Average Nearest Neighbor Summary

Given the z-score of 6.01, there is a less than 1% likelihood that this dispersed pattern could be the result of random chance.

Average Nearest Neighbor Summary

Observed Mean Distance:	95079.856450
Expected Mean Distance:	41658.564583
Nearest Neighbor Ratio:	2.282360
z-score:	6.009199
p-value:	0.000000

Dataset Information

Input Feature Class:	Int40kg_inSFA2ex_cent_2005
Distance Method:	EUCLIDEAN
Study Area:	41650464075.555733

Figure 10. Calculation of Average Nearest Neighbour Distance using the ArcGIS Average Nearest Neighbour Distance tool. This example is for the 2005 survey year. The significant z-score allow interpretation of the Nearest Neighbour Ratio which is showing a dispersed pattern.

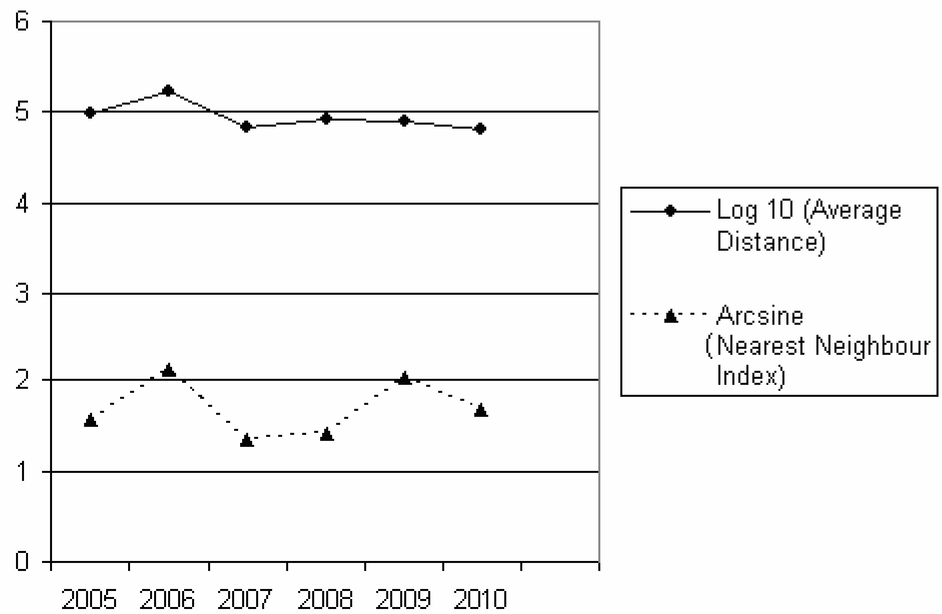


Figure 11. Trends in the Average Nearest Neighbour Distance and the Nearest Neighbour Index (Dispersion) (Table 6) calculated for sponge patches in Shrimp Fishing Area 2EX over a six year period.

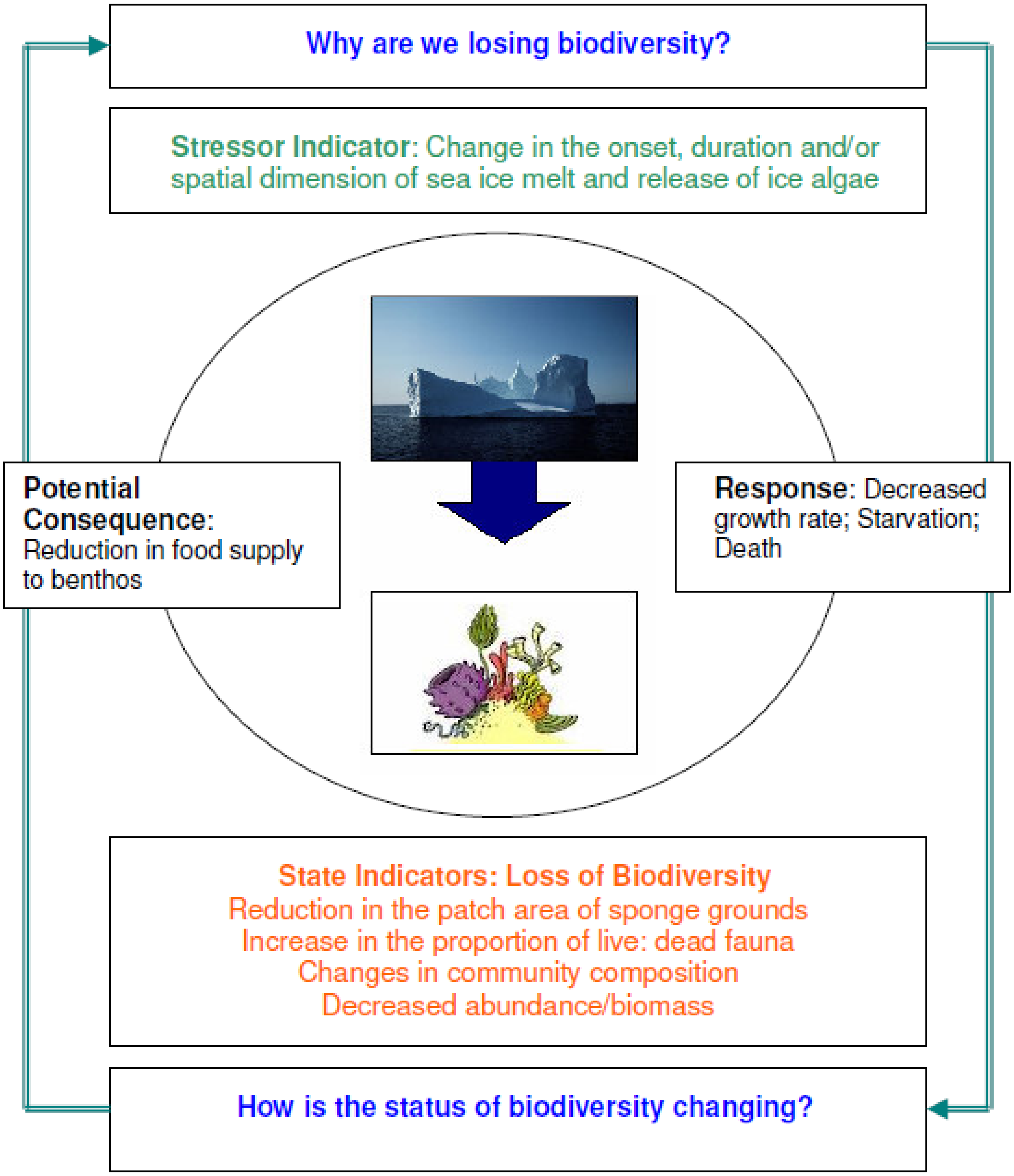


Figure 12. A simplified illustration of the relationship between state and stressor indicators and associated questions that each address. In real world scenarios state indicators may face more than one stressor with varying response times and degree of impact.